Open University of Cyprus

Faculty of Pure and Applied Sciences

Doctoral Thesis

An Evaluation of Strategic Conservation Planning Modelling Techniques and Analysis of the Barriers to their Wider Adoption and Implementation

Louise Sutherland

Supervisor
Associate Professor Ioannis Vogiatzakis

June 2017

ISBN 978-9963-695-55-3

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ABSTRACT

It is widely acknowledged that much conservation research does not support conservation practice because it is not implemented. Described as the research – implementation gap, its causes have been debated within the literature since the early development of conservation science.

This thesis explored the use of well established strategic conservation planning tools; species distribution modelling using MaxEnt and least cost path modelling within rule based and expert derived landscape permeability models, in order to increase understanding of conservation research implementation barriers and solutions. The tools were evaluated through a microethnographic case study within the applied setting of the Forestry Commission, UK. In addition, the wider validity of the findings was explored through a questionnaire survey to conservation practitioners in seventeen diverse conservation organisations across the UK.

Each modelling tool demonstrated potential to provide valuable data to support conservation management decisions for adder *Vipera berus* conservation in Wyre Forest, Worcestershire, England. However, there were differences in the extent to which each tool could address the research questions and how useful it was perceived by conservation practitioners. As evidenced by this study, practitioners considered landscape permeability modelling to be more useful than species distribution modelling using MaxEnt. The expert derived landscape scoring approach provide more accurate answers to the research questions related to landscape permeability compared to the rule based scoring approach.

Forestry Commission staff were keen to adopt the tools and use results within their conservation planning and management. Yet despite staff's enthusiasm for the tools' ability to provide scientific justification for management decisions, time constraints prevented the organisation from adopting these tools. However, the results of modelling undertaken within the case study were implemented, and used to determine the locations for adder's habitat restoration activities.

According to the findings of this thesis the research implementation barriers described in the literature can be overcome by appropriate research design. Therefore it suggests that the majority of implementation barriers are not true barriers, but merely the result of developing and undertaking conservation research without the involvement of conservation practitioners. This work concludes that research implementation requires the urgent

adoption of what is already normal practice in other applied sciences: namely partnership with the conservation industry. This would support the development of communication networks, similar to those between applied university research and other industries,, which support ongoing, reciprocal information flow at all stages of research, this enables the building of social capital and thus ensures research implementation.

CHAPTER ONE
INTRODUCTION

1.1 BACKGROUND

Conservationists responsible for habitat creation and restoration need to ensure these actions have maximum benefits for the target species. Habitat creation projects must increase habitat size, connectivity and landscape permeability to be effective (Sutherland 2014; Villard and Metzger 2014; Lawton 2010). There are numerous landscape permeability modelling tools, well documented in the scientific literature (Liu *et al.* 2013; Guisan *et al.* 2013; Franklin 2013; Meller *et al.* 2014) which are designed to support this work. However, a recent review of the scientific literature examining how spatial conservation prioritization analyses support the information needs of the Aichi Biodiversity Targets (to conserve 17% of terrestrial and 10% of marine areas by 2020), criticised conservation research and stated that "*little research directly supports the analytical needs of the CBD*" (Convention on Biological Diversity 2010). Modelling research was described as largely theoretical, therefore studies did provide guidance for conservation management. Although numerous conservation organisations, including the RSPB, WWF, Natural England, CCW, British Trust for Ornithology and World Conservation Society use a range of landscape permeability modelling tools to structure their work, many UK based and international organisations do not use the existing tools described in the literature (Hulme 2014; Kareiva *et al.* 2014). This research topic arose from the desire to understand whether landscape permeability modelling tools could benefit applied conservation projects in an organisation not currently using them, and to investigate the barriers and opportunities to adopt such modelling techniques to support their work and ensure it is strategic and effective.

1.2 STUDY AREA

Wyre Forest is the third largest remaining semi-natural ancient woodlands in Britain, and one of the most ecologically diverse (Evans 2014, Selman 2013, Hickin 1971), although it was coniferised after the Second World War (Boles, Forestry Commission, *pers. com*). It lies on the Worcestershire Shropshire border in the Midlands region. The forest covers an area of 2,510 hectares, two-thirds of the forest (1,754 hectares) is designated as Site of

Special Scientific Interest (SSSI). A further fifth of the forest (549 hectares) is listed as a National Nature Reserve. Sites of Special Scientific Interest are nationally protected areas in the United Kingdom designated under the National Parks Act of 1914, to promote site based biological or geological conservation. In the UK, National Nature Reserves are nature reserves designated under the National Parks and Access to the Countryside Act 1949, which are deemed to be of national importance, and therefore granted additional statutory protection using section 35(1) of the Wildlife and Countryside Act 1981.

Figure 1.1 UK Map illustrating the location of the Midlands Region and Wyre Forest

Figure 1.1 The blue shading illustrates the Midlands region and the red star illustrates the location of the Wyre Forest within the Midlands region.

Figure 1.2 Wyre Forest Study Area

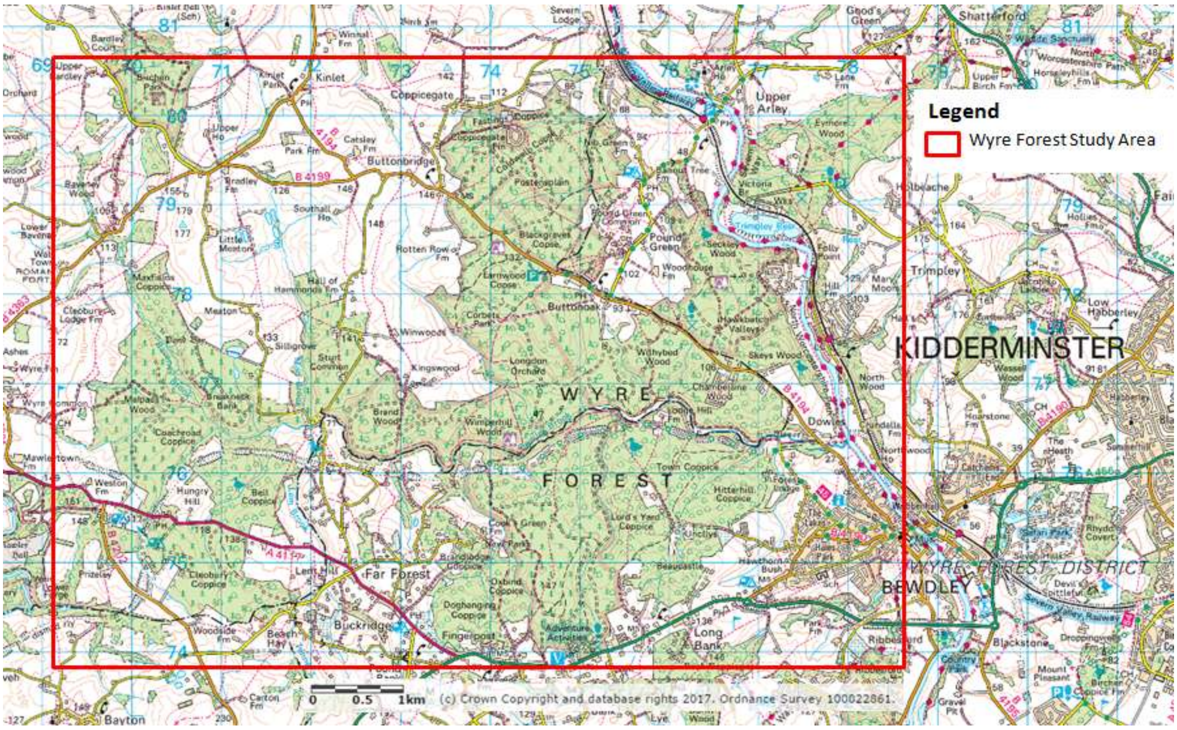


Figure 1.2 The red line boundary defines the Wyre Forest study area.

The Wyre Forest National Nature Reserve covers five hundred and forty-nine hectares and is one of the largest ancient lowland coppice oak woodlands in England (Thomas & Packham 2007). The Wyre Forest is jointly managed by Natural England and the Forestry Commission. The current management program aims to restore the coppice system to help diversify the age and species structure of the woodland (Herbert, Natural England *pers com*.). Wyre Forest has elements of both lowland and upland woodland and unimproved grassland meadows (Day 2001). Old orchards and areas of scrub also contribute to the variety of habitats present in the nature reserve (Smart 2006).

Wyre Forest was designated as a SSSI due to the exceptional lepidoptera and reptile assemblage. The adder *Vipera berus* is named as a key species (Natural England 2013). Wyre forest is one of the few places in the UK where four of the six native British reptile species can be found, namely Slow-worm *Anguis fragilis*, Viviparous lizard *Zootoca vivipara*, grass snake *Natrix natrix* and the adder *Vipera berus.* In addition to its reptile assemblage, the Wyre Forest is one of the three remaining English strongholds for the Pearl-bordered Fritillary *Boloria euphrosyne*, and supports England's largest colony of

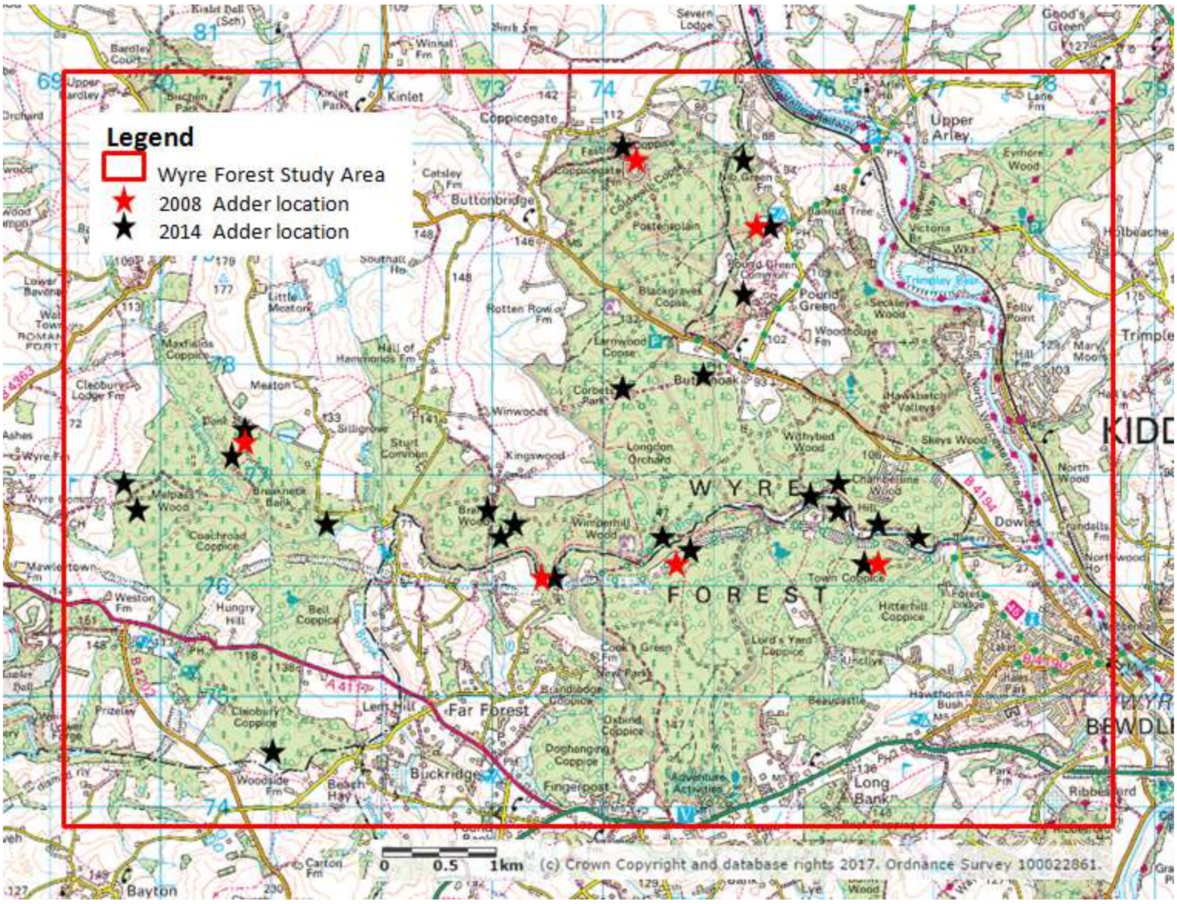
Pearl-bordered Fritillary butterflies (Smart and Winnall 2006). Moreover, the moth *Oecophora bractella* has one of its few English populations in Wyre Forest (Boardman 2005).

The statutory protection granted to Sites of Special Scientific Interest (SSSI) is based upon specific features of the landscape, these are termed the *"special features"* and their condition is assessed on a six year cycle by Natural England. These "*condition assessments"* monitor the long term health of the SSSI's. Every SSSI is divided into small units for monitoring purposes. Each unit is assessed against a set of targets, which have to be met in order for the unit to be judged in "*favourable condition"*. A list of *"special features"* and the targets against which they are measured, are specified in a "*favourable condition table"* for each SSSI. Each special feature will have one or more measurable characteristics that is used to determine its condition (Natural England 2013).

The Wyre Forest SSSI favourable condition tables state that for the reptile assemblage feature, specifically adders, to be in favourable condition there should be: *a) no loss of more than 5% of the habitat (2008 baseline) and b) a population of adders at least at the 2008 levels (baseline).*

The adder has been intensively studied in Wyre Forest for thirty years (Sheldon 1985 - 2015). Since 1988 adder populations in the study site have declined by over 75%, from 235 individuals in 1988 to 55 individuals in 2014. The 2008 reptile survey estimated the adder population to be 192 adders. Therefore, the 2014 reptile population represents a little over a quarter of the 2008 baseline population. Habitat loss can be described by comparisons of current and the 2008 baseline range around occupied *"adder sites"*. An adder site is defined here as a location where an adder was seen or a hibernaculum was located. The perceived boundaries of an adder site are determined by changes in vegetation structure, such as variation in age categories within the woodland, plantation types, rides or the presence of a perceived boundary for adders, such as large mature conifer plantations with no understory or areas with high visitor pressure and consequently high levels of disturbance (Sheldon, primary researcher Wyre Forest Society 2011 *pers. com*).

Figure 1.3 Map Illustrating Adder Records in Wyre Forest in 2008 and 2014



1.3 STUDY SPECIES

Snakes are in decline around the world (Reading *et al.* 2010), and they exhibit many traits recognised to enhance a species' sensitivity to extinction (Seigel *et al.* 1987). Therefore, they are believed to be more vulnerable to extinction than many other taxa. Among snakes, European vipers are of particular concern because they combine several of these traits: small home-range, low dispersal rate, low growth rate, delayed sexual maturation, ontogenic shifts in habitat use, low reproductive rate, and high specialisation in feeding habits (Seigel *et al.* 1987, Baron 1997, Baron *et al.* 1996).

European vipers are highly threatened by habitat loss, collection, persecution, population fragmentation and loss of genetic diversity, which has led in many areas to extinction (JNCC 2010, Jaggi *et al.* 2000, Ujvari *et al.* 2002). As they are venomous, viperids are often disliked by people, leading to intentional killing, and illegal collecting for captive breeders (Lyet *et al.* 2013).

In Europe, adder populations show a decreasing population trend and have been "*significantly fragmented*" by the intensification of agricultural methods and development (Isailovic *et al.* 2013). Adders can be common in suitable habitat, but in mountainous parts of its range, such as Bulgaria and Greece they are rare, while they are categorised as endangered in Switzerland (Monney and Meyer 2005). In Germany, UK, France, Sweden and Italy, where populations are monitored, there have been population declines of 20% and local extinctions across over 50% of their former range (Isailovic *et al.* 2013).

The adder is listed on Annex III of the Bern Convention, but is classified as least concern by the IUCN (Isailovic *et al.* 2013) because it is widely distributed, occurring throughout northwestern, southern and eastern Europe, to Russia, North Korea, northern Mongolia and northern China. Global populations are not believed to be declining more than 30% per annum, however, monitoring efforts across most of Europe are patchy and no coordinated monitoring programme exists (Isailovic 2015).

Like most snake species, adders are secretive and elusive, have long periods of inactivity and usually occur in the wild at very low density (Seigel, 1993). Therefore, evaluation of their status and extinction risk, which requires strong baseline data on distribution, population trends, habitat fragmentation and behavioural ecology, is difficult to achieve (Lyet *et al.* 2013). This study aims to contribute to the understanding and conservation of the adder in the UK.

The total adder population in the United Kingdom is estimated to be 1300 individuals (JNCC 2010). The adder is described as a *"declining species"*, suffering from "*habitat fragmentation, afforestation, public pressure, inappropriate habitat management, development"* and "*general tidying"* of the countryside (JNCC 2010). Baker, Suckling and Carey (2004) found population decreases in all UK regions studied, with the most severe decline in the Midlands. Adder populations in the Midlands are described as *"the most rapidly declining Adder populations in the UK"* (JNCC 2010). The declines observed at many sites in the Midlands are described as "*of most concern*" by Natural England (Natural England 2010). Wyre Forest is widely acknowledged the most important site for adders in the Midlands, making conservation of adders in Wyre Forest of critical importance for the species in the UK.

Figure 1.4 The Geographic Range of *Vipera berus* in Europe

1.3.1 Adder Biology & Ecology

Adders are small cryptically camouflaged snakes, growing to an average of fifty-five centimeters and weighing from 50 to 180 grams (Buczaki 2002). The colour varies from cream to brown, with a darker brown zigzag dorsal pattern on females and black zigzag dorsal pattern on males. There are also melanistic individuals which appear almost black. Being small and cryptically coloured, makes adders difficult to see; they can be missed during surveys and site managers may be unaware of their presence when making management decisions.

Adders are cold-adapted and hibernate from November to February. Hibernacula are often the abandoned burrows of small mammals, or the overgrown root systems of trees, typically located on high, dry, south facing ground (Claes and Nilson 1983). Adders usually use the same hibernation site for life (Beebee and Griffiths 2000). This makes them extremely vulnerable to forestry management operations which remove ground cover or disturb hibernacula, such as mowing and stump grinding.

During summer months adders are active. In warm conditions, they actively hunt small mammals through their underground burrows, but they also use a "*sit and wait"* technique (Beebee and Griffiths 2000). Juvenile adders feed on small lizards (Hand 2010), whereas adults prey primarily on field voles *Microtus agrestis*, which makes them vulnerable to variations in prey populations (Lindell and Forsman 1996). Reduction in prey numbers increases the interval between feeding, which may mean individuals enter hibernation with insufficient fat reserves and therefore, do not survive the winter (Forsman 1993; Blouin-Demers *et al.* 2007; Plummer and Mills 2000). Low prey density also means females take longer to regain the body condition needed to sustain pregnancy, thus slowing the population growth rate (Shine and Madsen 1992). The Wyre Forest reptile surveys demonstrate a positive correlation between lizard and adder numbers. Increased lizard prey available to juvenile adders is believed to increase the over-winter survival rate of juveniles, as they are more likely to enter hibernation with sufficient fat reserves (Hand 2010).

Figure 1.5 Male adder *Vipera berus.* *Photo credit Louise Sutherland*

Figure 1.6 Female adder *Vipera berus.* *Photo credit Thomas Brown (http://creativecommons.org/licenses/by/2.0)], via Wikimedia Commons)*

Adders have a very slow rate of population growth even in ideal conditions. They do not reach sexual maturity until five years, female adders reproduce once every two or three years (Edgar, Foster & Baker 2010) and males are unlikely to successfully mate until seven to eight years of age because males wrestle for mating rights (Sheldon, Wyre Forest Society *pers com.*). Female adders return to hibernacula to give birth in late August or early September. Adders are viviparous, giving birth to between 3 and 12 live young. Young adders disperse soon after birth and rely on ground cover such as bracken litter for protection from predators (Andersson 2003). Their slow rate of population growth makes adders less able to recover from losses and vulnerable to stochastic extinction events.

Structural habitat complexity is a crucial requirement for adders, diverse vegetation structure provides protection from predators and human disturbance whilst basking, hunting and hibernating (Edgar, Foster & Baker 2010). In Wyre Forest adders use a variety of habitat types including heaths, meadows, rough commons, woodland edges, sunny glades and clearings, rides, failed patches, road verges, bushy slopes, hedgerows and stone quarries (Hand 2010). This makes them vulnerable to management activities, such as mowing and scrub clearance, which woodland edges, scrub and open areas typically undergo.

1.4 RESEARCH AIMS

In the last decade there has been increasing interest in Predictive Species Distribution modelling and Habitat Suitability Models (Thuiller *et al.* 2008; Franklin 2009). These tools support planning of landscape connectivity restoration (Worboys *et al.* 2009); can identify unsurveyed sites with a high potential of occurrence of rare species (Teixeira *et al.* 2014, Engler *et al.* 2004); help select priority areas for species and habitat conservation (Klimek 2014); and identify potential movement pathways across fragmented landscapes for species of conservation concern (Watts *et al.* 2010).

These modelling techniques can provide relevant information that is difficult to obtain through other methods, especially for rare or elusive species (Lyet *et al.* 2013) and have previously been used to model spatial distribution of snakes in relation to environmental predictors (Ceia-Hasse *et al.* 2014; Gardiner *et al.* 2014; Hall 2014). However, these tools are still used by relatively few conservation organisations. Their utility in applied, on the ground conservation is unclear, as is the level of their adoption in conservation practice (Guisan 2013).

To overcome the decline of adders in Wyre Forest and gain favourable SSSI status by restoring the adder population to the 2008 baseline, a partnership project *'Restoring Wyre's Reptiles'* has been established by The Forestry Commission, in partnership with Natural England, Wyre Forest Society, West Midlands Safari Park, Wyre Forest District Council, and Worcestershire Wildlife Trust. The JNCC recommends "*habitat management measures"* and suggests that *"Countering the effects of habitat fragmentation at the local scale is a high priority"* (JNCC 2010). The conservation strategy for the adder in Wyre Forest aims to undertake habitat restoration to overcome habitat fragmentation, and include captive breeding and wild to wild translocation of adders.

The development of an appropriate and effective conservation strategy requires understanding of the threats and causes of adder decline, the adder's potential and actual geographic distribution, the environmental factors that determine it (Franklin 2009) and functional habitat connectivity (Harris *et al.* 2014). Therefore, Predictive Species Distribution modelling, Landscape Permeability and Habitat Suitability modelling could provide valuable information and support the development of this conservation strategy.

The *Restoring Wyre's Reptiles* project represented an opportunity to explore the use and ability of established modelling tools to provide relevant information for an applied conservation project. Furthermore, to undertaken a case study to investigate the impacts of the implementation barriers and solutions described in the literature, within the Forestry Commission, a conservation organization which does not currently use these modeling tools to support its work.

The aims of this thesis are to:

1. Explore the usefulness of ecological modelling techniques within an applied conservation project and conservation organisation, exemplified by a case study on The Forestry Commission.
2. Understand the barriers between scientific research and practical conservation projects carried out by the Forestry Commission.
3. Examine whether solutions presented in the literature could overcome these barriers and enable the adoption of these techniques within the Forestry Commission.

In order to achieve these aims, the following research questions will be addressed.

1.5 RESEARCH QUESTIONS

1. Can Landscape Permeability and Habitat Suitability modelling help to evaluate habitat suitability and connectivity in order to inform habitat restoration in Wyre Forest?
2. Can Predictive Species Distribution modeling help determine which environmental variables explain adder distribution in Wyre Forest and inform adder reintroduction in Wyre Forest?
3. How applicable are the results of ecological modeling exercises to an applied project in a UK conservation agency setting, as exemplified by the Forestry Commission case study.
4. What are the barriers to adopting Predictive Species Distribution modelling, Landscape Permeability and Habitat Suitability modelling in a UK conservation agency setting, and can the solutions proposed in the literature enable implementation of modeling results of adoption of these tools?

1.6 THESIS STRUCTURE

This research aims to evaluate the effectiveness of established strategic conservation planning modelling techniques and analyse the barriers to their wider adoption and implementation through an interdisciplinary case study in which the techniques are used to provide information for an applied adder conservation project.

- Chapter one provides an introduction to the research, the study species and area, the motivation for the research, its aims and research questions.
- Chapter two is a literature review examining the so called "*research-implementation gap"* between conservation science and conservation practice.
- Chapter three presents the use of a Predictive Species Distribution model, MaxEnt, and assesses its ability to provide the data required for the Forestry Commission's adder conservation strategy.
- Chapter four introduces landscape permeability modelling and presents a series of habitat suitability and permeability models of the Wyre Forest and assesses their ability to provide the data required for the Forestry Commission's adder conservation strategy.
- Chapter five describes the micro ethnographic case study in which the modelling techniques applied in chapters 3 and 4 were evaluated by the Forestry Commission. It explains the social research methods employed, and presents the results of using the modelling techniques within the organization, and in addition, a questionnaire survey to a wide range of UK based conservation agencies. Findings are used to examine the applicability of the implementation barriers and solutions presented in the literature and relevance of current theories on the research– implementation gap, in order to increase understanding of the implementation gap between conservation science and conservation practice
- Chapter five describes the social science research, a within the Forestry Commission,. It uses a micro-ethnographic case study approach to explore the suitability of Predictive Species Distribution modelling, Landscape Permeability and Habitat Suitability modelling to the Forestry Commission within their adder conservation work, and
- Chapter six presents the conclusion of the research with a discussion of the results and their implications, with reference to the original research questions.

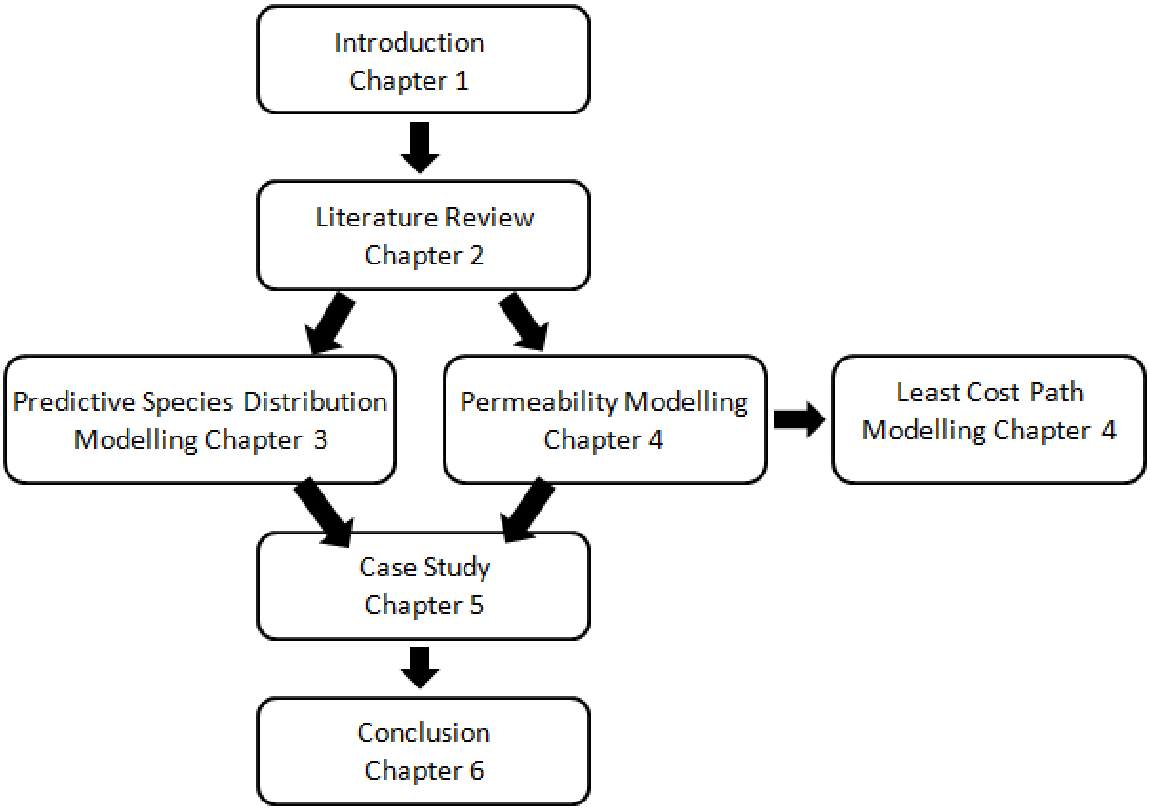


Figure 1.7 Flow chart diagram illustrating thesis structure.

CHAPTER TWO

THE SCIENCE - IMPLEMENTATION GAP

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2. INTRODUCTION

Arguably conservation science was developed to support applied conservation of global biodiversity. One of the goals of the Society for Conservation Biology is that "*its research should be useful"* (Meffe *et al.* 2006). Soule (1985) describes the evolution of conservation science as stemming from a belief in the importance of research with "*direct relevance"* to conservation and society. However, the usefulness of conservation research to conservation depends on its implementation.

There is an extensive literature debating the disjuncture between scientific research and practise, the so called "*science–implementation gap*". It is not unique to conservation science, it is described in numerous research fields (Bryant *et al.* 2014; Robinson 2014; Matzek *et al.* 2014; Pagell and Shevchenko 2014). As early as 1986, when conservation biology was still developing as a science, Soule described the communication between researchers and conservation practitioners as *"poor at best"* (Soule 1986). Almost 15 years later, Whitten (2001) posed the question "*If the science of conservation… is not leading to actions that effectively conserve nature, then what is the point of it?*" Another decade on Laurance *et al.* (2012) argue that despite the shared goals, conservation research makes "*surprisingly few direct contributions to environmental conservation*". Although the implementation gap between conservation research and conservation practice has been debated for almost three decades, it still exists and continues to be debated.

Within conservation science the phenomenon has been referred to as the '*great divide'* (Anon. 2007), *'knowing but not doing'* and the '*research–implementation gap'* by Knight and Cowling (2007). Recently, environmental scientists have adopted the term '*actionable science'* to describe research which aims to contribute to resolving environmental problems (Palmer 2012).

In response to the widespread acknowledgement that much conservation research does not provide benefits for conservation because it is not implemented, numerous scientists have sought to explain this lack of implementation, described a variety of "*implementation barriers*" and suggested methods to increase the implementation of conservation research. Authors have identified 6 key categories of research implementation barriers and solutions. These are:

1) Communication and access to scientific knowledge
2) Training
3) Relevance
4) Interdisciplinarity
5) Reward
6) Resource constraints

There is no consensus in the literature on which is the most significant implementation barrier or which has the greatest potential to enable implementation of research. Given the pivotal role that research could play in supporting conservation action, it is important to establish their relative importance. This literature review aims to examine whether or not the proposed implementation solutions can overcome the proposed barriers, which can enable the implementation of conservation research, and understand which have the greatest effects on implementation. The following sections critically review, in detail, the literature describing and evidencing the perceived implementation barriers and suggested implementation solutions. To facilitate critical debate, the barriers and solutions will be discussed within each of the six categories.

2.1 COMMUNICATION

There is agreement within the literature concerning the lack of communication between researchers and conservation practitioners (Addison *et al*. 2013; Knight *et al.* 2008; Campbell 2007; Whitten 2001), and that greater communication between researchers, policy makers and conservation practitioners would increase research implementation and successful conservation actions (Guisan *et al*. 2013; Schwartz *et al*. 2012; Milner-Gulland *et al.* 2012; Roux *et al.* 2006; Sutherland 2004, 2009, 2011). Despite communication being described as "*essential"* for successful collaboration with stakeholders and effective presentation and implementation of research (Knight *et al.* 2008), and "critical" in the case of modelling research (Addison *et al*. 2013; Guisan *et al*. 2013; Schwartz *et al*. 2012), the literature suggests that much conservation research is undertaken with little communication between researchers and conservation practitioners.

For example, Sutherland *et al.* (2011) describe the popularity of their 2006 '*UK Questions'* article (the most downloaded paper ever from any British Ecological Society journal and was the 3rd most downloaded paper from any of Blackwell's 850 journals in 2006) and their '*Global Questions'* article (the most downloaded paper in Conservation Biology in 2009); both of which were developed though asking policy makers and conservation practitioners their research needs and developing research questions with them. The popularity of the articles suggests three things. Firstly, that conservation scientists recognise the value of questions sourced from practitioners; Secondly that large numbers of researchers are interested in undertaking relevant, implementable science based on stated research needs. Thirdly however, it also suggests that the enormous numbers of individual scientists who downloaded the paper, are not themselves engaging directly with practitioners or policy makers, instead they may be aiming to use research questions elicited by Sutherland's research (Sutherland 2006).

Further evidence for the lack of communication is provided by an ongoing and increasing emphasis on so called '*knowledge transfer'*. In 2006 the Warry Report suggested research needed more emphasis on knowledge translation by "*influencing knowledge translation initiatives within universities and increasing engagement with user organisations"*. The Warry report suggested that although research councils have instigated a range of policies and frameworks to increase the impact of research, these were not enabling implementation of research (Warry 2006). By 2008 responsibility for knowledge transfer had been extended to individual researchers, and included as one of the basic responsibilities of UK researchers (Research Councils UK/Universities UK, 2008). In 2013 a book entitled '*Re-thinking science: knowledge and the public in an age of uncertainty'* described the role of universities in knowledge transfer and the importance of contextualising scientific knowledge (Nowotny *et al.* 2013). However, the phrase '*knowledge transfer'* makes it clear that the bulk of research is being undertaken without communication with practitioners: this emphasis on the *transfer of results*, describes one way communication, which suggests the research is not developed with conservation practitioners or other "*users*" of the knowledge.

There is considerable debate within the literature as to why there is a lack of communication between practitioners and scientists and who is responsible for it. Matzek (2014) suggests that when a knowing–doing gap exists, it could be blamed on either "*the knowers or the doers*". This poses two questions: *Are conservation scientists responsible for ensuring their research is implemented by communicating with conservation managers? Or are conservation managers unwilling to incorporate research into their practices?*

Hulme (2014), Milner-Gulland *et al.* (2010), Campbell (2007), Sutherland (2011); Whitten *et al.* (2001) all suggest that the majority of conservation scientists in academic positions have limited or no interaction with conservation practitioners. Hulme (2014) suggests that many conservation practitioners apply their own intuitive, largely experience based, hard to define, context dependent, personal knowledge when making decisions on conservation interventions. Hulme suggests the failure of scientists to translate and consider this type of tacit knowledge, may be the most significant reason their research is not implemented. Hulme, Milner-Gulland, Campbell, Sutherland and Whitten put forward convincing arguments based on empirical evidence and suggest it is scientists who are responsible for ensuring their research is implemented by communicating with conservation managers.

However, other authors disagree; Bainbridge (2014) states that equal emphasis should be placed on policymakers who have a responsibility to engage with scientists, in order to adopt an evidence-based approach. Similarly, Guisan (2013), Redford and Taber (2000) and Balme *et al*. (2014) criticise conservation practitioners for failing to report their experiences to scientists. Groffman *et al.* (2007) also suggest that sharing best practice between conservation managers would have great benefits to conservation implementation. Groffman's finding is supported by earlier research by Hopkinson *et al.* (2000) and Prendergast *et al.* (1999) who found most conservation organisations have developed their own (often unpublished) conservation assessment techniques. The case studies and examples presented by these studies effectively demonstrate that conservation practitioners rarely initiate communication with researchers to describe the results of their conservation management practices. Therefore the literature is able to illustrate that the lack of communication is due to both scientists not communicating directly with practitioners and practitioners not communicating directly with scientists.

The following two sections will critically review the literature which proposes lack of communication is both an implementation barrier and solution. Firstly a brief review of examples which explore how and why communication can be an implementation barrier, followed by an assessment of the literature suggesting communication can support research implementation.

2.1.1 LACK OF COMMUNICATION AS AN IMPLEMENTATION BARRIER?

There is mixed evidence in the literature about the effect of communciation on research implentation. To clarify the effect of communication on implementation, this section will present and explain the reasons for the divergent views in the literature.

Without access to scientific knoweledge much conservation action is acknowledged within the literature to be guided more by personal intuition and guesswork than by hard science (Hulme 2014; Milner-Gulland *et al.* 2011). Similarly Sutherland (2004) suggests a great deal of conservation practice is "*based upon anecdote and myth rather than upon the systematic appraisal of the evidence*". The value of Hulme, Milner-Gulland and Sutherland's work is due to its use of primary data. It is largely based on interviews with conservation practitioners, who admit their work is not based on science. Therefore, the authors conclusions support the theory that lack of science communication reduces implementation of science, and provides evidence of practitioners relying on non-scientific sources to guide their conservation practice.

In developing countries, the poor level of scientific literacy of field practitioners, is believed to contribute to the failure of conservation research to inform action (UNESCO 2008, de la Rosa 2000) and recently this has also been reported as a problem within more developed countries (Pietri *et al.* 2013). However, Pietri's research, although valuable is largely dependent upon the findings of students. The UNESCO report is based on the assumption that increased access is valuable and is concerned with how to increase access, neither it, or the work of de la Rosa, provide examples of where access to published research has directly led to its implementation.

The literature suggests some conservation scientists are critical about the effectiveness of publishing in scientific journals as a means of communicating and implementing research (Milner-Gulland *et al.* 2012). It is suggested that the requirements of articles in many peer reviewed journals are fundamentally at odds to what practitioners need, due to incompatibility between relevance to practitioners and scientific novelty and rigor (Cook *et al.* 2013; Arlettaz et al. 2010; Knight et al. 2008; Meff 2006). After a worldwide survey Van Dalen and Henkens (2012) state that pressure to publish negatively affects the orientation of researchers towards policy and knowledge sharing. This study presents compelling evidence from across Western Europe and the UK that direct communication with practitioners is reduced by pressure to publish and the high rewards of publishing. Cook (*et al.* 2013) suggest the requirements of journals encourage science which is not relevant, well-timed, credible or trusted by practitioners, and is therefore lacks the salience, credibility, and legitimacy required for implementation. Cook's study made a major contribution to understanding how communciation can enable implementation by embedding research scientists within organizations, boundary organisations, training conservation professionals and embedding researchers in resource management agencies. Cook's conclusions are based on both a review of the literature and examination of case studies where salient, credibile, legitimate science has been achieved and impemented and is therefore based on strong empircle evidence across a wide range of conservation research types.

Cook's views are supported by Hulme (2014), Matzek *et al.* (2014), and echoed in earlier studies by Laurance *et al.* (2012), Sutherland (2009), Pullin *et al.* (2004), Coloma and Harris (2005) and Siepen and Westrup (2002) who also suggests that publishing research in peer-reviewed journals will only ever be a small part of closing the research-implementation gap, and that the scientific literature is largely inaccessible to conservation managers who rarely read them. For example; Sutherland *et al.* (2009) highlights that a high proportion of papers published in scientific journals are seldom read outside of the academic world. A landmark study by Matzek *et al.* (2014) exploring the implementation gap in conservation biology, specifically on research into the control of invasive species, surveyed 207 California land managers and conservation practitioners whose jobs involve decision making about plant invasions, to evaluate engagement with scientific research. They found that practitioners rely on their own experience and largely do not read the peer-reviewed literature which they regard as only "*moderately useful"*. Although this study was not carried out in the UK and explored only one element of conservation (invasive species control), the value of Matzek's work lies in the large number of practitioners surveyed. The evidence from the literature suggests that reliance on publishing in scientific literature creates a lack of communication with conservation practitioners. Further evidence for the lack of communication and access to research comes from subscriptions to the journal Conservation Biology, which show only 4.6 percent of subscribers are from developing countries, including tropical biodiversity hotspots (de la Rosa 2000).

Although lack of access to journals is suggested as an implementation barrier by many (see Moody 2013; Yang 2012; Campbell 2007; Knight *et al.* 2008; Sutherland 2009), the main limitation of this theory is that the bulk of this work does not provide empirical evidence or examples of publication in a journal directly leading to its implementation by practitioners. For example, the main limitation of Moody's work is its reliance secondary sources and opinion, it does not provide examples of where access to published research has directly led to its implementation. It is also restricted in scope to modelling research communication and implementation. The conclusion of Knight et al. (2008) is based on case studies in which direct involvement of practitioners in the development of science questions and research led to its implementation. It is therefore suggested, that this does not provide an example of published work increasing implementation, but that involving practitioners in research supports successful communication and implementation. Similarly, in a powerful editorial, Milner-Gulland (2012) state that "*it is no good... to disseminate findings to practitioners post-hoc in the hope that they will be taken up; these unidirectional approaches, though still prevalent, are by and large doomed to failure."* These views are based on their review of the impact of published work and makes a compelling case that in order for communication to lead to implementation, it must involve more than the publishing of findings in journals, it must instead involve directly engagement with practitioners in research design, method and finally results.

There is no agreement in the literature on why conservation managers do not use available scientific data published in journals. Suggestions include lack of financial resources and operational capacity to implement findings (Young and Van Aarde 2011); irrelevancce of research (Young and Van Aarde 2011; Pannell et al. 2006; Fazey et al. 2005); difficulty accessing and interpreting relevant scientific information (Yang 2011; Arlettaz et al. 2010); organizational cultures that do not promote the use of science (Young and Van Aarde 2011); complexity of research (Moody 2014; Laurance *et al.* 2012) and scientific uncertainty (Bradshaw and Borchers 2000; Kinzig and Starrett 2003). Yang (2011) and Nelson (2009) illustrate how information flow between conservation research projects and conservation agencies is not easy. Data sharing is restricted due to institutional, legal barriers, confidentiality and cost and source codes of many models and tools are not open to the users. Evaluation of the relative merits of these papers leads to the suggestion that all of these factors can prevent communication of research leading to its implementation.

However, Kahan (2014) research was able to demonstrate that implementation and communication can be hindered by more than lack of understanding. The cultural, economic and political significance of research results also affects communication of results. Exploring climate science using a "*science comprehension test*", Kahan found that science communication can be hampered, not by a person's level of understanding, but the cultural conflict or political impact of the knowledge.

2.1.2 COMMUNICATION AS AN IMPLEMENTATION SOLUTION?

Communication can take many forms, but perhaps most fundamentally it can be direct or indirect. Direct communication occurs face to face between researchers and practitioners. Publication of research in journals is an examples of indirect communication, which is largely relied on as the normal route for communication of research and is rewarded within academic institutions (Van Dalen and Henkens 2012).

Greater access to scientific journals and their data has many proposed benefits to the implementation of conservation research. Suggested benefits include cost savings and innovation (Parr and Cummings 2005), the potential to speed up the geographic coverage of conservation research, enabling integrated research and assisting the transmission of conservation technology (Yang 2011).

The assumed benefits of access to journals and scientific data have led to a significant increase open access publishing and *knowledge transfer*, which is increasingly endorsed by scientific funding agencies, research institutions, and researchers to improve science communication. The Directory of Open Access Journals provides access to more than 5,000 journals (Callen and New 2014; Yang 2011). Research is being made more available through the European Commission's Science in Society programme and the EU Horizon 2020 initiative (Owen *et al.* 2012. In addition, the Conservation Commons Initiative (http://conservationcommons.net), Global Biodiversity Information Facility (http://www.gbif.org) and National Ecological Observatory Network, promote open access of published papers, working papers and data (Pullin and Salafsky 2010). Goering *et al.* (2010) described changes in which research councils are beginning to insist research outputs link to policy and practice, and incorporate knowledge transfer into the funding application process. However, Ward *et al.* (2010) urges researchers to consider the issues associated with knowledge translation early in the research planning process, to avoid a *"tick box reaction"* to knowledge transfer, suggesting that new requirements will not necessarily improve communication or implementation.

However, the value of these measures are not universally agreed upon. Hart and Calhoun (2010) warn that emphasis on scientific communication via peer reviewed journals facilitates information exchange and collaboration within the scientific community, but not between different stakeholders. Several authors suggest implementation requires journals to widen their audience and scientists to publish work in other more accessible venues (Matzek *et al.* 2014; Hulme 2011; Pullin and Knight 2009). If indirect communication through access to scientific data in journals can increase research implementation and support conservation, the literature should be able to provide examples where this has happened. Yet there are surprisingly few example of real-world impact of research which is directly due to the publication of that research.

Two such examples are seen in the work of Hart and Calhoun (2010) and O'Donnell, Webb and Shine (2010). Hart and Calhoun (2010) present case study evidence that access to published data lead to conservation implementation. They provided conservation managers with a popularised synthesis of recent scientific findings, including studies on salmonid conservation from peer-reviewed literature, which promoted seven conservation strategies and described their management advantages and disadvantages. In response to this information, fishery managers changed their conservation management practices, and stated that previously they had used one technique as the sole conservation management activity, mainly due to lack of awareness of other more or equally effective options. Similarly, O'Donnell, Webb and Shine (2010) demonstrated that it was possible to condition taste aversion in northern quolls *Dasyurus hallucatus,* such that they avoided eating toxic cane toads. This led to improved survival of 'toad-smart' quolls in an experimental reintroduction. The research described in the paper had direct, clear, local-level conservation management impacts on quoll conservation. O'Donnell, Webb and Shine (2010) resaerch findings are valid, but the local level impact of their research may have been due to the wide press coverage it garnered, the taste aversion test even featured on YouTube, rather than its publication in a journal. Consequently it is not possible to quantify the effect of the published paper, in relation to the effect of its promotion in other media. Similarly, Hart and Calhoun (2010) did not find that conservation managers had changed their salmonoid conservation strategies after the publication of research into salmonoid conservation. In fact they were unaware of it, until it was synthesised and presented to them by Hart and Calhoun within the study. This suggests that further steps are needed in order for research results to reach practitioners and change their practises.

However, the literature also provides contrasting examples of where direct communication of results previously published in journals has not led to implementation or change in conservation management practise. For example Rhodes, Closs and Townsend (2007) found farmers responces to provision of information on stream health had no significant impact on the health of the streams. This Before-After Control-Impact (BACI) based study found no significant difference in the subsequent behaviour of farmers or stream health in the information and no information groups. Although valid, this study involved relatively few individuals (n 30), and a larger study may have produced different results. In addition, lack of conservation action by farmers after presentation of conservation relevant information may be due to reasons such as cost or lack of interest in conservation etc. Therefore the study does not nessessarily reflect how this information might change conservation practise of practitioners or policy makers.

Teasing apart the literature suggests that the impact of communication on implementation is dependent upon the type of communication; direct or indirect. It appears to be increasingly well recognised in the literature that publishing the results of conservation research in scientific journals is unlikely to support conservation activities on the ground, unless it is also supported by direct engagement with conservation practitioners, however even direct presentation of research findings may not be enough to ensure results are implemented.

In light of much research communication not leading to research implementation, many authors have suggested how science communication could be improved to support implementation. Suggestions include:

- Communication training for scientists (Burns 2014; Moody 2014; Bik and Goldstein 2013; Laurance *et al.* 2012; Farley *et al.* 2008, 2009, 2010; Siepen and Westrup 2002). Moody (2014) specifically suggests scientists need to better describe their data and its uncertainty, in order for it to support practical implementation decisions. Laurance *et al.* (2012) agrees that scientific uncertainty prevents implementation and criticizes the scientific literature for being written in academic rather than practical terms.
- Explaining research findings and recommendations as a persuasive story. Farley and Miles (2008) suggest that compelling stories influence policymakers more than dry facts.
- Ongoing communication between the producers and users of knowledge (Bainbridge 2014; Sarewitz and Pielke 2007). Bainbridge (2014) suggests conservation scientists can improve communication and engagement with policymakers through engaging early with them, building ongoing, long-term relationships, thinking of their needs and perspectives and ensuring results are well presented, simple, clear, available to all and well documented.

- Provision of up-to-date systematic reviews or other syntheses of research findings, in which the key messages for different target audiences (Proctor *et al.* 2013; Grimshaw *et al.* 2012).
- Identifying the target audience and tailoring outputs to the knowledge needs of recipients (Wansbury 2015; Hulme 2014). However, other authors have demonstrated that tailoring outputs and communication to audiences is not effective (Milner-Gulland 2012). They state "*It is no good attempting to retrofit research to management questions... these approaches are by and large doomed to failure*." Their conclusion is based on convincing analysis of many hundreds of papers during their work as editors of the Journal of Applied Ecology.
- Formal and informal links between organisations and individuals have been also been suggested (Guerrero *et al.* 2013; Borland and Holley 2011; Bode *et al.* 2010; Carlsson and Sandstrom 2008; Isaac *et al.* 2007).
- Improved relationships between researchers and practitioners. This has been shown to enable social learning and create social capital (Lauber 2011; House 2010; Knight 2006).

Analysis of this literature makes it clear that *direct communication* has led most often to implementation. Specific types of direct communication are more successful than others. For example: communication which is ongoing and begins early, so that research is informed by practitioners needs; and communication which supports the development of social capital.

A significant body of research demonstrates that improved relationships between scientists and decision makers creates social capital *(trust, respect and cooperation)* which subsequently supports research implementation (Lauber *et al.* 2011; House 2010; Farley *et al.* 2010; Gibbons *et al.* 2008; Durrant *et al.* 2007). Several authors describe how the relationships between researchers and conservationists inhibit or enable cooperation, learning and conflict resolution (Williams 2012; Bodin and Crona 2009; Olsson *et al.* 2007; Hahn *et al.* 2006; Tippett 2005). For example, Lauber *et al.* (2011) conducted 60 interviews with government and nongovernmental organization representatives and followed these up with six case studies, in order to identify factors that influence availability and use of scientific information. They found both availability of scientific information and conservation practitioners' willingness to use the information depended on the quality of interpersonal relationships and communication. Their work demonstrates empirically that interpersonal relationships and communication can directly lead to agreement on objectives and implementation. Similarly, House (2010) investigated how the Mediterranean Integrated Coastal Management (ICM) plan could be better implemented. Using data from semi-structured interviews and a review of Mediterranean Coastal Foundation ICM Conferences, the research identified issues preventing implementation and identified social capital as crucial for implementation. These conclusions are supported by Durrant *et al.* (2007) who examined the conservation impact of the Serengeti Cheetah Project and found that informal dialogue between the researchers and park managers was essential in influencing conservation actions. However, this dialogue was dependent on social capital and good relationships between researchers and managers, which were supported by the long term nature of the research project. Gibbons *et al.* (2008) also suggest that successful research–policy partnerships are built around personal relationships. Similarly, Farley *et al*. (2010) stress the importance of relationships between researchers and conservationists for implementation. The strength of the work of Lauber (2011), House (2010), Durrant (2007) and Farley (2010) is that it is based on empirical evidence and can cite genuine examples where research has been implemented due to direct communication between researchers and conservationists.

In conclusion the literature suggests that *direct communication* between researchers and conservationists, is most likely to lead to implementation *provided* this communication successfully develops social capital.

2.2 TRAINING

The literature suggests that implementation of scientific findings could be supported through training in diverse range of skills, which are not usually part of research training or undergraduate science or ecology degree programmes (Bainbridge 2014; Reyers *et al.* 2013; Kenward *et al.* 2011; Putz and Zuidema 2008). These skills include trust building, public communication, policy formation science communication, leadership, adaptive management and interdisciplinary training.

2.2.1 LACK OF TRAINING AS AN IMPLEMENTATION BARRIER?

Although lack of training has frequently been cited in the literature as a reason for the research–implementation gap (Burns *et al.* 2014; Bainbridge 2014; Reyers *et al.* 2013; Niesenbaum and Lewis 2003) there is little evidence which directly links lack of training in the skills described above to lack of implementation. No BACI designed studies have compared the research implementation of academics with and without training in the suggested skills, to examine whether or not lack of skills is an implementation barrier.

However, there are cases in the literature where implementation failures have been linked to lack of skills. Gerhardinger *et al.* (2011) researched the failure to implement the National System of Marine Protected Areas in Brazil. Their findings highlight the need for strong leadership to support their implementation. Similarly, Kenward *et al.* (2011) investigated the performance of different systems of governance in achieving successful conservation outcomes at local and international levels. The case studies in Kenward's work also provide a powerful example of the importance of leadership. Correspondingly, Manolis *et al.* (2009) also suggest that effective leadership leads to implementation. The strength of this work is its use of empirical evidence supporting the potential of integrative leadership, to improve conservation implementation.

Lack of other skills has also been found to prevent implementation. Ban *et al.* (2013) and Ives *et al*. (2015) describe case studies demonstrating implementation failures due to insufficient consideration of the social processes that influence conservation decisions. Weak governance and low capacity has also been demonstrated to be responsible for failure of conservation programmes due to lack of conservation practitioners skills (Mitchell *et al.* 2015; Bennett 2011). Ban, Ives, Bennett and Mitchell's conclusions are based on analysis of case study data and appear to be valid. Although it is likely that additional factors were also involved, poor leadership, lack of social data use and low capacity appear to the primary causes of failure to implement research in these cases. It is therefore, not an unreasonable assumption that increasing these core skills could support implementation of results in some cases.

The main reasons described in the literature for this lack of implementation related skills are that the skills required for conservation are not traditionally included in biological degree programmes (Burns *et al.* 2014; Bainbridge 2014; Niesenbaum and Lewis 2003) and a lack of interdisciplinary training (Pietri *et al.* 2013; Newing 2010; Campbell 2005). Cost and time constraints are also described as barriers to researchers accessing training (Burns *et al.* 2014). However, Burns *et al.* (2014) also provides evidence for the increase of science communication training within undergraduate and postgraduate degree training.

This literature review will now examine the evidence in the literature for training as an implementation solution.

2.2.2 TRAINING AS AN IMPLEMENTATION SOLUTION?

There is no mention of questionnaire surveys or BACI designed studies in the literature which compare the research implementation of academics with and without training in the skills suggested, to examine whether or not these improve research implementation. However, evidence for the importance of training comes from authors of research which was implemented, in which specific skills are frequently cited as essential to implementation.

For example, Reyers *et al.* (2013) suggest that due to its long-time frames implementing conservation research requires trust building, patience and persistence, and that these skills are not part of the usual conservation scientist training. Similarly, Knight *at al.* (2006) also suggest research students should be trained in skills for "*doing*" conservation. Burns (2014) and Farley *et al.* (2010) have both stressed the need for conservation scientists to learn effective communication skills. Putz and Zuidema (2008) suggest scientists need training to be able to tackle "*inelegant, wicked conservation problems",* i.e. those which do not fit classical research formats. Kenward *et al.* (2011) and Manolis (*et al.* 2009) suggest leadership training can help implement conservation science. Muir and Schwartz (2009) and Bainbridge (2014) suggest that conservation could be improved through the increased emphasis in graduate programs on understanding decision making and implementation of policy. The significance of the conclusions of Burns, Farley, Kenward, Knight Reyers and Manolis is due to their use of empirical evidence from case studies of research which was implemented, this lends significant credibility to their studies and shows that at least in some cases, particular skills have been demonstrated to support implementation. It is therefore a reasonable conclusion that training in these skills, which enabled researchers to develop these skills, could support research implementation.

Further evidence for the importance of specific skills comes from Lees and Peres (2008) and Barlow (2007) who describe their inter-disciplinary research involving collaboration with social scientists, environmental economists and numerous NGOs, which influenced Brazilian Forestry policy in 2012. This led to the conservation of wider forest buffers along rivers and perennial streams and supported geographic selection and design of Amazonian forest reserves. It's implementation contributed to the creation of 12 new protected areas in Amazonia. Their research demonstrated the importance of trust building, public science communication, leadership, adaptive management and interdisciplinary skills and therefore provides evidence for their importance within wider research implementation.

In conclusion, critical analysis of the literature on training has led to the conclusion that there is reasonable evidence for the value of several skills improving research implementation. These skills include trust building, public science communication, leadership, patience, "*doing*" conservation, understanding decision making and implementation of policy, adaptive management and interdisciplinary skills. Therefore, this research supports the assumption that training in these skills could increase research implementation.

2.3 RELEVANCE

The literature seems to agree that implementation relevant science is timely, authoritative, believable, trusted and legitimate (Mair 2014; Cook *et al.* 2013; Robinson et al. 2010; Böcher 2008; Cash et al 2002). Relevant scientific information can improve conservation practice and management (Hart and Calhoun 2010) and help mitigate biodiversity loss (Rockström 2009). It can also increase probability of making good policy and decision making (Pullin and Knight 2003) and improve policy making by clarifying choice and filtering out policy options with a low likelihood of success (Rigby 2005). However, conservation research has been criticized as irrelevant to both policy and practice.

2.3.1 POLICY IRRELEVANCE AS AN IMPLEMENTATION BARRIER?

There seems to be general agreement within the literature about the importance of policy relevance to implementation and the lack of policy relevance in much conservation research (see Reyers 2013; Nicholson *et al.* 2012; Jones *et al.* 2011; Sutherland 2011; Morton *et al.* 2009; Gibbons 2008; Robinson 2006). It has even been suggested that the persistence of the gap between the scientific information and what is required by policy makers, has led to new funding requirements for scientific research to be comprehensively incorporated into policy (Sutherland 2011; Lawton 2007). The literature illustrates that for the last 15 years governments, NGO's and scientists have all appealed for an increase in the policy relevance of environmental and conservation research due to the shared belief that this will increase research implementation and benefit policy making. For example: in 2008 the UK Council for Science and Technology stated that both academics and policymakers still had a "*considerable way to go"* to use scientific evidence more systematically in the policymaking process (Ward *et al.* 2010; Council for Science and Technology 2008). In 2001 the European Environment Agency (2001) identified the delay between scientific identification of a problem and policy action to resolve it as key lessons from environmental crises including asbestos, Bovine Spongiform Encephalopathy and sulphur dioxide (Anderson 2007; EEA 2001). In 2005, after the Bovine Spongiform Encephalopathy crisis, the UK Government published guidelines recommending the use of scientific analysis in policy making (HM Government 2005). The American National Research Council also states that ''*science gathered to inform environmental decisions, it is often not the right science"* (NRC 2005). Consequently**,** a great deal of research has focussed on understanding the reasons for the lack of policy relevance and how to increase the policy relevance of research.

There is no consensus in the literature for the reason for the lack of policy relevance of much conservation research. Jones *et al.* (2011), Nicholson *et al.* (2012) and Robinson (2006) suggest this is a consequence of not structuring scientific research around polices that influence conservation and not supporting policy development on delivery of conservation targets. However, Reyers (2013), Pretty (2009); Gibbons (2008) and Morton *et al.* (2009) suggest the lack of policy relevance is due to a lack of communication between researchers and policy makers. They describe researchers as "*out of touch*" with policy making, and suggest scientists should be "*proactive*" and move beyond the "*comfort zone of biology … all the way to the complex world of politics*." While Jones (2011), Nicholson et al. (2012) and

Robinson's (2006) work is correct in its description, structuring research around policies is dependent on communication between researchers and policy makers, therefore Reyers (2013), Pretty (2009), Gibbons (2008) and Morton et al (2009) are more exact because lack of communication is the fundamental cause of lack of policy relevance.

Evidence for the importance of communication between researchers and policy makers is also supported by agreement within the literature that the dynamics and social setting of policy making strongly affect the translation of research into policy (Burns *et al.* 2014; Sarewitz and Pielke 2007; Jasanoff *et al.* 2004) and authors who criticize the current response to calls for more policy relevance and accuse researchers of simply increasing the supply of scientific information and funding more research that lacks relevance to decision makers (see McNie 2007; Lahsen and Nobre 2007; Sarewitz and Pielke 2007). Communication between researchers and policy makers places researchers within the social setting of policy making and makes them more able to influence the implementation of research into policy, which enables scientific research to be relevant to policy makers and therefore implementable.

There is no consensus in the literature for reasons for this lack of communication between scientists and policy makers. Some authors have suggested policy advocacy tarnishes scientific credibility (Farley *et al.* 2010; Scott *et al.* 2008; Ehrlich 2002), and Wagner (2001) describes political engagement as "*dishonest, subjective and not part of scientific research*". The literature reports that the credibility of scientists has been both improved and tarnished by their involvement in or advocacy for implementing research. Blockstein (2002) suggests lack of communication between scientists and policy makers is due to fear connected to unfamiliarity with the legislative and other political processes, or dissatisfaction with the political system. However others suggest communication barriers exist because of scientific uncertainty or because "*scientists and politicians are often at cross-purposes*", therefore they have mis-matched agendas and conflicting views about what constitutes legitimate information (see Cook *et al.* 2013; Geburek and Konrad 2008). Cook *et al.* (2013) suggests scientists must balance the need for relevance, with novelty and rigor. They suggest communication that considers the values and perspectives of all stakeholders is essential to achieve this. This lack of consensus suggests that there is not a single reason for lack of policy relevance which can be applied to all research, however it is possible that a single underlying cause, or highly significant factor, common to this lack of communication can be found.

This research acknowledges that it can be difficult to assess the impact of research on policy because the effect of the research may not always be apparent, due to the slow movement from science to specific policy initiatives, or a lack of visible manifestation of research in policy even when the contribution of science to policy is important (Lane 2010; Cash *et al.* 2003; Albaek 1995). In addition, policy implementation is highly complex and conflicts with other policies or institutional concerns can also affect the ability of research to influence policy making (Sayer *et al.* 2013; Reyers *et al.* 2010). For example lack of interrelated land-use planning policy and national values, which prioritize economic growth and development, often limit implementation of conservation focused policy. However, in agreement with Cash *et al.* (2003), this research suggests that potential research impacts on policy should be apparent from the definition and framing of issues within it, and the presentation of possible policy alternatives.

2.3.2 IRRELEVANCE TO PRACTISE AS AN IMPLEMENTATION BARRIER?

Over the last 15 years there seems to be general agreement within the literature on a lack of relevance to conservation practitioners of much conservation research (see Coetzer *et al.* 2014; Darling 2014; Braunisch *et al.* 2012; Sutherland 2011; Hulme 2011; Knight *et al.* 2008; Noss *et al.* 2006; Pullin *et al.* 2003; Marris 2007; Balmford 2003; Brummitt and Lughadha 2003; Salafsky *et al.* 2002; Whitten *et al.* 2001; Redford and Taber 2000; Mace *et al.* 2000). The literature describes both a collective responsibility, in which conservation scientists have not been successful in giving practitioners the knowledge needed to make conservation effective and a lack of understanding of the relevance of research by conservation practitioners (Sutherland *et al.* 2004, 2009). In a landmark study, Young and Van Aarde (2011) argue that conservation managers describe the lack of research relevant to their needs is the major impediment to their use of science to inform conservation practise, and that irrelevant or unrealistic recommendations can undermine the credibility of scientists. Milner-Gulland *et al.* (2012) suggest that applied research with the most obvious impacts is that which is driven by the needs of implementers, be they managers or policymakers, rather than by the interests of academics. Their conclusion is credibly based on their work as editors of the *Journal of Applied Ecology*. Similarly to the problem of policy relevance, the literature suggests the numbers of publications are increasing, but that these contribute only marginally to management of species and ecosystems (see Hulme 2011; Arlettaz and Mathevet 2010).

However, there is no consensus on the reasons for this irrelevance; different authors suggest different casual factors. It is proposed by some that conservation research rarely supports conservation action because most researchers do not intend their research to be implemented (see Moody 2013; Salafsky 2011; Knight *et al.* 2008, 2006; Meijaard and Sheil 2006). Reviews of conservation studies from 1986 to 2014 suggest that very few published studies aim for implementation. The value of these studies lies in the sheer volume of conservation research assessed. Moody (2013) reports on a review by Fazey *et al.* which reviewed publications from 2001 ($n = 547$ papers) in three prominent conservation journals (*Biodiversity* and *Conservation*, *Biological Conservation and Conservation Biology*). Only 27% of studies had relevance to policy or management and only 12.6% of these studies actively went out to test or review conservation actions. Balme *et al.* (2014) reviewed scientific literature on leopards *Panthera pardus* in South Africa to demonstrate the discrepancy between research and conservation priorities. They found research focused disproportionately on basic research, such as leopard feeding ecology inside protected areas. Most articles were published by academics in high impact journals but these articles avoided applied studies. Salafsky (2011) reviewed 15 essays on conservation published as a book entitled "*Tackling Wicked Problems through the Transdisciplinary Imagination"* reports with dismay that the book offers nothing to conservation practitioners because the focus of each paper is a philosophical discussion on the various modalities of inquiry for solving problems, rather than any focus on solutions or their implementation. Knight *et al.* (2006) undertook a questionnaire survey to conservation researchers involved with systematic conservation planning and found that two-thirds of the researchers did not intend their research to be implemented. A subsequent literature review of conservation assessments published between 1998 and 2002 indicated a third (n = 29, total n = 88) of conservation assessments led to any implementation. Of these, only 14 were considered "*highly effective"*, whereas 21 were "*poorly effective*" or "*ineffective*" (Knight *et al.* 2008). Meijaard and Sheil (2006) reviewed 284 publications on tropical conservation, including 153 papers from peer-reviewed journals. They found few studies which aimed to address threats to species and even fewer which provided guidance for conservation management, concluding that conservation research across most of the tropics is failing to address conservation needs. The temporal scope of these reviews and the volume of conservation research assessed demonstrates that a significant body of conservation research does not have implementation as its primary purpose.

Some suggest conservation scientists work is often irrelevant because scientists are reluctant to study practical conservation issues which do not fit into rigorous experimental designs. Laurance *et al.* (2012), Knight *et al.* (2008) and Putz and Zuidema (2008) have all accused conservation scientists of being more interested in testing fashionable hypotheses, than solving real-world problems. Similarly several authors suggest research questions are irrelevant to the needs of conservation practitioners because academia and publishing have different objectives for a study (e.g. novelty, broad focus) than developing tools to help conservation practitioners (Balme *et al.* 2014; Moody 2013; Laurance *et al.* 2012). Balme *et al.* (2014) suggests this means many researchers are reluctant to tackle applied topics perceived to be less competitive for publishing or too impractical to study. Others suggest the reasons for the lack of applicability of research are due to science training and classic research structure in which scientists are trained to devise and conduct '*elegant research'* which by definition, has clear hypotheses, strong sampling and robust statistical analysis. However most conservation problems faced by conservation managers do not fit this mould and are therefore not subjects of research (Putz and Zuidema 2008; Ludwig 2001). This suggests that in order to enable conservation problems to meet the requirements of 'elegant research', conservationists and scientists must work together to develop research questions.

Suggestions by other authors, that many conservation scientists management recommendations lack applicability and tend to neglect crucial economic or societal constraints (Arlettaz *et al.* 2010; Knight *et al.* 2008), also points to a lack of communication between researchers and practitioners, which could ensure implementation constraints where incorporated into research design. Laurance *et al.* (2012) claim that although deceptively simple, few conservation scientists initiate dialogue with practitioners when planning potential research projects. Lack of proactive communication and failure to engage with decision makers are described as primary reasons for research being irrelevant to practitioners by Darling (2014) and Laurance *et al.* (2012). Examination of the literature leads to the conclusion that lack of communication appears to be the underlying, causal factor in most of the other relevance-related implementation barriers described in the literature.

Additional evidence for university led research being irrelevant to practitioners comes from the proliferation of conservation research carried out within conservation agencies. If research was meeting the needs of conservation agencies, there would be no need for NGO's to divert their scarce resources into research. Although there are examples of partnership research between universities and conservation agencies, numerous conservation NGOs and charities employ their own scientists, which they describe as "*central*" to implementing conservation based on applied ecological science (Hulme 2014). NGOs and conservation charities such as the Royal Society for the Protection of Birds, Natural England, the Nature Conservancy, Fauna and Flora International and WWF fund their own research programmes, include independent scientists on their boards of governance, publish their own journals and have developed their own metrics and mechanisms to estimate the impact of their research (Hulme 2014). Kareiva *et al.* (2014) in a review of the history and achievements of the Nature Conservancy, highlights that it employs around 600 scientists, who publish more than 200 peer-reviewed papers per year. Clearly, the need for answers to applied conservation questions led these organisations to create and fund their own research departments, which suggests that conventional, university led science did not meet their information needs.

2.3.3 POLICY RELEVANCE AS AN IMPLEMENTATION SOLUTION?

There are examples in the literature of policy relevant science directly influencing policy, for example: a paper by Green *et al.* (2004) demonstrated for the first time that the drug diclofenac, widely used in the treatment of inflammation, pain and fever in livestock, was the major driver behind catastrophic vulture declines in south Asia. Vultures feeding on livestock carcasses ingest the diclofenac, which leads to renal failure and death. A recent paper (Cuthbert *et al.* 2011) evaluated the effectiveness of the policy action that followed Green *et al.*'s revelations (a ban on the veterinary use of diclofenac, instituted in three countries in 2006). They found that this policy action is likely to have reduced the rate of vulture decline. Another example of research positively influencing policy are the horizon scaning exercises by Sutherland *et al.* (2011), which generated research questions by asking policy makers and practitioners for their information needs. Subsequent research based on this supported the development of Marine Conservation Areas and influenced the UK's marine conservation policies.

Although there is agreement within the literature that increasing the policy relevance of research increases its implementation likelihood (see Sutherland 2011; Lawton 2007; Burns *et al.* 2014; Reyers 2013), there is no consensus in the literature about how to ensure the policy relevance of research. Bloor *et al.* (2013) and Rudd (2010) suggest researchers must better align research with policy needs through collaborative processes which source questions from policy makers. They also suggest researchers must understand the ways research can influence policy, in terms of its symbolic, conceptual or instrumental impact, as defined by Weiss (1977). Albaek (1995) suggests research should focus on informing the debate on policy alternatives and helping policy makers discuss facts in order to be policy relevant. While Rudd's work has some limitations in that it is based on Canadian examples, the collaborative process of communication and engagement between scientists and decision makers it describes, did successfully generate and prioritize research questions at a national level to support Canadian conservation policy. The importance of collaboration, communication and engagement is also supported by Sutherland *et al.* (2011) who also suggest scientists must consider the different possible types of research impact and use a participatory approach to enable collaboration between policy makers and scientists. Sutherland *et al.* (2011) describe horizon scanning exercises which were able to bridge the gap between conservation policy and research and stimulate the development of policy-relevant conservation science; identify research priorities; find potential threats and opportunities; and identify emerging issues in conservation (Sutherland and Woodroof 2009; Sutherland *et al.* 2006, 2008, 2009, 2010a, 2010b, 2011). The value of Sutherland's work is illustrated by the development of the UK Marine Science Strategy, which was based on the results the 2006 '*UK questions'* exercise.

Several authors suggest advocacy for research outputs can achieve policy relevance and implementation. They urge scientists to effectively communicate their results and address issues that really matter to local, national and global communities (Leith *et al.* 2014; Peterson *et al.* 2010; Blockstein 2002; Flyvbjerg 2001). Leith *et al.* (2014) argue against the traditional construction that science must distance itself from values and what is at stake, and urge it to influence policy making. They suggest it is possible to identify "*appropriate processes,* *institutions, objects (e.g. tools, information products) and relationships"* which can connect science and decision-making in conservation management and policy and describe this as "*essential"* for ensuring conservation practice is informed by science. Blockstein (2002) presents guidelines on how to maintain scientific credibility while engaging with the political process and suggests a variety of methods of political engagement from letter writing, to giving testimony at hearings. In addition, Peterson *et al.* (2010) suggests that enhanced collaboration between social and conservation science could increase the political power of conservation concerns and thus increase their implementation. Whilst advocacy may be an effective way to support the implementation of research into policy and encourage communication between policy makers and researchers, Leith and Peterson also stress that unless the research is policy relevant, no amount of advocacy will encourage its incorporation into policy. They use empirical evidence to support their findings which suggests that advocacy alone will not ensure research is policy relevant, communication with policy makers needs to occur during research development, not only when presenting research results.

Different authors suggest different benefits to participatory communication between policy makers and researchers. Karl *et al.* (2007) suggest that participatory approaches can support diverse and adversarial parties to collaborate and identify, define and answer critical scientific questions that inform policy development. Shulha and Cousins (1997) suggest involvement of decision makers in the research process increases the perceived quality of methods, credibility of researchers and organizations and therefore positively influence research uptake and impact. Diamond and Saez (2011) suggest this communication helps ensure policy recommendations are socially acceptable and not too complex to implement. This research agrees that increased credibility, trust and conflict resolution are important facets of communication and ensuring policy relevant research.

Additional solutions suggested in the literature to enable policy relevance include: using protected areas as policy experiments (Fox *et al.* 2012); timely research in order to aid the development of evidence-based policy (Lawton 2007); basing research on economic mechanisms that are "*empirically relevant and first order to the problem"* and robust to changes in assumptions (Diamond and Saez 2011) and increased accessibility of research to policy makers (Milner-Gulland 2012). To support this a free news and information service published by Directorate-General Environment, European Commission '*Science for*

Environment Policy', which publishes the latest environmental research findings needed to design, implement and regulate effective policies is now provided to policy makers.

In conclusion there is no single solution suggested to ensure research is policy relevant, instead numerous factors have been identified which could contribute to ensuring research is policy relevant. However, lack of communication appears to be the underlying causal factor in most of the policy relevance-related implementation barriers described in the literature. Therefore increased communication between policy makers and researchers is the most important implementation solution, because it is foundational to understanding how research influences policy; ensuring credible, timely, collaborative, participatory research aligned with policy needs; and enabling advocacy for the importance of research findings.

2.3.4 RELEVANCE TO PRACTICE AS AN IMPLEMENTATION SOLUTION?

Similarly to the generation of policy relevant questions by involving policy makers, involving practitioners has been found to support the generation of questions relevant for practitioners. There is widespread agreement within the literature that sourcing research questions directly from practitioners can support implementation and ensure relevant research (see Matzek *et al.* 2014; Moody 2013; Farley 2010; Sutherland *et al.* 2009; Morton *et al.* 2009; Durrant *et al.* 2007; McNie 2007; Knight *at al.* 2006; Roux *et al.* 2006; Pielke 2000). Organisations such as Conservation Evidence at the University of Cambridge (Dicks *et al.* 2014 ; Bruelle *et al.* 2015; Sutherland 2014), the Centre for Conservation-Based Evidence at Bangor University (Ruiz-Frau 2015; Ressurreição 2012); Gallo *et al.* (2009) are providing case studies and research examples demonstrating how to increase research relevance by involving practitioners. The strength of their research is based on its use of empirical evidence and therefore their conclusions, that connection between researchers and practitioners at the beginning of the study, and the attentiveness of the researchers to the importance of the implementation are fundamental, seem justified. Case studies by Laurance *et al.* (2012) demonstrate four practices and principles that scientists can use to ensure research findings are implemented and support conservation work, all of which are based on proactive dialogue between conservation scientists and practitioners whilst devising research priorities.

Further examples from the literature include Fleishman *et al.* (2011) who describe participatory processes involving decision makers, scientists and individuals responsible for managing and developing natural resources used to develop a list of the top 40 high-priority, multidisciplinary research questions to support current and future decisions about conservation management in the United States. They describe how this research built on lesson learnt in previous priority-setting exercises for the United Kingdom (Sutherland *et al.* 2006, 2010), Australia (Morton *et al.* 2009), and the world (Sutherland *et al.* 2009). This finding is supported by research from other parts of the world, which all come to the same conclusion: Knight *at al.* (2006) review of eight South African conservation planning processes concluded that research questions should be sourced from conservation practitioners and basing the conservation planning exercise on real needs is critical for implementation. Durrant (*et al.* 2007) also cite empirical evidence and suggest sourcing questions from practitioners and relevance of research activities as key to successful implementation, in their analysis of the Serengeti Cheetah Project.

In response to this need for academic scientists and practitioners to interact more effectively and earlier in the research process, the *Journal of Applied Ecology* launched *Practitioners' Perspectives* in 2011 (Hulme 2011). This gives practitioners a platform upon which to share their experience and what they require from applied ecological science and to highlight successful examples of the practical application of science to management. Within this, Thorpe and Stanley (2011) describe setting targets for habitat restoration, based upon their experience with land managers in the Pacific Northwest of the USA, and highlight the importance of collaborative working. Hill and Arnold (2012) also find this and highlight a number of ways in which both can benefit from a more collaborative approach to tackling applied ecological problems. The validity of their conclusions is based on the successful implementation of their collaborative work.

While there is agreement that sourcing questions directly enables researchers to understand practitioners needs, there is disagreement on the reasons for the successful implementation of research based on questions from practitioners. Several authors suggest it enables researchers to include relavant social information such as the role of public communication, politics, economics and sociology on conservation outcomes (see Braunisch *et al.* 2012 ; Laurance 2008b, 2009; Putz and Zuidema 2008; Ghazoul 2009). Braunisch *et al.* (2012) surveyed

Swiss conservation practitioners to identify and prioritize their information needs and found questions related to economic, societal and stakeholder conflicts were more important to practitioners than conceptual questions. Farley (2010) suggests sourcing questions directly means they are identified on the local level, therefore are locally relevant and thus used by those who will be responsible for implementing the research. Roux *et al.* (2006) suggest that the "*co-production*" of knowledge through collaborative learning between "*experts*" and "*users*" creates a more suitable approach for conservation implementation. Moody (2013) suggests that involving conservation practitioners early enables them to guide the research process and thus ensure its relevance. O'Connell and Yallop (2001) suggest it enables researchers to understand statutory conservation frameworks. Laurance *et al.* (2012) and Milner-Gulland *et al.* (2012) suggest it enables determination of the most pressing questions, which are therefore most likely to be implemented. Smith *et al.* (2009) propose that it helps develop research topics that are innovative and multidisciplinary, access new or non-traditional sources of research funding and develops important collaborations between conservation scientists and practitioners which is why it supports implementation. McNie (2007) proposes that sourcing questions directly enables a problem-oriented approach, focused on resolving the problem rather than theoretical inquiry. Hayward (2011) suggests directly sourced questions might sometimes be those linked to conservation activities which are easiest, and therefore, more frequently implemented. Hayward (2011) found significant differences in management of declining and non-declining species on the 2009 IUCN Red List, with some conservation actions more effective than others. They also found declining species faced different threats to improving species, suggesting some threats (e.g. hunting) were easier to treat than others (e.g. climate change and invasive species). Hall and Fleishman (2010) and Beierle and Cayford (2002) suggest that the participation of "*end users*" in research activities increases the probability of them implementing research findings. Burns *et al.* (2014) argue that when conservation science engages with non scientists it involves the broader public who control what knowledge and priorities are applied to natural resources. These diverse findings appear valid, as they draw their conclusions from cases studies. However, they are not mutually exclusive, which suggests that sourcing research questions from practitioners has a wide range of *context dependent* implementation benefits.

Changing the design of research has also been highlighted as an implementation solution to increase relevance to practitioners. Long term research, working in partnership with conservation agencies, and focusing on key knowledge gaps is suggested by some (see Likens and Lindenmayer 2012; Meijard and Sheil (2007). Smith *et al.* (2014) suggest conservation research should compare the effectiveness of a series of management interventions, not simply one type of intervention with a control of no intervention, in order to inform conservation practitioners which intervention is the best option relative to others. Meijard and Sheil (2007) call for research to develop long-term, applied projects in partnership within conservation agencies in order to overcome conservation problems and direct threats to species. They demonstrate that long term projects do not require more time or funding per annum; recommend using graduate students to implement aspects of projects; and suggest the financial and logistical viability of applied long term research depends on researchers' willingness and skill convincing academic institutions of the importance of conservation goals. Changes to research design to ensure it is tested and demonstrated in "*real world conditions"* has also been suggested (Hall and Fleishman 2010). Hall and Fleishman (2010) suggest that in order to solve real-world problems and be accepted by conservation practitioners, conservation research should be evaluated under field conditions and suggest this reduces scientific uncertainty, validates whether or not a management approach is effective and financially sustainable, assesses management interventions and enables researchers and conservation practitioners to avoid trial-and-error approaches. The conclusions of Likens and Lindenmayer, Meijard and Sheil and Hall and Fleishman are all based on the case studies they cite and therefore they provide direct empirical evidence for their conclusions, although the results of case studies may not be genrealisable to all situations, the shared conclusions from a series of diverse case studies suggest these conclusions are robust, valid and widely applicable. Each of these suggested changes to research design involves collaboration with practitioners and improved communication between conservation and research. The suggestions for improvements to research design (such long term, partnership work and field testing) are changes most likely to occur when research is developed with practitioners, therefore these suggestions could support implementation, but again fundamentally they rely on greater communication with and involvement of practitioners in conservation research.

In summary, the evidence from the literature suggests most of the solutions to increased policy relevance and relevance to practitioners are similar; each involves moving away from the traditional scientific approach and is a variation on increasing communication with conservation practitioners.

2.4 INTERDISCIPLINARITY

There is evidence that interdisciplinary conservation research is becoming increasingly common and that conservation researchers and practitioners are increasingly incorporating socio-economics and human dimensions into their work (Lennox and Cooke 2014; Sayer *et al.* 2013; Newing *et al.* 2011; Lepczk *et al.* 2004). For example; In 2011 the first textbook on social science research methods, written specifically for use in environmental conservation was published (Newing *et al.* 2011). Sayer *et al.* (2013) describe how the landscape research has shifted away from purely conservation-orientated perspectives toward increasing integration of poverty alleviation goals.

2.4.1 INTERDISCIPLINARITY AS AN IMPLEMENTATION SOLUTION?

There is agreement in the literature that the integration of conservation and social science is important for the effectiveness of conservation research and practice (see Wei *et al.* 2014; Moon *et al.* 2014; Harry *et al.* 2011; Awruch *et al.* 2011; Clarke *et al.* 2011; Hart and Calhoun 2010; Farley 2010; Knight *et al.* 2010; Ban *et al.* 2009; Vaccaro and Norman 2008; Baskent et al. 2008; Wendt and Starr 2009).

Conservation problems are acknowledged to be highly complex, transdisciplinary and multi-causal, involving interactions between human values, natural and social systems and across temporal and spatial scales which cut across conventional academic disciplines (EEA 2010; Farley 2010; Ascher 2001; Berkes 2004). In addition the increase in human-wildlife interaction, related to human population growth, has increased demand for understanding of the human dimension of wildlife conservation (Decker *et al.* 2012). NGO's, governments and researchers have all promoted the integration of social science into conservation research and practice and suggested interdisciplinary research supports implementation (see Matzek et al. 2014; Redpath *et al.* 2013; Barmuta *et al.* 2011; Farley *et al.* 2005; Knight *et al.* 2006; Blackmore *et al.* 2007; Meffe *et al.* 2006; Millennium Ecosystem Assessment 2005; Convention on Biological Diversity 2000; Chornesky *et al.* 2001; Community Conservation Coalition 2003; Machlis 1996; Noss 1997).

Recent case studies highlighting both implemented work and failure to implement, suggest interdisciplinary research was fundamental to implementation and that lack of interdisciplinary work is the cause of implementation failure. For example: Harry *et al.* (2011) describe how integrative research exploring how human activities interact with shark and ray populations helped implement conservation management. In agreement with this, Clarke *et al.* (2011) also illustrate how interdisciplinary social and biological research helped develop and evaluate tools which investigate sub-lethal effects of human interaction on sharks and rays. Similarly interdisciplinary research enabled Awruch *et al.* (2011) to implement use of a portable field kit for determining the level of stress of sharks in a variety of conditions. These findings are supported by Hart and Calhoun (2010) who also describe how successful interdisciplinary research enabled implementation of a conservation project for native brown trout *Salmo trutta* in over 2800 km of rivers in the French Alps and Wendt and Starr (2009), who describe how interdisciplinary research was effective in implementing science-based management of marine resources. Further support is provided by Ban *et al.* (2009), who provide case study examples of how interdisciplinary social, economic, political and biological research data improved the implementation of conservation research. Wei *et al.* (2014) illustrate that interdisciplinary research enabled researchers to dispel the idea that giant pandas (*Ailuropoda melanoleuca*) are an "*evolutionary dead-end*" and supported conservation implementation. Research by Baskent *et al.* (2008) also suggests effective liaison between interdisciplinary institutions is required for the successful implementation of conservation research. These case studies present evidence based on the implementation of their own work and conclude that this is due to its interdisciplinary nature. It is therefore clear that interdisciplinary research is widely accepted as necessary for implementation of conservation research within the literature.

Although there seems to be general agreement on the implementation benefits of interdisciplinary work, different authors suggest different reasons for the importance of interdisciplinary work to implementation.

Barmuta *et al.* (2011) see interdisciplinary work as necessary to communicate that human uses can coexist with biodiversity conservation and Bryan *et al.* (2011) describe attention to the social values as "*critical for the success of science-based conservation plans".* While others suggest interdisciplinary research enables acceptance of tradeoffs and compromise (Redpath *et al.* 2013; Fleishman *et al.* 2011; Peterson *et al.* 2010; Van Houtan 2006).

Redpath *et al.* (2013) suggest interdisciplinary research enables conflict management by generating understanding of the social and ecological trade-offs involved in conservation. Similarly, Peterson *et al.* (2010) suggests interdisciplinarity research enables researchers to perceive conservation issues differently, in terms of the local or indigenous people involved. Viewing conservation through "*cultural lenses"* allows conservation researchers to resolve stakeholder conflicts, understand the historical, religious and cultural context, distribution of political and economic power, and not miss important realities that affect the failure or success of conservation actions. Fleishman *et al.* (2011) describe how priority setting exercises have highlighted the need for inclusion of societal context and trade-offs among alternative policies and actions. Van Houtan (2006) also suggests that conservation scientists must understand the underlying value systems that affect "*cultural legitimacy"* if conservation research is to be implemented. While Barmuta and Bryan's work is valuable, it is important to recognize that win:win situations cannot always be established. Van Houtan, Fleishman, Peterson and Redpath's work recognizes that compromise of various kinds is often involved in the implementation of conservation, that conflicts do occur and must be understood and resolved, therefore these factors should be recognized within interdisciplinary work designed to support implementation.

Other authors suggest interdisciplinary research is valuable because it generates understanding of complex, nonlinear interactions, and the unpredictable feedback loops between social, economic and ecological system components which is required for conservation implementation (Max-Neef 2005; Lawrence and Despr´es 2004). Similarly, Simpfendorfer *et al.* (2011) state that even accurate, well planned biological research will not support conservation management of sharks and rays, unless social and economic research is also undertaken. Whereas some authors describe interdisciplinary research as important because of the additional knowledge and resources it makes available to support implementation. For example, Czech (2006) suggests interdisciplinary conservation research engages the economic and policy sectors, which makes research more relevant and implementable. Similarly, Peterson *et al.* (2010) suggest interdisciplinary research increases implementation because it provides additional knowledge and man power. Although focused on different types of knowledge, Max-Neef, Lawrence and Despr´es, Czech and Peterson are all describing an increase in knowledge as the primary benefit of interdisciplinary research and this knowledge as key to its implementation.

Other authors have suggested interdisciplinary research supports implementation because it can enable fragmented institutions to work together effectively (Gelderblom *et al.* 2003). This proposal is contradicted by Farley (2010) who suggests that interdisciplinary research supports implementation because it helps overcome the communication barriers which prevent implementation by reducing the use of specialised jargon. In contrast to this, Vaccaro and Norman (2008) suggest interdisciplinary research improves conservation policy design and therefore its implementation likelihood. Despite the differences, these proposed benefits are not mutually exclusive and it is likely that bringing diverse organizations together and improvements to policy and research design are all benefits based on improving communication which therefore supports research implementation.

Understanding of social values is cited by many as the main implementation benefit of interdisciplinary research (Knight *at al.* 2008; Sutherland *et al.* 2009; Rudd *et al.* 2011; Toropova *et al.* 2010; Fox *et al.* 2012; Kinzig 2001; Mascia *et al.* 2003; Balmford and Cowling 2006; Rudd 2010; Balint *et al.* 2011). Case studies by Knight (*et al.* 2010) suggest interdisciplinary research enables understanding of what motivates people to conserve and therefore lead to implementation. Similarly, Reyers (*et al.* 2010) suggest that interdisciplinary research enables implementation by enabling science to be becomes a social process, in which implementation problems are resolved through the participation and mutual learning of stakeholders. Further support for this is provided by Bryan (2010) who found understanding the values people assign ecosystems as *"critical for the success of science-based conservation plans"* and suggests the inclusion of both ecological and social values improves the implementation success of conservation research (Bryan 2010). In addition, conservation is described as: "*socially complex*" due to the values and ideologies of those involved Balint *et al.* (2011); "*primarily not about biology but about people and the choices they make*" (Balmford and Cowling 2006); dependent upon human behavior which is shaped by social factors such as markets, cultural beliefs, values, laws, policies and demography (Mascia *et al.* 2003); and "*at its core about understanding relationships" (*Kinzig 2001) and humans are acknowledged to be an integral part of ecosystems (Gowdy 1994). The research undertaken by these authors is convincing, and in agreement with those findings, this research acknowledges that understanding social values which affect conservation implementation is fundamental to successful implementation. However, it is also suggested that interdisciplinary research must also involve practitioners to ensure it is implementation relevant, and in addition, that practitioners can benefit from increased understanding of social factors affecting implementation, and often provide relevant social and economic data to support interdisciplinary conservation research.

Interdisciplinary research is also described as an important way to engage those responsible for implementing conservation (Farley *et al.* 2010) and it has been suggested that the most relevant applied conservation research questions are interdisciplinary in nature (Matzek *et al.* 2014; Costanza *et al.* 2013; Sunderland *et al.* 2011, 2009). Sunderland *et al.* (2009) suggest that interdisciplinary research is needed to ensure research questions are complex enough to inform conservation practice. Costanza *et al.* (2013) suggests that the '*knowing–doing'* gap exists because scientific recommendations often don't take the social context of conservation into account and results are therefore "*irrelevant"* to practitioners. This is supported by the findings of Matzek *et al.* (2014), who found research needs of California land managers and conservation practitioners were not restricted to ecology, but included social science questions. The work of Matzek, Farley, Costanza and Sunderland is valuable and highlights an overlap with irrelevant research as a barrier and citing questions from practitioners as an implementation solution. The main value of this work lies in how it draws attention to the social dimension of implementation of conservation research and its suggestion that engagement of science and conservation may require the formation of interdisciplinary research teams.

In summary, the literature presents compelling evidence to suggest interdisciplinary research can increase implementation and a variety of reasons for why it supports implementation. The main implementation benefits of interdisciplinary research appear to be how it supports relevance of research by enabling greater understanding of social values, it supports diverse organisations to work together effectively, and it provides additional knowledge and therefore helps to resolve conflicts.

Despite the widespread agreement on the benefits of interdisciplinary research, lack of interdisciplinarity within conservation research has been cited as an implementation barrier and reason for the research–implementation gap.

2.4.2 LACK OF INTERDISCIPLINARITY AS AN IMPLEMENTATION BARRIER?

The literature proposes a lack of interdisciplinarity is reducing implementation of research. Several conservation researchers urge fellow researchers to undertake interdisciplinary research, describe its ability to support research implementation and suggest failures to meet conservation targets are often due to lack of interdisciplinary work (Coetzer *et al.* 2014; Matzek et al. 2014; Fox *et al.* 2012; Meffe *et al.* 2006; Knight *et al.* 2006).

Although Lange (2011) and Schaaf (2011) describe UNESCO projects as excellent examples of interdisciplinary research. Coetzer *et al.* (2014) contradict this in a review UNESCO's Biosphere Reserves, which attempt to merge environmental protection with sustainable development. They suggest that although there are some successful integrated conservation and development projects on UNESCO sites, there are few examples of genuinely successful integrated conservation and development projects, and present numerous case studies of unsuccessful projects. They suggest that the lack of success of Biosphere Reserves is due to failures to include different stakeholders in decision making and project design, which could be avoided through the use of interdisciplinary research methods. Fox *et al.* (2012) suggest that meeting the Convention on Biological Diversity (CBD) target for Marine Reserves requires "*dramatic advances"* in interdisciplinary ecological and social science because the challenges associated with scaling up MPAs are interdisciplinary and include the divergent interests of stakeholders, scale, type and distribution of positive and negative social impacts, organisational and financial capacity limitations, boundary delineation and conflict resolution. Other authors also suggest integrating research is difficult and therefore rarely achieved (Margles *et al.* 2010; Reyers *et al.* 2010). Margles *et al.* (2010) suggest that recent publications highlight the need for more effective ways to integrate research and Reyers *et al.* (2010) suggests that implementation challenges remain in engagement of the social sciences and in understanding the social context of implementation. Roy *et al.* (2013) surveyed 323 researchers involved in research at the human—environment interface and conclude that interdisciplinary research had eluded most respondents.

The challenges of interdisciplinary work, and its apparent importance to conservation implementation, have led to a great deal of discussion in the literature on the barriers to interdisciplinary research. However, there is no agreement within the literature as to the most significant factors preventing interdisciplinary research. A variety of technical, linguistic and institutional barriers have been described including: lack of common vocabulary; institutional barriers such as lack of credit in promotion and tenure; lack of funding; limited institutional mechanisms for research integration; tension with departments and differing disciplinary approaches (Roy *et al.* 2013; Restif *et al.* 2012; Mulder *et al.* 2007; Tappeiner *et al.* 2007; Fox *et al.* 2006). Roy *et al.* (2013) surveyed 323 researchers and found significant challenges and obstacles to implementation of interdisciplinary research, including tension with departments (49%) or institutions (61%), communication difficulties, and differing disciplinary approaches and institutional barriers such as lack of credit in promotion and tenure. These results are similar to those found seven years earlier by Fox *et al.* (2006), who surveyed 360 social and natural scientists. These scientists perceived the strongest barriers to integration of the social and natural sciences were the lack of common vocabulary between biologists and social scientists, the traditional academic reward systems discouraging interdisciplinary collaboration and applied problem solving and the lack of funding for collaborative work.

However, these principals are criticized by researchers who suggest compartmentalization is the most significant barrier to interdisciplinary research (see Darling 2014; Reyers *et al.* 2010; Baumgärtner *et al.* 2008; Balmford and Cowling 2006; Robinson 2006; Max-Neef 2005; Hadorn *et al.* 2006). Reyers *et al.* (2010) describes compartmentalization of knowledge and sectorial responsibilities as the main barrier to successful research implementation. Similarly Baumgärtner *et al.* (2008) suggest the difficulty is due to the training undertaken within different sciences which creates different and incompatible basic constructions of the world within different disciplines. In contrast, other authors have suggested deeper rooted causes for the lack of interdisciplinary research. Becker (2012) and Strang (2009) suggest that the barriers to interdisciplinary research are due to the dualist thinking of western society, in which nature is believed to be separate from human culture. Although the authors above suggest different barriers to interdisciplinary research, these barriers described are interrelated. Compartmentalization of knowledge and sectorial responsibilities is related to a mechanistic dualist world view and the perceived efficiency benefits of compartmentalization. Compartmentalization contributes to a lack of common vocabulary and the development of specialized disciplinary approaches.

Although the literature and describes many barriers to interdisciplinary research, the majority of these could be overcome through increased communication between different research sectors. Therefore lack of credit in promotion and tenure and lack of funding appear to be the most significant barriers to interdisciplinary collaboration.

The potential of interdisciplinary research to support conservation and the acknowledged barriers to it have led to discussion within the literature on solutions to enable interdisciplinary research. A variety of methods have been suggested in the literature to support interdisciplinary research including the establishment of interdisciplinary working groups (Burns *et al.* 2014; Camp *et al.* 2014; McShane *et al.* 2011); scientific ateliers (Farley *et al.* 2010); citizen science (Burns *et al.* 2014); participatory monitoring (Danielsen *et al.* 2009); Collaborative Research Units (Wendt and Starr 2009); personnel exchange mechanisms, such as secondments and internships (Council for Science and Technology 2008); development of interdisciplinary implementation guidelines and examples of best practice (Coetzer *et al.* 2014; Reyers at al. 2013; Curran *et al.* 2012; Mills and Clark 2001); boundary organisations (Tallis *et al.* 2010; Cash *et al.* 2003; Agrawala *et al.* 2001); community-based research in 'science shops' within universities (Fischer *et al.* 2003); and use of post-normal science approaches (Ludwig 2001).

Brandt *et al.* (2013) and Tress and Fry (2005) suggest ensuring questions are clearly framed; use of common terminology; and the development of a broad suite of appropriate methods support interdisciplinary research. Wendt and Starr (2009) suggest funding institutions should request joint proposals from scientists and practitioners to encourage interdisciplinary research, similarly Baker *et al.* (2009) suggest financial investment in interdisciplinary research is required to support it. There is no consensus in the literature for which of these diverse suggestions might be most effective in supporting interdisciplinary research, however its clear that investment in interdisciplinary research is crucial. In addition, these suggestions are not mutually exclusive, for example scientific ateliers, interdisciplinary working groups, community-based research in 'science shops', post-normal science approaches and personnel exchange mechanisms could all support the development of development of interdisciplinary implementation guidelines and examples of best practice. Therefore all of this research has value, the diversity of approaches could support the wide range of interdisciplinary research required to address diverse conservation issues.

In addition a wide variety of frameworks have been suggested to support interdisciplinary research. These include analytical frameworks for conservation research with a social definition of conservation, which explains the role of individuals and social groups in conservation issues and includes socio-ecological issues (CICR 2014); unifying frameworks to aggregate knowledge (Lennox and Cooke 2014); cognitive frameworks based on mental models Biggs *et al.* (2011); Cook *et al.* (2013) suggest four institutional frameworks which help science to inform management: 1) Boundary organizations, 2) Embedding research scientists in resource management agencies, 3) Formal links between decision makers and scientists at research-focused institutions and 4) Training programs for conservation professionals. Other proposed frameworks include those based on resilience thinking and social learning Barmuta *et al.* (2011); transdisciplinary frameworks (Reyers *et al.* 2013); Interactive Systems Frameworks (Wandersman *et al.* 2008); two-way frameworks with connections across global, regional and local scales (Tappeiner at al. 2007); methodological frameworks which help integrate social data into conservation research (Siedlok and Hibbert 2014; Pasquini *et al.* 2010; Stephanson and Mascia 2009); iterative frameworks which help build internal and external networks (Lemos and Morehouse 2005); and frameworks based on participation (Blumenthal and Jannink 2000). These mechanisms are not mutually exclusive, nor the only solutions. These frameworks aim to help diverse sectors work together effectively and integrate social data into conservation research. Frameworks which are systematic, rigorous, explicit, and can be consistently applied, could help improve communication and relationship building to overcome the barriers to interdisciplinary research.

2.5 REWARD

There is a concensus in the literature that historically conservation research has been judged based on its academic merits, researchers have been awarded with tenure and promotion for bringing in research funding and publication in highly regarded journals, rather than the efficiency of research in terms of pragmatic problem solving, impact or application (see Arlettaz *et al.* 2010; Hart and Calhoun 2010; Meijard and Sheil 2007; Knight *at al.* 2006). Although publication and funding are still important factors, research impact is now part of how '*research excellence'* is judged and universities are ranked (Tetroe *et al.* 2008).

The Research Excellence Framework (REF) is the new system for assessing the quality of research in UK higher education institutions. The University of York was the highest scoring university for biological science research in 2014, with 92% of submissions awarded the highest score of 4* *"outstanding impacts in terms of reach and significance"* (REF 2014). Three conservation science case studies undertaken by the University of York are available online (see http://results.ref.ac.uk/Results/ByUoa/5/Impact). The case study entitled '*Developing the rationale for landscape-scale conservation policies'* describes work by York researchers Thomas et al. (2012), demonstrating that populations generally require networks of habitat patches to persist and spread. This researwch is described as "*changing conservation mind-sets, strategies and practice*" and stimulating a "*paradigm shift permeating NGOs, governmental agencies and intergovernmental bodies, whereby the 20th century 'isolated population' conceptual framework for conservation has largely been replaced by landscape-scale thinking and policies".* As metapopulation theory was already well understood and taught to undergraduate students in the late 1990's, this claim represents a gross exaggeration of the research's impact. However, the case study does describe collaborative research with Butterfly Conservation and Buglife, which enabled both organisations to implement conservation projects based on the results of these partnership research projects (REF 2014). York research is also described as "*critical*" to Defra's Lawton Review (Lawton *et al.* 2010) and within the case study a quote from Sir John Lawton, states that the Lawton Review has *"more citations to Thomas and Hill than to any other ecologists upon whose work we draw".* This suggests that partnership research, leading to implementation provides sufficient evidence for the validity of research as to warrent policy development to support its expansion. It also suggests that the REF award for the successful impact of the University of York's biological science research, is due in part to its engagement with conservation agencies and their subsequent production of science-led conservation projects for declining UK butterfly species.

Although the York case studies provides examples of how the REF's focus on research impact can faciliate partnership work with NGO's, other reseachers have suggested changes towards a focus on impact are *"an attack on intellectual autonomy by an interfering and ideologically driven state*" *(*Parker and van Teijlingen 2012*).* Similarly Sarewitz (2011) suggests the changes are unpopular and will only "*produce more hype and hypocrisy"* and many criticise that the added focus on research impact, suggesting it will skew funding towards applied research, and calling for impact to determine only 10–20% of the research agenda (Gilbert 2010). Parker and van Teijlingen (2012*)* suggest demonstrating the impact of academic research is not straightforward and report problems of expense; impossible to verify conceptual and theoretical impacts; anecdotal evidence; data protection issues; attrition of research participants; and the '*messiness'* of demonstrating clear causal links between the research and changed practices. Whilst Parker and van Teijlingen's conclusions are valid, their paper illustrates the problems of proving the impact of investigative research which did not aim to change society through its findings, therefore any impact is difficult to prove. It is suggested that the impact of conservation research which *aims to have an impact*, and is therefore clearly structured towards this impact will not be difficult or expensive to prove, as evaluation of the research impact would be part of the research design, enabling adaptive management, in much the same way as conservation projects are managed and implemented.

Other changes to the traditional reward system are also described, Burns *et al.* (2014) depict a "*paradigm shift*" in which changes to the reward system are occurring. They cite examples including new recognition for data sharing, data being increasingly recognised as a significant research output in itself, and published datasets are being recognised as part of an individuals or institutions research impact. The strength of Burn's work is its use of real examples to support its conclusions, for example they refer to the Terrestrial Ecosystem Research Network (TERN) in Australia, which has produced protocols and licensing agreements to enable data sharing.

These changes to the way research is judged, and the inclusion of impact on how research is rewarded, suggest that lack of reward has been a significant barrier to implementation. The following section will explore the evidence for this within the literature.

2.5.1 LACK OF REWARD AS AN IMPLEMENTATION BARRIER?

Lack of reward for involvement with conservation, has been frequently cited as a reason for the research–implementation gap (Schmidt 2014; Reyers *et al.* 2013; Arlettaz *et al*. 2010). Schmidt (2014) describes barriers to research implementation linked to lack of contact with relevant industries, no role models for moving ideas out of the academic environment, and how academics are discouraged from moving between industry and academia through tenure, hard-to-transfer superannuation, and research quality measures. However, Schmidt suggests the biotech industry provides an example of how partnerships between an industry and research benefit both. Burns *et al.* (2014) explains how the current institutional reward system, still primarily based on assessment of the number and ranking of publications produced discourages researchers share their data and risk these others 'scooping' the primary researcher. Burns *et al.* base their conclusions on the number of journal articles, published since 1962 with '*publish or perish'* in the title (n 72) and suggest this is evidence for the widespread effect of the pressure to publish, the main weakness in this approach is that no examples of this occurring are cited in the paper. It is also based on the assumption that practitioners also represent a threat, and that they are likely to publish research findings ahead of the researchers they collaborate with. However, it is more likely that collaborations with other academic institutions carries this risk, in fact conservation practitioners are critised for not publishing their work (Balme *et al*. 2014). Therefore, the pressure to publish is unlikely to negatively affect collaboration with conservation agencies, in terms of scoops, but may reduce competitiveness due to the long time scales of collaborative projects (Hart and Calhoun 2010). Tress and Fry (2005) suggest integrated research is more likely to be implemented but provide strong evidence for integrative landscape research facing barriers linked to lack of reward. Data from 19 semi-structured qualitative interviews and a survey of 207 people found that the negative aspects of integrated research were related to problems with publishing work and earning merit points.

2.5.1 REWARD AS AN IMPLEMENTATION SOLUTION?

As yet there is little evidence that rewarding research partially on its impact will support research implementation. Changes to REF reflect widespread belief that lack of reward hinders implementation, over the next few years it will be interesting to see if the new focus on impact does reduce the research implementation gap or whether "*funder speak*" will enable the majority of research to remain unimplemented, but sound as though it has impressive impacts.

However, there is evidence that funding rewards for implementation of research are increasing. Zavaleta *et al.* (2008) researched motivation for investment in conservation science by private foundations and found proposals which included an explanation of how the research project would be implemented to benefit conservation, motivated funders to support conservation research. They suggest research which is able to provide evidence for its future implementation is more likely to be financially supported by private foundations. In addition, the Canadian Social Science and Humanities Research Council's 2008 *Environmental Issues* call for proposals, unambiguously stated that funded research must advance the objectives of the Canadian science and technology strategy (Government of Canada 2007) by focusing on government priorities.

2.6 RESOURCES

Lack of resources including time and funding are frequently cited as one of the key reasons for the research–implementation gap within the literature (Gaillard and Mercer 2013, Cook 2013). The following two sections will examine the evidence for lack of resources as an implementation barrier and increased resources supporting implementation.

2.6.1 LACK OF RESOURCES AS AN IMPLEMENTATION BARRIER?

Several researchers illustrate that implementation is rarely included within a funding proposal and suggest this inhibits implementation (Arlettaz *et al.* 2010; Knight *et al.* 2008; Flashpohler, Bub and Kaplin 2000; Meijaard and Sheil 2006). The validity of their conclusions is supported by the 15 year time frame in which the same conclusions have been drawn by diverse studies and the use of case study evidence within these studies, in which resource availability has been demonstrated to support implementation. In addition, conservation practitioners involved in university led research (Dr Bodnar, Birmingham University, *pers. comm.*) suggest that without funding, the time commitment they provide to universities to support the implementation of research, would not be possible. This suggests that although currently most funding proposals are currently written by university staff, and therefore aim to support the work of staff within the university, if partnership conservation projects are to be developed and implemented, funding applications will need to consider both the needs of the researchers and the conservation professionals involved.

2.6.2 RESOURCES AS AN IMPLEMENTATION SOLUTION?

Increasing available resources has been suggested to improve implementation by enabling sufficient communication and stakeholder engagement (Burns *et al.* 2014), paying for training (Burns *et al.* 2014) and enabling demonstration and implementation of research (Lauber *et al.* 2011; Hall and Fleishman 2010). Lauber (*et al.* 2011) also found implementation cost was one of the factors which affected the availability of scientific information and willingness to use it. Burns *et al.* (2014) cite case studies where budgets for communication and stakeholder engagement, were crucial to implementation of research in Australia. They suggest science communication and implementation could be supported by increased funding for communication and stakeholder engagement, which although costly is necessary for implementation of research. The research of Burns, Lauber and Hall and Fleishman is based on the implementation of their own work, thus draws on genuine case studies for its conclusion, and although other factors are identified as important contributors to implementation, the funding for stake holder involvement and field testing demonstrations was considered the key factor in its success.

In summary, the literature suggests that adequate funding for engagement with local stakeholders; communication with practitioners; research demonstration and implementation itself, are all key factors which support research implementation.

2.7. LANDSCAPE MODELLING IN CONSERVATION RESEARCH

Thus far, this literature review discussed the general conservation research–implementation gap, the reasons proposed for it and possible solutions to it. The following section will briefly discuss the implementation gap in relation to the use of the predictive species distribution modelling and landscape permeability modelling tools used within this research.

2.7.1 IMPLEMENTATION OF MODELLING RESEARCH?

Although the applicability of modelling analyses to conservation problems is widely described (Parks *et al.* 2013; Rose 2013; Lawler *et al.* 2011; Franklin 2013; Lui 2013; Zhang *et al.* 2012), there is contrasting evidence within the literature as to how often modelling tools are applied to real conservation problems.

Guisan's (2013) assessment of the scientific literature found less than 1% of published papers using SDMs are targeted at conservation decisions. Cayuela *et al*. (2009) reviewed the application of SDMs to tropical conservation and found similar results, less than 5% of studies addressed conservation issues. Sewall *et al.* (2011) also criticises systematic conservation assessment, claiming published assessments have rarely resulted in conservation action. Grimm's (1999) mini-review of 50 individual-based animal population models, suggested although the majority are driven by pragmatic motivation, and aimed towards practical use in the field, these studies were not specifically applied. Numerous studies describe the use of MaxEnt to plan the location of conservation areas, but it is usually unclear as to whether or not this resarch involved practitioners or policy makers, or how its findings will be implemented (see Remya *et al*. 2015; Cuevas-Yáñez et al. 2015; Gormley et al. 2051; Wang *et al.* 2015).

However, there are recent examples of the application of modelling tools to real conservation problems which suggest the situation may be changing as familiarity with the tools and their promotion in the literature increases. Spatial modelling has been developed by non-governmental organisations to help prioritise conservation activities (Conservation Fund 2013). In India, MaxEnt was used by researchers working in partnership with the Gibbon Conservation Breeding Centre to help identify suitable areas for the reintroduction program of the eastern hoolock gibbon *Hoolock leuconedys* (Sarma et al. 2015). In Australia, models are routinely used to inform invasive species management. Australia has implemented advanced invasive species detection, prevention and impact mitigation programmes based on modelling data (DEPI 2013; NTA 2007; Pheloung *et al*. 1999). The implementation of their studies is supported by the recently contribution of modelling studies to the official listing of gamba grass (*Andropogon gayanus*) as a weed in the Northern Territory of Australia (NTA 2009). In Madagascar, SDMs were used to define priority areas for conservation (Kremen *et al*. 2008; Moilanen *et al*. 2009; Watts *et al*. 2009). The areas highlighted by the models as conservation priority areas, were subsequently designated as no mining and no forestry areas (Guisan 2013). SDM's have also been applied to identify suitable translocation sites for the bighorn sheep (*Ovis canadensis sierrae*) in the Sierra Nevada (Johnson *et al*. 2007). Research by Poff *et al.* (2010) and McFreeman *et al.* (2012) highlights how hydrologic models are now commonly used to develop conservation strategies for rivers and catchments and provide case study evidence to support their findings.

Similarly, models have been used for the identification of critical habitats, defined as habitats necessary for the persistence, or long-term recovery of threatened species (Greenwald *et al*. 2012). Critical habitat identification is required by law in Canada, USA and Australia. Modelling tools have been applied in the identification of critical habitat for Ord's kangaroo rat (*Dipodomys ordii)* in Canada (Heinrichs *et al*. 2010). Guisan (2013) reports how species distribution models were used in Spain, to identify critical habitats for four threatened bird species. These SDMs were developed by scientists (Brotons *et al*. 2004), explained to practitioners (CTFC 2008) and finally influenced policy. The results of the models were included in the Natura 2000 network management plan (DMAH 2010).

An examination of the literature to understand why and how modelling studies are implemented, and when they are not implemented, what the barriers are, reinforces the earlier findings in relation to the implementation of other types of conservation research, this is described below.

2.7.2 BARRIERS TO MODELLING IMPLEMENTATION

Similarly to other types of conservation research which is not implemented, the majority of modelling studies do not intend to implement their results and are not based on applied questions (Guisan 2013; Moody 2013; Cayuela *et al*. 2009). Suggesting that "*all models are wrong, but some are useful*" Moody (2013) proposes modellers should ask themselves *"useful for whom?"* Most of the peer-reviewed modelling literature lacks the involvement and perspective of conservation practitioners, despite SDM construction being justified based on their potential utility for decision making (Guisan 2013). Guisan and Moody suggest it's easy for scientists to become focused on developing and improving modelling tools, without considering the needs of practitioners but urge scientists to "*do a better job of engaging decision makers early in the development of SDMs*", as well as highlighting the need for conservationists to involve scientists in their conservation management decision process. Similarly, Loiselle (2003) describes the importance of engaging with conservation planners, in order for them to evaluate and understand model results and limitations in their conservation work.

The use of SDMs is conditional on the availability of data, skilled staff, funds and time (Guisan 2013). In Australia, funding by commonwealth and state governments, data availability and sufficient lead-time for skilled staff to develop models appropriate for the conservation objectives, made the use of models in the decision-making process possible (Guisan 2013). Lack of time, training, staff and funding and pressures to meet deadlines all reduce the capacity of agencies to adopt scientific techniques such as landscape models (Flanaghan 2015 Natural England *pers comm*.). Flanaghan explains how the baseline population for favourable SSSI status for the Wyre Forest reptile population was not science led. Due to resource constraints, no population viability analysis was undertaken by Natural England staff responsible for deciding the favourable population size. A subsequent population viability analysis (Sutherland 2013 *unpublished data*) indicated that the target population size is not large enough to prevent the extinction of the adder in Wyre Forest.

There is little guidance on how models could be used to assist applied conservation decision making (Addison *et al*. 2013; Guisan 2013; Possingham *et al*. 2001). Guisan (2013) suggests more practice-oriented assessments of the use of models to support conservation are urgently needed. In addition, several authors suggest model complexity reduces their implementation (Addison *et al*. 2013; Moody 2013; Sutherland and Freckleton 2012; Soberón 2004). However, Addison, Sutherland and Freckleton, Soberón and Moody's conclusions are based on secondary data and a review of the scientific and grey literature to determine why models are not used by practitioners, rather than engaging with practitioners to gather primary data.

The lack of integration of social data into modelling is described as an implementation barrier by several authors (Burns *et al.* 2014; Franklin 2010; Ban and Klein 2009). Although the inclusion of social data is described as "*cultural imperative"* (Burns *et al.* 2014), most modelling studies usually do not accommodate legislative directives, budgetary uncertainties or implementation mechanisms, as effected by stakeholders, which reduces their applicability to complex, real world implementation.

Lack of access to scientific literature, irrelevance of research questions, terminology, modelling philosophy, confidential communication streams are also all raised as barriers to implementation of modelling studies (Cash *et al*. 2003, Addison *et al*. 2013, Schwartz *et al*. 2012, Knight *et al*. 2008).

In summary, the literature suggests that many of the same barriers to implementation prevent both the application of modelling studies and general conservation research, including communication, attitudinal and institutional barriers, resource constraints, the complexity of the contexts in which conservation is carried out.

2.7.3 SOLUTIONS FOR MODELLING IMPLEMENTATION

The literature suggests that modelling studies are implemented for the same reasons as other types of conservation research are implemented, providing further support for the conclusions on research implementation solutions.

Evidence for the solutions for implementing modelling research comes from the published examples of their applied use. Sewall *et al.* (2011) suggest reserve planning and landscape modelling would support conservation action if they were applied and used to inform real conservation decisions, therefore questions should be based on applied problems from conservation managers and organisations. Ferrier *et al*. (2002) provide evidence to support this from Australia, where models have been used to create and implement conservation plans, through a process which involved all relevant stakeholders.

According to some authors, implementation of modelling studies requires improved communication, clear understanding of the decision problem, appropriate translation of scientific and decision-context knowledge, mediation and timely collaboration between researchers and decision makers (Guisan 2013; Addison *et al*. 2013; Schwartz 2012; Cash *et al*. 2003). Schwartz *et al*. (2012) and Addison *et al*. (2013) provide evidence for these conclusions and present case studies which highlight the importance of communication and "*translation and mediation*" between scientists and practitioners as "*particularly critical*" to overcoming the research-implementation gap in their modelling research. Graham *et al*.

(2010) and Jetz *et al*. (2012) report on online initiatives and suggest these are making it easier for practitioners to build models through user-friendly web interfaces. However, Guisan (2013) argues that these web applications are limited and should not be considered sufficient alternatives to the direct involvement of professional modellers in conservation management decision processes.

Numerous researchers have recommended the inclusion of social data into spatial conservation planning and modelling to enhance its implementation (Tans 1974; Wright 1977; Williams *et al.* 2003; Knight and Cowling 2007, 2010). Polasky (2008) and Pressey and Bottrill (2008) provide evidence for this through examples in which modelling research is not implemented when it does not include the cultural, economic and institutional context in which conservation actions are to be implemented.

There is evidence for increasing use of social data within ecological modelling studies. Social scientists have developed techniques for eliciting and mapping a variety of social values for biological diversity (Raymond *et al.* 2009; Ban *et al.* 2009a, 2009b*;* MacIntyre *et al.* 2008; Alessa *et al.* 2008; Tyrv¨ainnen *et al.* 2007; Brown 2005). Modelling research into spatial prioritisation for conservation now includes recreation values (Bryan *et al.* 2011; Klein *et al.* 2008; Larsen *et al.* 2008), cultural values (Janssen *et al.* 2005) and food provision (Ban *et al.* 2009*a*). Although Ban and Klein (2009) suggest more social data is required and modelling research must learn to integrate multiple, disparate social values with ecological and economic criteria and difficulties organising and incorporating social data into models are described (Siedlok and Hibbert 2014; Pasquini *et al.* 2010).

Although there is no clear consensus in the literature, various authors over the past decade have suggested why social data is important in conservation modelling and the reasons cited are the same reasons that social data is described as important in other types of conservation research. For example: identification of the opportunities and constraints to implementation (Branquart *et al.* 2010; Knight *et al.* 2010; Cowling and Wilhelm-Rechmann 2007); legitimizing results through consideration of the values and perspectives (Cook *et al.* 2013); ensuring a realistic context (Carpenter and Folke 2006); because conservation action often requires "*land stewardship rather than acquisition*" (Gallo *et al.* 2009); and integrating the knowledge of local experts (Haenn *et al.* 2014).

Similarly to implementation of other types of conservation research, boundary organizations and frameworks are suggested to support the implementation of modelling research. Guisan (2013) suggests that boundary organisations or individuals could translate between modellers and decision makers, but also encourage modellers to get involved in "*real decision-making processes*". Schwartz *et al*. (2012) suggest implementation of modelling studies could be improved by making models compliant with the '*Open Standards for the Practice of Conservation*', an operationalised multi-criteria framework used to plan and prioritise conservation actions. Several authors have suggested guidelines, aimed at conservation managers, explaining how to use models, would support their implementation (see Stafford and Williams 2014; Young *et al.* 2011; Elith *et al.* 2011; Clark 2007). Restif *et al.* (2012) proposed practical guidelines to help integration between mathematical modelling, fieldwork and laboratory work. However, as yet there is little empirical evidence to support these theories and the weakness of these studies is their lack of case study evidence.

In summary the evidence in the literature suggests that implementation of modelling research is reliant on the same key factors as the implementation of other types of conservation research. Factors which have been demonstrated to increase implementation include developing research questions with practitioners, involving all stakeholders, ensuring model results are relevant, inclusion of social data and funding support.

2.8 CONCLUSION

Although no single solution is likely to completely resolve the research implementation gap, and most authors stress the importance of several methods and the importance of context dependent solutions (Farley 2010; Tappeiner 2007; Forester 1984), this literature review concludes that some barriers and solutions are more important than others. Many of the barriers and solutions are interrelated, for example: irrelevance, access to data, lack of training, and lack of interdisciplinarity are all overcome by increased communication. In addition funding availability is linked to increasing rewards for implementation. Communication between practitioners and researchers appears to be the most significant implementation solution and able to overcome the majority of the perceived implementation barriers. However, the literature suggests this communication must build social capital to ensure that communication between practitioners and researchers leads to research implementation. It is possible that increasing focus on research impact will shift the focus of the academic reward system, increase funding opportunities for applied research and therefore encourage communication between researchers and practitioners.

CHAPTER THREE
MODELLING *VIPERA BERUS* IN WYRE FOREST

ABSTRACT

Globally snakes are in decline and believed to be more vulnerable to extinction than many other taxa. Among snakes, European vipers are of particular concern, threatened by persecution, collection and habitat loss. Adder *Vipera berus* populations in across Europe are declining, and *V.berus* populations in the Midlands are the most rapidly declining in the UK. Effective conservation action requires strong baseline data on distribution, habitat fragmentation and behavioural ecology, which can be difficult to achieve for secretive, cryptically camouflaged species which occur at low density, such as *V.berus*. This applied study aimed to contribute to the understanding and conservation of *V.berus* in the UK by developing a habitat suitability model to inform restoration of habitat connectivity in the Wyre Forest, the most important stronghold for *V.berus* in the Midlands. The maximum entropy modelling method (MaxEnt) was used to predict potential suitable habitat for *V. berus* in the Wyre Forest and four habitat characteristics, including temperature, vegetation and disturbance variables were included in the model.

The Maxent model had high predictive performance with a statistically significant Area Under the Curve (AUC) score of 0.94. It predicted that 15% of the total study area was suitable habitat for *V. berus*, the majority of the study area had a less than 25% chance of species presence. Maxent's jackknife test determined that aspect was the most important predictor of reptile presence, significantly more important than human caused disturbance or vegetation type, suggesting that effective habitat restoration should be targeted in areas with suitable aspect. Model outputs enabled spatial targeting of habitat restoration work to support adder conservation. Field testing of the model led to the discovery of *V. berus* in three previously unsurveyed areas predicted by the model to be highly suitable, indicating that maximum entropy modelling is a valuable tool for predicting habitat suitablity for *V. berus* in Wyre Forest. GIS analysis of model results and reptile survey data demonstrated 90% of reptile positive survey points lay within the areas with high predicted probability of presence.

3.1 INTRODUCTION

Predictive species distribution models create statistical models of the relationship between a species and its environment. Species distribution models are experimental models relating field observations to environmental predictor variables, based on statistically or theoretically derived response surfaces (Guisan and Zimmermann 2000). They enable conservation and management based on understanding of the relationship between species records at sites and the environmental and/or spatial characteristics of those sites (Franklin 2009).

Species data can be presence, presence–absence and abundance observations based on random or stratified field sampling, or observations obtained through natural history collections (Graham *et al.* 2004a). Environmental predictors can exert direct or indirect effects on species, and may be proximal or distal predictors (Austin 2002), and should be chosen to reflect the three main types of influences on the species: (i) limiting factors such as climate, vegetation type; (ii) disturbances both natural and human-induced and (iii) resources such as prey availability, or other food and water (Guisan and Zimmermann 2000, Huston 2002, Guisan and Thuiller 2005). These environmental data can be manipulated in a geographical information system (Bonham-Carter 2014).

3.1.1 THE DEVELOPMENT OF SPECIES DISTRIBUTION MODELS (SDMS)

SDM's arose from studies which linked biological processes to environmental factors (such as Murray 1866; Schimper 1903), and later research which provided evidence for the benefits of modelling individual species (Whittaker 1956; MacArthur 1958). The earliest examples of modelling correlations between distributions of species and climate seems to be those of Johnston (1924), on predicting the invasive spread of a cactus species in Australia, and Hittinka (1963) on assessing the climatic determinants of the distribution of several European species (Pearson and Dawson 2003).

Quantitative modelling and mapping began in earnest as two distinct sciences progressed and converged. Ecological studies of species and habitat associations, originally largely field-based and reliant on simple linear regression analyses (Capen 1981; Stauffer 2002), progressed to use of new regression methods that treated the error distribution of presence-absence and abundance data (Elith and Leathwick 2009). These Generalised Linear Models (GLM's) enabled more complex SDM's to be developed (see Austin 1985). In tandem, advances in physical geography meant new data and digital models of earths surface, climate parameters, remote sensing of surfaces and the development of geographic information systems (GIS), meant new data sets were available to ecologists (Swenson 2008). Modern SDMs emerged as statistical methods from field-based habitat studies were linked with GIS-based environmental layers. The earliest examples, are Ferrier 1984 (cited in Ferrier *et al*. 2002), who applied GLMs (logistic regression) to predict the distribution of the Rufous scrub-bird using known locality records and remotely mapped and modelled the environmental variables and the Nix *et al.* (1977), who used niche-based spatial predictions of crop species in Australia.

The increasing interest in predictive species distribution models (Guisan and Thuiller 2005; Thuiller *et al.* 2008) was also due to their applicability to conservation questions which are difficult to answer through other methods (Andelman and Willig 2002). SDM's have a multitude of potential uses, Table 3.1 illustrates some of these.

Table 3.1 Potential Uses of Species Distribution Models

Application	Study area	Author
Identify un-surveyed sites with a high potential of species occurrence	Distribution of Lymphatic Filariasis in Zambia; Deep sea coral research off US West Coast	Mwase *et al.* 2014; Guinotte and Davies 2014
Support conservation planning for species reintroduction	Reintroduced species, Australia and New Zealand; California condors USA; Amphibians and reptiles in a climate transition area.	Chauvenet *et al*. 2015; D'Elia *et al.* 2015; Soares and Brito 2007,
Select priority areas for species and habitat restoration or conservation	Seabird communities Timor Sea; Review of application of modeling to conservation issues.	Lavers *et al*. 2014 ; Rodríguez 2007
Target control of invasive species	Fire ants, Brisbane Australia	Baxter and Possingham 2011
Enable risk mapping	Cuvier's beaked whale *Ziphius cavirostris* Alboran Sea; Dugong *Dugong dugon* Eastern coast of Africa	Azzellino *et al*. 2011; Briscoe *et al*. 2014
Explore different management options	Waterbird communities southeastern Spain	Sebastian-Gonzalez *et al.* 2011
Support where alternatives (e.g. survey) are expensive or not feasible	East Texas Freshwater Mussels	Marshall *et al.* 2014
Where data is incomplete and spatially biased	Butterflies southern Spain	Fernández *et al*. 2015

3.1.2 COMPARING SPECIES DISTRIBUTION TECHNIQUES

Several authors have undertaken comparative studies, to assess how different methods perform differently in terms of model fit or prediction (Li and Wang 2013; Moisen and Frescino 2002; Reese *et al.* 2005; Anderson *et al.* 2006; Hernandez *et al.* 2006; McPherson and Jetz 2007a and b; Loiselle *et al.* 2008; Graham *et al.* 2008) or assessed their strengths and weaknesses (Phillips and Dudik 2008). Other authors have explored why differences in model results occur (Austin *et al.* 2006; Kearney *et al.* 2008; Meynard and Quinn 2007; Reineking and Schröder 2006). Yet Townsend Peterson *et al.* (2007) describe the criteria for selecting models as incomplete and call for a synthesis of existing knowledge.

Tsoar (2007) compared the relative performance of six different presence-only modelling methods and found predictive accuracy varied between modelling methods, but differences in predictive accuracy were consistent over species specific models. This highlights the need to understand the importance of the ecological and geographical factors that influence species distribution, and the factors affecting the different results between models. Other authors have also compared MaxEnt predictions, which are based on the principal of maximum entropy, with the Genetic Algorithm for Rule-Set Prediction (GARP). The area under the ROC curve (AUC) was almost always higher for MaxEnt, indicating better discrimination of suitable versus unsuitable areas for the species (Townsend Peterson *et al.* 2007). Another comparative study tested the ability of six predictive species distribution models and their associated algorithms, GARP and MaxEnt performed best of the 6 algorithms tested. This concluded that MaxEnt's algorithm constrains predicted species ranges and thus reduces and avoids commission errors (Urbina-Cardona and Loyola 2008). Warton (2013) also found that where presence-only species records are available, MaxEnt's predictive performance is consistently on par with the highest performing presence/absence regression modelling methods. MaxEnt has been found to outperform GARP when using a small number of data points, however MaxEnt is more sensitive to sampling bias (Costa *et al.* 2010) but can over fit the prediction therefore under estimate distribution, in comparison to GARP models which created more false positives, therefore overestimated predicted distribution (Peterson *et al.* 2007).

MaxEnt methodology has recently been proposed to be mathematically equivalent to a Poisson regression, known as '*log-linear modelling*' and used within Generalised Linear Models (GLM) (Warton 2013; Hastie and Fithian 2013). Renner and Warton (2013) discuss the similarity of MaxEnt to GLM and suggest improvements to MaxEnt such as, a point process model approach to facilitate choosing the appropriate spatial resolution, assessing model adequacy, and choosing the LASSO penalty parameter (which is MaxEnts default). Warton (2013) explains that point process models (PPMs), which can often be implemented as GLMs provide an appropriate statistical framework for modelling data that arise as a set of point locations, because they enable choice of the number and location of pseudo-absences. However, the applicability of point process models to presence-only data was only recently understood (Warton and Shepherd 2010; Charaborty *et al.* 2011; Geert Aarts *et al* 2012). Due to this similarity MaxEnt's methodology can no longer be criticised as a '*blackbox'* because it can now be described as a point process model. When MaxEnt was first posed as a tool, Phillips *et al.* (2006) acknowledged that formal inferential and model checking tools were not available in MaxEnt, in part because the methodology is not as well understood as classical competitors, such as GLMs. Warton (2013) proposes that as MaxEnt functions in a similar way to PPM models, existing GLM or PPM model-checking tools could now be used.

However, the equivalence of MaxEnt and GLM requires that presence-only locations are randomly sampled (or systematically). This assumption is required to be able to estimate the actual prevalence from the data, otherwise the output of MaxEnt is only proportional to the occurrence probability of GLMs (Li *et al.* 2011). Thus, unless the background data are sampled with the same strategy as the presences, MaxEnt and GLM will not be equivalent (Dorazio 2012, Li *et al.* 2011). MaxEnt is not used for this type of data – models which use both absence and presence data are used when this type of data is available. MaxEnt is generally used with data when there is no information on sampling type, this is one of its major advantages over other methods. Therefore, prevalence cannot be accurately defined – hence the work around used by MaxEnt. Papers which suggest similarity between MaxEnt and Poison process often do not state their assumptions clearly. Therefore, although it is statistically correct that MaxEnt and GLM are equivalent under very specific and typically rare conditions, it is irrelevant for most of the analyses using MaxEnt (Dorazio 2012; Li *et al.* 2011).

The internal model process of selecting the most influential predictors, can cause erroneous results, if it is not accurate (Johnson and Omland 2004). Serious faults have been identified in the popular stepwise selection procedures in regressions (Guisan *et al.* 2002). Modelling approaches such as regression and classification trees (CART), artificial neural networks

(ANN), genetic algorithms (GA) or Bayesian analyses (BA) base their background selection on the explained deviance of a multinomial model for CART, or based on multiple simulations to optimize selection for ANN, GA and BA. Multi-colinearity and interactions between predictor variables can affect model selection and end results (Austin 2002). MaxEnt overcomes both of these problems through its range of feature types, from simple linear functions to more complex quadratic, hinge, threshold and product features (Elith *et al.* 2011) and its ability to compare the influence of interactions between predictor variables through plots and a jackknife test of variable importance.

3.1.3 PREDICTIVE SPECIES DISTRIBUTION MODELLING OF REPTILES

Predictive species distribution models and habitat suitability models have previously been used to model spatial distribution of snakes in relation to environmental predictors (see Guisan and Hofer 2003; Santos *et al.* 2006 ; Araujo *et al.* 2006; Ceia-Hasse *et al*. 2014; Gardiner *et al* 2014; Hall 2014). For example; Fong *et al.* (2015) found MaxEnt robust enough to predict amphibian species distributions successfully in the Caribbean and assess gaps in the protected area network. They concluded that conservation planning should include results of predictive modelling, rather than rely on protecting only known populations. Predictive species distribution modelling of Eastern Massasauga (*Sistrurus catenatus*), a declining endemic snake species, enabled a range-wide, spatially explicit, climate change vulnerability assessment which showed demographic sensitivities to winter drought, maximum summer precipitation and proportion of the surrounding landscape dominated by agricultural and urban land cover. In addition the models were robust and able to predict the location of known extant and extirpated populations well (AUC = 0.75) (Pomara *et al.* 2014). Hall (2014) also used predictive species distribution models to assess the potential distribution of the Copper-Bellied Watersnake (*Nerodia erythrogaster neglecta*) and suggested that these models are useful tools which can reduce survey effort and save conservation resources.

In addition, predictive species modelling with genetic analyses has been used to infer the role of climate in the evolutionary history of the endemic Iberian adder *Vipera seoanei* (Martínez-Freiría *et al.* 2014). Model projections spatially fit genetic results in past periods, indicating robust models and illustrating the range contractions to north-western Iberia during the last interglacial and expansions during the last glacial maximum (Martínez-Freiría *et al.* 2014). Wagner *et al.* (2014) used predictive species distribution mapping based on soils data to determine the potential range of the declining Louisiana Pine Snake (*Pituophis ruthveni*), and concluded that although the soil type is still suitable for its prey, habitat modification means that the vegetation structure above it is suitable for neither snake nor prey. Predictive species distribution models have even been used to assess snake bite risk. One such study concluded that mapping distributions of environmental suitability for venomous snakes and combining this ecological information with socioeconomic factors can help infer potential risk areas for snakebites (Yañez-Arenas *et al.* 2014). In summary, the literature on predictive species distribution modelling of reptiles, provides evidence that the techniques are suitable for use with snakes, and can provide robust results and useful data for conservation planning.

3.1.4 MODEL SELECTION

The selection of an appropriate model type for this research project within Wyre Forest was based on information available in the literature. As GARP and MaxEnt consistently outperform other presence only models, these were highlighted as the best choices for this research project.

Models that are inappropriately complex or inappropriately simple show reduced ability to infer habitat quality, reduced ability to infer the relative importance of variables in constraining species' distributions, and reduced transferability to other time periods (Warren and Seifert 2011). The processes used within the MaxEnt software help to prevent this: MaxEnt assists parsity in modelling, through testing the importance of different environmental criteria, helping to prevent inappropriately complexity of model design (Phillips and Dudík 2008), it's therefore described as a "*minimal assumption"* model (Warton 2013). An additional useful feature of MaxEnt is the inbuilt L1- regularization method for model regularization which nullifies the effect of related environmental variables (Wollan *et al.*, 2008, Hastie *et al.*, 2009).

Three key factors led to the selection of MaxEnt as the modelling method for this research project. These were;

1) MaxEnt's consistent ability to outperform other models when using limited data points (Elith and Leathwick 2009).
2) MaxEnt's ability to determine which environmental factor included in the model is having the greatest impact on predicted distribution (Warren and Seifert 2011).
3) The ability of MaxEnt to reduce risk of over complexity by assisting with environmental criteria selection and its minimal assumption approach (Phillips and Dudík 2008; Warton 2013).

In addition, the low transferability of MaxEnt (Townsend Peterson 2007) does not represent a drawback within this study, as the results are to be applied to the study area.

3.1.5 AIMS AND OBJECTIVES

In this study, a fine-scale model of predicted species distribution was created to explore adder distribution in Wyre Forest and evaluate habitat suitability and connectivity in order to understand where to undertake habitat restoration and an adder reintroduction program in Wyre Forest. The specific objectives were a) to identify the environmental variables with the greatest impact on adder distribution in Wyre Forest; b) In the absence of survey data identify where adders might be found; and c) determine the extent and arrangement of potentially suitable habitat for adders in Wyre Forest.

3.2 METHODOLOGY

3.2.1 OCCURRENCE DATA

This study used a secondary data set of species localities collected from reptile survey data. Adder occurrence data were accessed from: (a) Wyre Forest Society survey records. The Wyre Forest Society holds annual reptile surveys and has adder records from 1983 to the present date; (b) The Forestry Commission survey data. The Forestry Commission has adder records from 1995 to 2015; and c) The Grow with Wyre project survey records. Four years of reptile survey were undertaken, from 2008 to 2012, to evaluate the survey findings of the Wyre Forest Society. The four years of survey results of the Grow with Wyre project support and agree with the survey findings of the Wyre Forest Society, indicating Wyre Forest Society species records represent a reliable dataset.

The survey records show some presence and absence locations, however many sites show no absence records, therefore, it is unclear whether or not these sites were surveyed, and whether the sites were found to be negative. The author worked with local surveyors to georeference the data from recorded occurrence locations. In total, the Wyre Forest Society dataset had 4237 adder records and the Forestry Commission dataset had 3858 records, the Grow With Wyre dataset had 554 records.

Lahoz-Monfort *et al.* (2014) warn that imperfect detection during survey can substantially reduce the inferential and predictive accuracy of presence–absence and presence–background methods that do not account for detectability. Detectability during sampling may vary with the environmental covariates that determine occurrence probability (Yackulic *et al.* 2013). Environmental covariates used in this model were: vegetation type, aspect, footpath density and distance to infrastructure such as car parks. Each of these is highly likely to affect detectability during surveys. However, the impact of these factors on species records has been assumed to be significant and to prevent error, a bias grid has been included in the model (Kramer-Schadt *et al.* 2013; Elith *et al.* 2010). The process was undertaken as recommended in the literature and the results of the model with and without a bias grid were compared, the fit of the model was improved when using a bias grid. Therefore, it is assumed that data bias was adequately dealt with by the bias grid.

The questions which the model aimed to answer were applied, and related to the habitat currently presence in the Wyre Forest landscape, therefore, the model was trained using 10 years of data from 2004 to 2014. Soberón and Peterson (2005) point out that model bias can be introduced through the effects of historical factors on species distribution, for example, recent dispersal barriers, speciation or extinction, could limit a species' distribution to an area smaller than that in which its ecological needs are met. However, this model has deliberately used a smaller species dataset than is available, in light of recent extinction events in the study area, to model the reduced species range, based on the assumption that the areas in which the species have remained are more suitable than those from which they have been lost. This assumes that the loss from other areas is not due to deliberate persecution, over hunting, climate change, the species colonising a new area or disease (Townsend Peterson *et al.* 2007; Dormann 2007). These assumptions are justified because the survey data used contains information on dead adders and their probable cause of death. The survey results prove that persecution did not lead to the loss of adders from the areas concerned. Disease is not believed to be a major cause of adder death in Wyre Forest. No disease issues were found within the Wyre Forest population, during a national study on the genetic health of adders and testing for a captive breeding programme, therefore disease is unlikely to bias the model results. Climate change has been ruled out as a possible source of bias because only recent records were used. Comparisons between species distribution data used in the model and all the available data provides evidence that the adder has not recently colonised a new area in Wyre Forest; in fact the species has been undergoing a sustained range contraction.

All occurrence data was corrected to remove duplicates, standardise survey site names, digitise paper records and gain more precise location records for vague or dubious records via discussion with surveyors and land managers. When these records were cleaned of repetition, a total of 120 adder records remained for use within the model.

3.2.1a Ecological Theory and Clarification of the Niche Concept

Species Distribution Models as based on the niche concept (Guisan and Zimmermann 2000). Hutchinson's realized niche (1957) describes the ecological space occupied by a species, as modified by inter and intra-specific competition and predation, which is very different from the fundamental niche defined by Grinnell (1917), which may not actually be filled by a species. Austin (2002), Pearson *et al.* (2004) and Thuiller *et al.* (2004a) highlight the importance of ecological theory within the model building process and selection of causal environmental predictors. Within this research, knowledge of ecological theory has been used to select the most relevant predictor variables and assess the validity of model results, for example the impact of aspect on predicted distribution. The model used the best available data on the species and ecological theory to include variables which accurately describe the realized niche of the adder in Wyre Forest. Additionally, the relatively narrow niche of the adder, should help ensure the model is more accurate than any model could be for a species with a wide niche (Tsoar *et al.* 2007; Urbina-Cardona and Flores-Villela 2009). Therefore, it is assumed that all relevant environmental factors were included in the model and the realised niche was accurately modelled. However, any misrepresentation of the realized niche could reduce the accuracy of the predictions. Guisan (2005) suggests the niche used in a species distribution model should be defined from empirical observations of individuals that reproduce successfully, and thus support a positive growth rate for the entire population. However, this data was unavailable in the current study and the SDM was built using species presence observations.

3.2.2 Environmental Variables

Observed spatial patterns of species distribution relate to the different scales of observation (Wu 2013). Over a large area, at coarse resolution distribution they are often controlled by climatic regulators, whereas at local scale, patchy distribution is more likely to be due to distribution of resources, micro-topographic variation or habitat fragmentation (Pickett and White 2013). This analysis was undertaken within a relatively small area (6200 hectares), therefore the chosen variables reflect local habitat suitability variables.

3.2.2a Weather Patterns and Precipitation

At coarse scales precipitation has been found to be a significant factor in the distribution of many reptile species (Brito *et al.* 1999; Guisan and Hofer 2003). However, due to the fine scale of this analysis, there was no fine resolution climatic data available, therefore precipitation was not included within the model.

3.2.2b Altitude

Altitude has also been shown to influence life history traits in reptiles. Rohr (1997) and Iraeta *et al.* (2008) illustrated how altitude affects sexual maturity and egg size in lizards. Over large scale areas, such as countries, topographic isolation can determine reptile diversity patterns (Flores-Villela 1993). However across the Wyre Forest study area, altitude is not highly variable and therefore, was not included in the environmental factors.

3.2.2c Soil Type

Reptiles are known to be associated with light sandy soils in the UK (Edgar *et al.* 2012). Predictive species distribution models typically use information on soil types (Long 2011), however it is available only at very low resolution. In Great Britain the Natural Environment Research Council (NERC) "*soil portal"* available online at:
http://www.bgs.ac.uk/nercsoilportal/maps.html provides access to soil variables at 1 km^2 resolution. This analysis was based on grid cells of $10m^2$ and soil types within Wyre Forest are acknowledged to be highly variable (Hickin 1971). Therefore, this dataset was too coarse to used in model development.

3.2.2d Climate and Environmental Temperature

At the meso-scale, climate and topography influence amphibian and reptile distribution (Duellman 1966; Pearson *et al.* 2004). Environmental temperature affects behavioural responses in reptiles (Gifford *et al.* 2008; Cury de Barros *et al.* 2010), can trigger reproductive activity (Cruz *et al.* 1999; Winck and Cechin 2008) and minimum temperatures limit the environmental niche occupied by many reptile species (Boretto and Ibargüengoytía 2009; Anadón *et al.* 2012). In adders, basking temperatures is known to determine how quickly males shed their skin in readiness for mating (Sheldon 2008). Behavioural changes in adders have also been observed in relation to temperature and weather. In exceptionally wet and cold spring weather, male basking periods can be substantially reduced, with subsequent delays in the timing of mate searching and courtship (Sheldon 2009, 2010).

Reptile habitat modelling frequently includes environmental temperature as measured by the Land Surface Temperature, because the thermal environment is especially important for ectotherms (Row and Blouin-Demers 2006; Sabo 2003). This data is collected during the daytime by the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite, and available to download from:
http://earthobservatory.nasa.gov/GlobalMaps/view.php?d1=MOD11C1_M_LSTDA
However, data at this scale appears uniform across the study area. Therefore, aspect was used as a proxy for land temperature. South facing areas receive significantly more sun than north facing areas, and therefore have higher surface temperatures for longer daily and annual

periods. Aspect was calculated on the basis of topographic elevation data in the Spatial Analyst extension in ArcView 10.1.

3.2.2e Vegetation

Vegetation type and its spatial pattern effect reptile thermoregulatory processes and behaviours (Cardozo *et al.* 2012; Chiaraviglio 2006; Chiarello *et al.* 2010). Several authors have proposed how vegetation structure affects reptile distribution (Gardiner *et al.* 2014; Sheldon 2011; Cardozo *et al.* 2007; Cardozo and Chiaraviglio 2011; Nogueira *et al.* 2009; Kearney *et al.* 2009). Large scale MaxEnt models have shown that vegetation cover can be a limiting factor for reptile presence in climatically favourable areas (Opdam and Wascher 2004; Chiarello *et al.* 2010; Fouquet *et al.* 2010; Lanfri *et al.* 2013). Therefore vegetation type was included in the model, using classifications determined by the Natural England management plans and the Forestry Commission Forest Design Planning process. This data was resampled into $10m^2$ grid cells. Vegetation classes included: coniferous woodland, deciduous woodland, deer lawns, ponds, streams, rides, tracks, meadows, orchards, coppice, heath, agricultural, bog/marsh and railway embankment.

3.2.2f Disturbance

Several authors have described the effect of disturbance on reptiles (Wolf 2013; Brown 2001; Moore and Seigel 2006). Human disturbance in the study area is mostly determined by the number of visitors to the area. However visitor numbers in different areas of Wyre Forest are not available, therefore footpath density and proximity to disturbance features such as houses, roads, car parks and recreational areas were used as a proxy for disturbance. Information available in the literature and expert opinion data was used to determine appropriate distances (from 10m to 500m), and score disturbance from 1 to 10 based on the distance from disturbance features. This data was mapped across the study area and resampled into $10m^2$ grid cells.

All environmental data layers were georeferenced to the British National Grid, Geographic Coordinate System: GCS_OSGB_1936 and resampled to adjust the pixel size to 10m × 10m. Resulting data layers had 1068 x 751 pixels.

3.2.3 PROXIMAL VARIABLES

Proximal variables can be used where data on the variable of interest is not available, or when generalised models are created, intended to be used in different regions or climates. In this research, aspect was used as a proxy for hours of sunlight, vegetation type helped to infer ground light levels and footpath density was used as a proxy for visitor numbers and disturbance due to human presence inferred through distance to houses and car parks.

The accuracy with which predictive species distribution models predict real-world species distributions depends on the complexity of the model, the quality of the environmental data, the amount and reliability of the species distribution data, barriers to dispersal and any biotic interactions which increase the difference between the realized niche and the fundamental niche. This research has sought to avoid taxonomic errors through use of accurate species records and used multiple data sources to reduce the risk of spatial errors and suggest using multiple data sources to help identify outliers which may bias model results (Lui *et al.* 2011). In addition, remote sensing has not been used to determine habitat type, which has reduced the risk of errors linked to resolution and grain size, and errors linked to land cover type and its habitat potential (Guisan *et al.* 2007; Bradley *et al.* 2012).

3.2.4 MODELLING TECHNIQUE

Predictive species distribution models were generated using MaxEnt (Version 3.3.3k), which uses the principle of maximum entropy to determine environmental features associated with species' presence, from the range of environmental features across the rest of the landscape (Warren and Seifert 2011; Phillips *et al.* 2009; Elith *et al.* 2011). The software requires data on geographical locations of species occurrences and gridded data of environmental variables. MaxEnt estimates species distribution by finding the distribution of probabilities closest to uniform (maximum entropy), of a set of samples (species occurrence data) and set of features (environmental variables), constrained to the fact that feature values match their empirical average (Phillips, 2004).

Potential environmental predictors of species distribution must be selected based on the bio-ecological processes believed to influence the species (Austin 2007). As recommended in the literature (Elith and Leathwick 2009b, Phillips *et al.* 2006, Wollan *et al.*, 2008, Hastie *et al.* 2009) environmental variables have been minimised to only those believed to have ecological relevance to the species, and the effect of correlated environmental variables have been dealt with using MaxEnt's inbuilt L1- regularization method for model regularization.

3.2.4a Dispersal Ability and Intraspecific Competition

The inclusion of dispersal ability and competition have been suggested to improve the accuracy of predictive species distribution models (Ceia-Hasse *et al.* 2014; Sahlean *et al.* 2014; Leathwick and Austin 2001; Anderson *et al.* 2002). However, this model does not include dispersal or competition, this limitation means that barriers to dispersal and dispersal distance must be taken into account when examining the predicted distribution maps, and planning further survey. It is possible that the entire predicted suitable habitat is not occupied by the species if it is too far from existing populations or separated by dispersal barriers. To overcome the lack of data on species ecological and life history traits in the species distribution model, an approach similar to that of Cabrelli *et al.* (2014) was used. Cabrelli *et al.* (2014) developed a framework for assessing that considered species traits together with the projections of SDMs. Competition is not a significant problem for the adder, although predation, especially by non-native introduced species such as pheasants, can have a significant impact. As this model was designed to assess habitat suitability and to be used within an applied conservation project to support habitat restoration decision making, a framework of species trait data was used in conjunction with the MaxEnt projection. The dispersal behaviour of the species and competition is already well understood through earlier telemetry studies (Sutherland and Sheldon 2013). Dispersal distance data and locations of known pheasant release sites, was combined with MaxEnt output maps to inform management decisions on where to create connections between suitable habitat patches.

3.2.5 CONSTRUCTION OF MODEL: SETTINGS AND FEATURE CLASSES

MaxEnt was used to fit ("*train*") a species distribution model to a random sample of 75% of the species occurrence data (96 species presence records), with the remaining 25% of the data used to assess ("*test*") model performance (Elith *et al.* 2011, Guisan and Zimmermann 2000). The training and testing process was repeated on multiple random subsamples, over 20 model runs, to assess uncertainty of the SDM predictions.

Within MaxEnt the study area is represented as *L* the '*Landscape of Interest'*, *L1* is defined as the subset of the landscape of interest *L* where the species is present. The data on environmental factors (covariates) is supplied in the form of pixelated grids of which cover the landscape. The distribution of covariates in the landscape is described by a survey (the background sample) taken by the model, which randomly samples 10,000 points from the covariate grids which describe *L* (Phillips *et al.* 2006).

MaxEnt includes a range of feature types, from simple linear functions to more complex quadratic (when there are at least 10 samples), hinge (at least 15 sample), threshold and product features (when there are at least 80 samples) (Elith *et al.* 2011). Increasingly complex features are fitted with increasing numbers of presence points. However, subsets of these features can be used to simplify the model. The default settings restrict the model to simple features if few species presence samples are available. This is because low number of species records provides less information for determining the relationships between the species and its environment (Barry and Elith 2006; Pearson *et al.* 2007). Excluding features creates an additive model that is easier to interpret, although less able to model complex interactions.

Various authors have explored the effects of fitting different feature types in MaxEnt models (Elith *et al.* 2010; Elith *et al.* 2011; Syfert and Smith 2013). Syfert and Smith (2013) conclude that choice of feature type has negligible effects on predictive performance, and conclude that simple feature types should be accurate provided sampling bias is accounted for. Therefore this MaxEnt model was run under the "auto-features" mode as suggested by Phillips and Dudik (2008). The default options meant that MaxEnt chose 10,000 uniform, random background samples of the landscape of interest, to represent the environmental conditions in the region (Phillips *et al.* 2009).

Other user specified parameters were set to their default values: convergence threshold 10-5, maximum iterations 500, regularization multiplier 1, replicated run type (subsample), output format (logistic), and "auto features" activated. The model was run with 100 replicates and a random seed. The logistic output format was used because it is robust when prevalence is unknown and easier to interpret as the estimated probability of a species' presence given the constraints imposed by environmental variables (Phillips and Dudik 2008). 25% of the species presence data was chosen at random and used as the training set for validation of the model. This use of the default settings was reasonable given that it was validated in other studies with a wide range of species, environmental conditions, individual species records, and in cases with sample-selection bias (Phillips and Dudik 2008; Syfert and Smith 2013).

To compare the effect of each variable, identify which environmental variables have greatest effect on species presence, this application included a "*Jackknife test"*. This test undertakes three actions: firstly this excludes each variable in turn, creating a model with the remaining variables. Secondly it creates a model using each variable in isolation. Thirdly it creates a model using all variables.

MaxEnt's cross-validation option was used to assess the predictive ability and usefulness of the model (Pearson *et al.* 2007). The test gain and the test area under the operator receiving curve (AUC) produced by the software were used to determine model fit. The test AUC measures the probability that a randomly chosen presence site will be scored above a randomly chosen pseudo-absence point (Fielding and Bell 1997; Phillips and Dudik 2008). The value of AUC is that it provides a measure of the degree to which a species is restricted to a part of the range of environmental variables. A high AUC value indicates that the species has a restricted distribution across the range of predictor conditions (Walters 2012).

3.2.6 DEALING WITH DATA BIAS

A fundamental assumption of predictive species modelling, including MaxEnt, is that the entire area of interest has been systematically sampled. In reality, models are built from occurrence records that are spatially biased towards better-surveyed areas. To provide accurate results, MaxEnt relies on an unbiased presence sample, therefore the model must be manipulated to prevent survey bias affecting the model (Yackulic *et al.* 2013; Royle *et al.* 2012). To deal with the biased species data, the survey data was cleaned to remove duplicate presence records and errors. A bias grid was created to enable spatial filtering of occurrence data (Dudı´k *et al.* 2006; Phillips *et al.*, 2009; Elith *et al.*, 2010), and remove survey bias within Wyre Forest (Kramer-Schadt *et al.* 2013). The bias grid was based all known survey sites, which were downweighted from the rest of the background landscape L, to enable the model to reduce the significance of environmental values at species presence sites if they were also reptile survey sites.

3.2.7 PERSISTENCE AND PRESENCE EVALUATION

Following the method of Giovannini *et al.* (2012) a persistence evaluation was undertaken to evaluate whether *Vipera berus* was more likely to persist in areas identified by a high predicted probability of presence. The cell presence probability values were compared to the distribution of *Vipera berus* occurrences in two independent data sets: the 2015 reptile survey (Sheldon 2015 *unpublished data*) and adder distribution in 1990. The 1990 and 2015 data sets contained 56 and 14 occurrences, respectively. The predicted probability of presence value of the $10m^2$ cell with the species present, and cells within a $100m^2$ buffer of the presence point (to account for mobility of the species) were calculated, to ensure ecological representativeness of the species presence sites and enable a robust statistical analysis.

For every presence cell and the buffer area, the probability of presence was recorded and these values were used to build frequency distributions of habitat suitability, grouped into four classes (with upper limits of 10, 30, 60 and 80). A Chi square goodness-of-fit test was used to evaluate differences between the frequency distributions of cell suitability values obtained for the 1990 and for the 2015 occurrences and the null hypothesis, that distribution would be unaffected by the MaxEnt's predicted probability of occurrence scores.

3.3 RESULTS

3.3.1 RECEIVER OPERATING CHARACTERISTIC

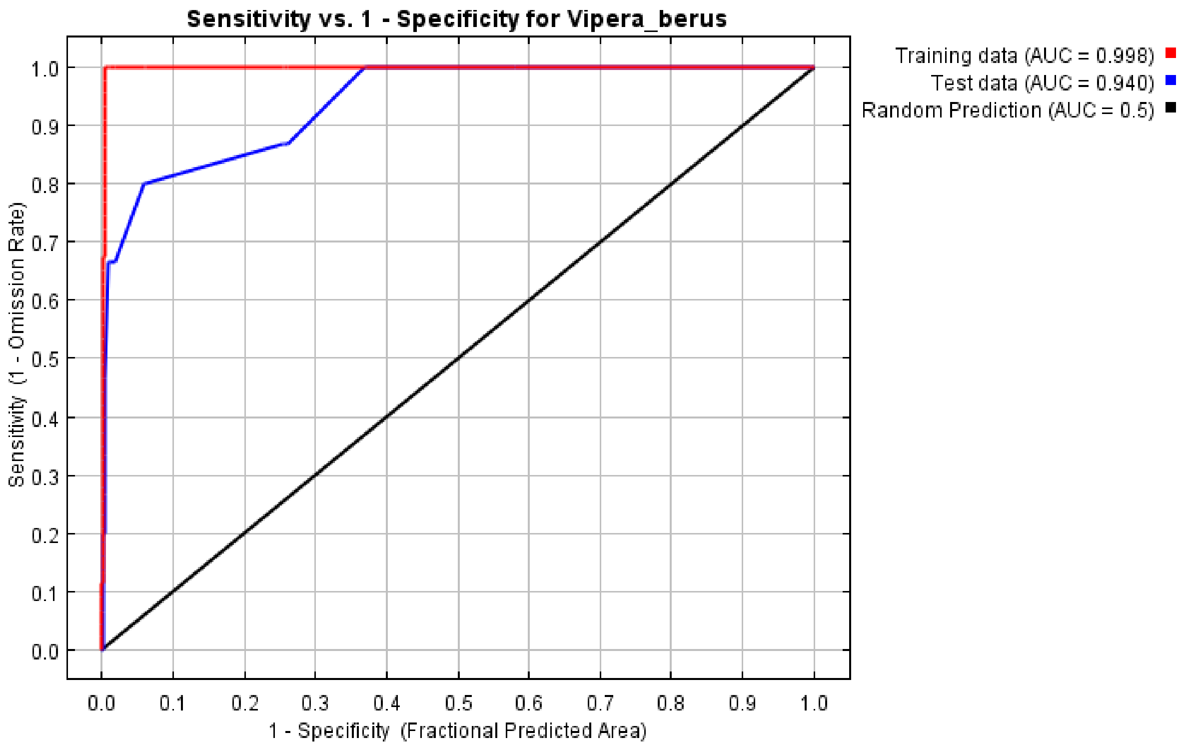

Figure 3.1 The receiver operating characteristic (ROC) curve for Wyre Forest MaxEnt analysis.

The AUC of 0.94 indicates a well fit model and illustrates the MaxEnt model performed significantly better than random. AUCs > 0.75 are typically thought of as useful, and considered to indicate a well fit model (Elith, 2002).

3.3.2 JACKKNIFE TEST

The results of the '*Jackknife Test'* of variable importance are shown in Figure 3.2. The red bar represents a model using all the variables. The length of each dark blue bar in relation to the red bar, shows the effect of including that variable in the model. Its length is known as its 'gain' i.e. how close the variable comes to the value of the red bar. The variable (or environmental characteristic) whose inclusion has the most significant effect on predicted distribution has the highest gain and appears closest in length to the red bar. The relative difference in length between the red bar (a model using all variables) and the green bars shows the effect of omitting this variable from the model. The green bars, therefore show which variable contains information that is not already contained in the other variables.

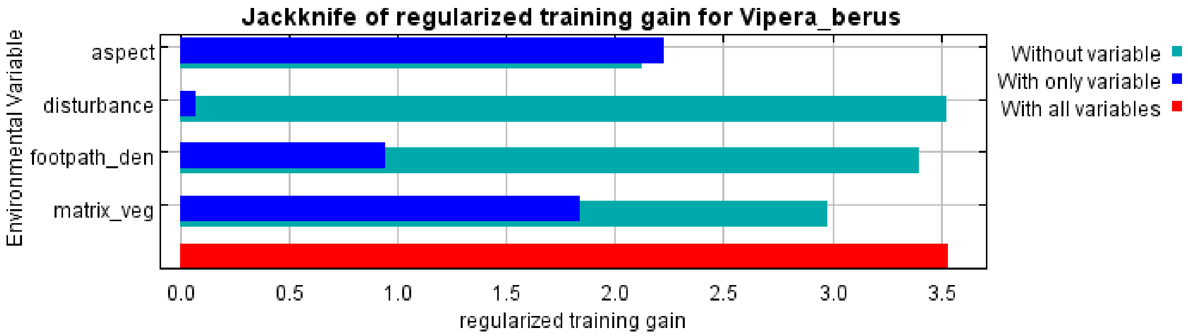

Figure 3.2 Illustrating How Environmental Variables Relate to Adder Presence

The results of the jackknife test suggest that aspect is the strongest predictor of species presence, followed by vegetation type. When MaxEnt uses only disturbance it achieves almost no gain, so that variable is not (by itself) a good predictor of the distribution of adders. Omitting disturbance results in no change to the predicted distribution. However, omitting aspect has the greatest effect on distribution.

3.3.3 PLOTS

The marginal response curves shown in Figure 3.5 also illustrate how each environmental variable affects the MaxEnt prediction. The logistic output, the probability of presence, from 0 to 1, is shown on the vertical axis. The horizontal axis shows the values for the environmental factor. The curves show how the logistic prediction changes as each environmental variable is varied, keeping all other environmental variables at their average sample value. If the variables are strongly correlated variables, these curves show the marginal effect of changing exactly one variable, whereas the model may take advantage of sets of variables changing together. However, comparison of these marginal response curves with the plots representing a model with only one variable, highlights relationships and correlations between variables.

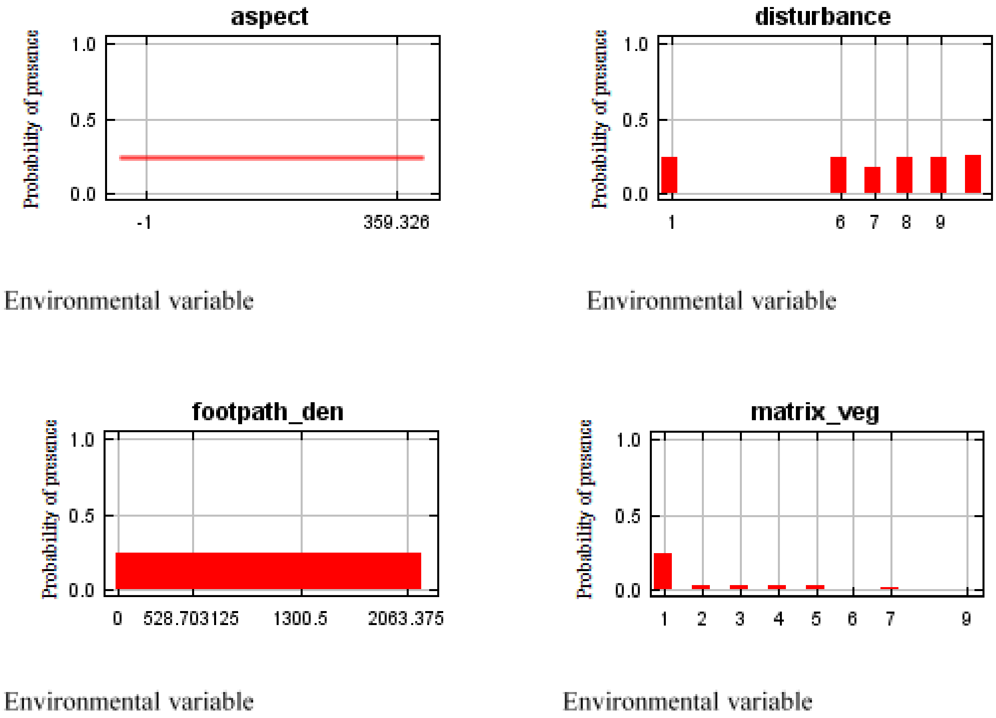

Figure 3.3 Marginal Response Curves

The aspect marginal response curve, shows a logistic output of just over 0.24 (24%) probability of presence while the disturbance marginal response curve, almost 0.26 (26%) probability of presence. Footpath density marginal response curve shows a logistic output of just over 0.24 (24%) probability of presence and vegetation type marginal response curve, just over 0.24 (24%) probability of presence.

In contrast to the marginal response curves, Figure 3.6 shows a plots based on a MaxEnt model created using only the corresponding variable. These plots reflect the dependence of predicted suitability, both on the selected variable, and on dependencies induced by correlations between the selected variable and other variables. If there are strong correlations between variables these plots provide a more accurate representation of the effect of each variable on species presence.

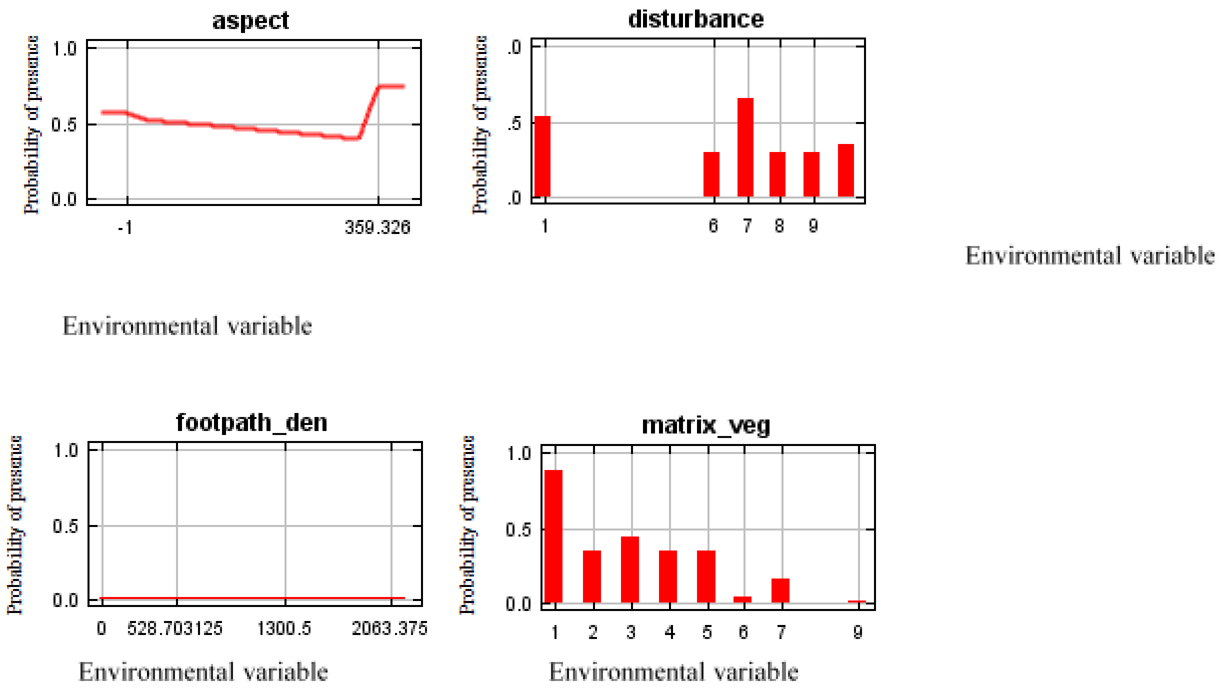

Figure 3.4 Plots showing MaxEnt model created using only 1 variable.

The aspect plot shows the effect of different aspects on reptile probability of presence. Models using continuous predictors have been found to give a better fit and explanatory power than ordinal predictors (Caryl *et al.* 2014), therefore the model was run using continuous data. Aspect scores from -1 to 359, 316° to 45° represents north facing areas, east facing areas 46° to 135°, south facing areas from 136° to 225° and west facing areas from 226° to 315°. The plots show that north facing areas effect probability of presence by 0.75%, whereas east, west and south facing areas effect probability of presence by between 0.41% and 0.52%. Disturbance effects probability of presence by a maximum of 0.65% at disturbance level 7, which is equivalent to a 300m distance. All types of footpath Density effect probability of presence by 0.1%. Vegetation class 1, which included the vegetation types determined to be most suitable for reptiles by experts, effects probability of presence by 0.89%. Other vegetation classes effect probability of adder presence by no more than 0.42%.

Analysis of the marginal response curve and plots suggest that both vegetation type and aspect are the most important environmental characteristics associated with adder distribution.

3.3.4 PREDICTIVE DISTRIBUTION MAP

The MaxEnt analysis has been run using the four environmental variables described, to show the probable area of occurrence for *Vipera berus*. An output map of the predicted species distribution was produced to explore locations most likely to be able to support adders and the extent and arrangement of potentially suitable habitat for adders.

Probability of occurrence is continuous between 0 and 1. Zero represents the lowest probability of occurrence and one represents the highest probability of occurrence. Since probability is continuous, the probable area of occurrence was split into suitable and unsuitable grid cells by setting a threshold. Thresholds optimize map accuracy, and can be decided based on one of several criteria (Freeman and Moisen 2008; Phillips *et al.* 2006). For this analysis a threshold which places equal weight on presences and absences, thus minimizing the difference between sensitivity and specificity was most appropriate (Negga 2007; Lobo *et al.* 2008), therefore the cut-off value of equal training sensitivity and specificity was applied, because although conservative, this cut-off value performs better than other commonly used thresholds (Liu *et al.* 2005).

The majority of the forest scored 0.23, just under a 25% chance of occurrence, which suggests that the conditions are not optimal for the species across most of the forest. The highest scoring sites in Wyre Forest are 0.77, which represents just over 75% probability of occurrence. Predicted Adder occurrence is concentrated in three main areas, as shown in Figure 3.6. These are the Pound Green Common heathland in the north of Wyre Forest; the open, south facing areas of Cleobury Woods in the west of the forest; and the south facing slopes along the Dowles Corridor within the central Wyre forest block.

The extent and arrangement of potentially suitable habitat can be seen in Figure 3.7. The extent of potentially suitable habitat for adders is small, 15% of the total study area is highly suitable for adders. The areas where MaxEnt's predicted probability of presence is high indicates the most suitable habitat areas, which are spatially clustered. However, these high probability of presence and high habitat suitability areas are isolated from each other by larger areas of unsuitable habitat, shown in figure 3.5 in red and orange areas with low predicted probability of presence and therefore low habitat suitability.

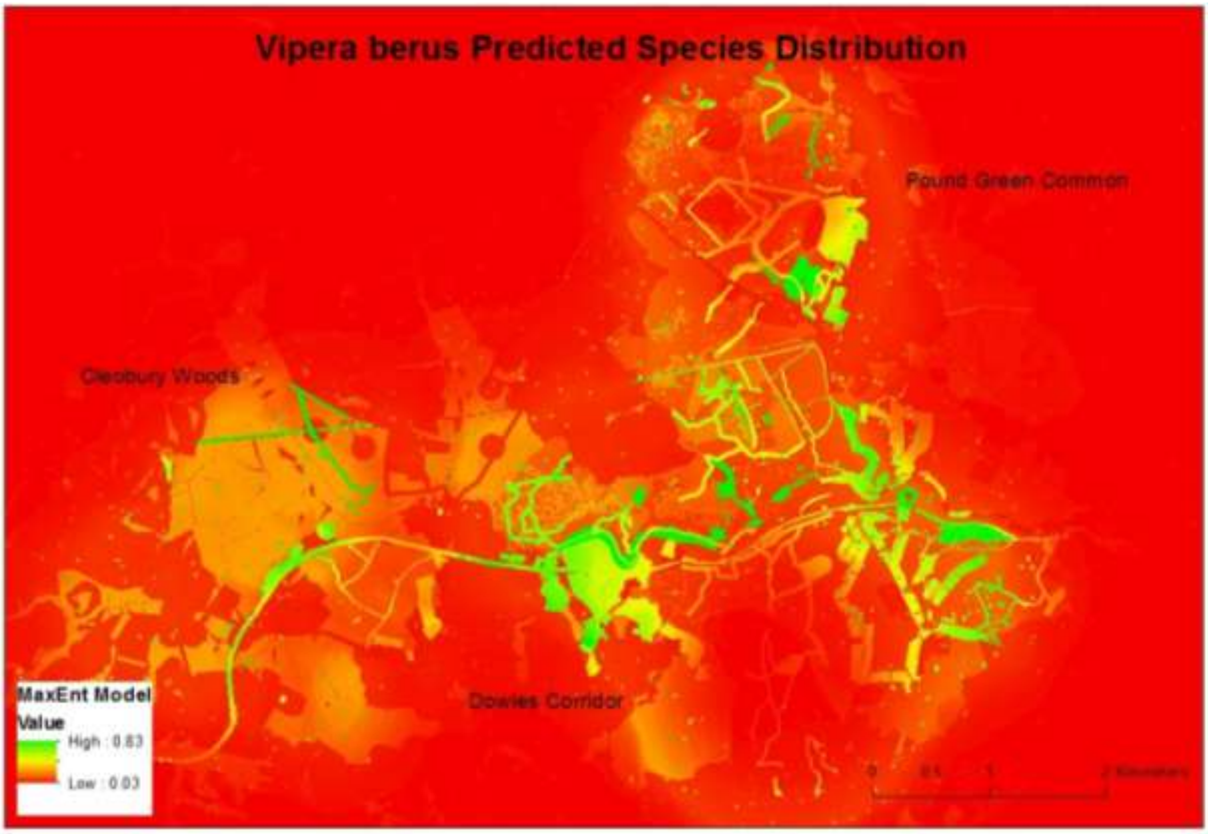

Figure 3.5 Predicted Species Distribution Map showing the Extent and Arrangement of Potentially Suitable Adder Habitat in Wyre Forest.

Importing MaxEnt's output map into GIS, and overlaying other data layers, such as current survey sites, enabled identification of currently unsurveyed areas where the study species has a high probability of occurrence. Figure 3.6 shows current reptile survey sites overlaid with the output map, illustrating spatial variation and overlap between areas with a high predicted occurrence (in green) and currently surveyed areas (in purple).

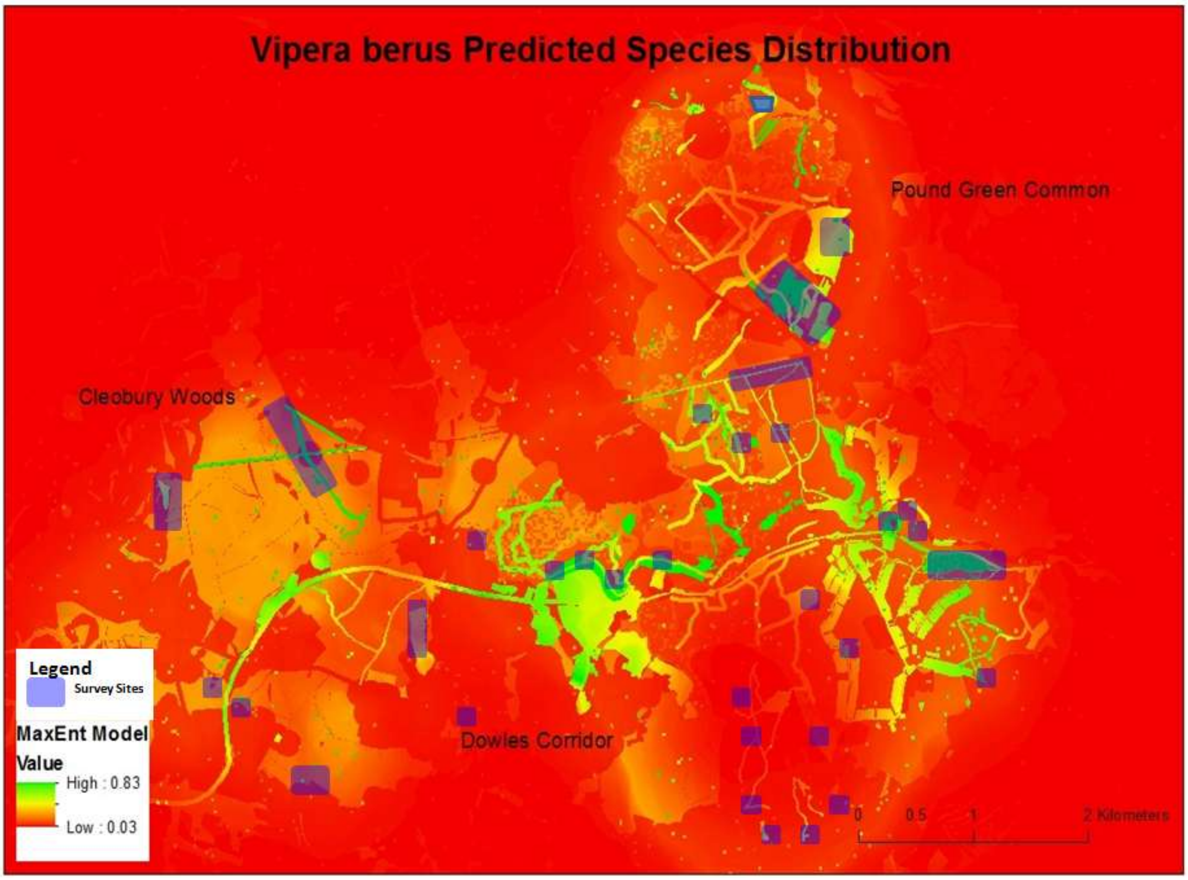

Figure 3.6 Comparison of Reptile Survey Sites with Species Probability of Presence

3.3.5 PERSISTENCE EVALUATION

Habitat suitability indexes have been categorised into four classes, based on MaxEnt's % predicted occurrence. The average suitability value was 22 (n = 56) for the historical occurrence sites and 62 (n = 14) for sites of recent observation. The frequency distributions of cell suitability values were significantly different between 1990 and 2015 occupancies (Chi square goodness-of-fit test, Chi2=7.43, DF=1, p-value equals 0.0064 and Chi2=6, DF=1, P value equals 0.0143 respectively). The chi square tests and p values indicate that the 2015 occurrences are significantly more likely to be located in areas classified as highly suitable by the model and the 1990 occurrences are significantly more likely to be located in areas classified as poor suitability by the model, based on the independent sets of records.

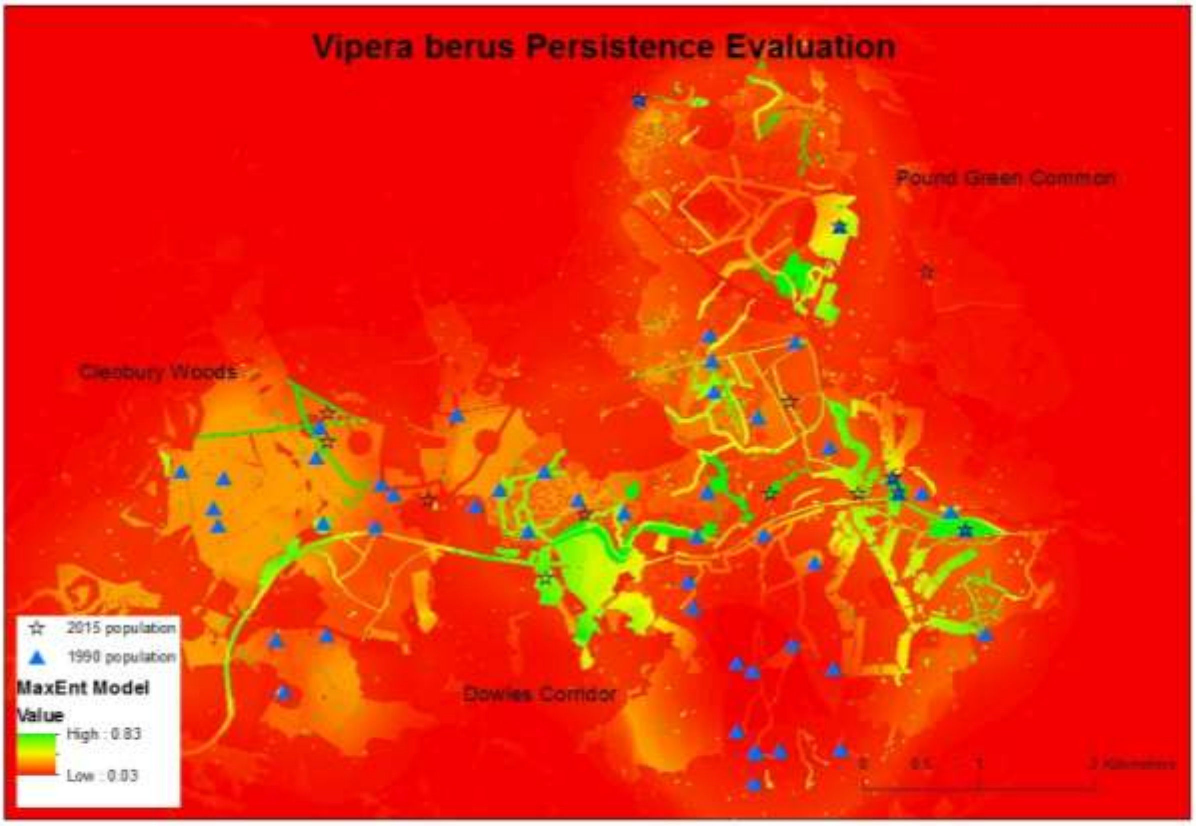

Figure 3.7 Persistence Evaluation

The overlay of the MaxEnt output map, with the reptile presence data in 1990 and 2015 shows a strong spatial overlap between areas predicted to be suitable where reptiles are still found, and areas predicted to be unsuitable where reptile populations have been lost.

3.4 DISCUSSION

3.4.1 RESEARCH OBJECTIVES

One of the key objectives for this study was to identify the most important environmental variables associated with adder distribution, in order to assess how habitat management could benefit the species. The environmental variables with the greatest impact on adder distribution in Wyre Forest were identified through the variable plots and the results of the jackknife test. The analysis suggests adder distribution is primarily determined by aspect, which cannot be influenced by management. However, vegetation type was the variable of secondary importance for reptiles, and this can be influenced by management.

The plots and marginal response curves provided an unexpected result, indicating that south facing slopes were not the most significant predictor of reptiles. The model suggests reptiles avoid north facing slopes. South, east and west facing areas had equal impacts on species presence, whereas north facing areas showed a negative impact on the probability of reptile presence. This suggests that habitat creation and vegetation management for reptiles, on south, east and west facing slopes, could benefit reptiles in Wyre Forest. The models used continuous aspect data because continuous predictors have been found to give a better fit and explanatory power than ordinal predictors (Caryl *et al.* 2014). Re-running the model after reclassificating aspect data into categorical data did not change the model result, which strengthens the relevance of this finding for Wyre Forest.

Although this appears to be relevant to conservation management in Wyre Forest, this result may not be transferable to other areas where adders are present due to two possible biases: firstly the study area is relatively small and secondly the largest reptile population in Wyre Forest does not occupy a south facing slope; instead it is found in the largest open space in the forest. Due to the largely wooded nature of the study area, species presence points in Wyre Forest are likely to be strongly affected by vegetation type, which could mask an underlying preference for south facing areas. Therefore, it is possible that background data taken by MaxEnt at species presence points in Wyre Forest may skew the model to reduce the importance of south facing aspects.

Gardiner *et al.* (2014) assessed microhabitat selection in Canadian Prairie Rattlesnakes (*Crotalus viridis*) using radio-telemetry and found prairie rattlesnakes select for specific sites within 1 m of shrub cover and burrows, which suggests that rattlesnakes select habitat at a very fine level. This species is at its northern range limit in the Canadian study location, which represents a thermally challenging environment, in which burrows and shrubs are likely to be crucial for thermoregulation. It could be that the adder, the world's only cold adapted viper, is not thermally challenged by the temperature in the UK Midlands region during the spring survey season, when presence data points are collected. It is possible that preference for south facing areas is limited to certain aspects of their ecology, for example, hibernacula locations used over winter. No data was available on hibernacula locations, a further study could use MaxEnt to investigate which environmental factors most significantly affect their location.

The MaxEnt analysis predicted locations in Wyre Forest most likely to support reptiles in the predicted occurrence output map, and by proxy, suggests the extent and arrangement of potentially suitable habitat for adders. The predicted occurrence is based on the variables associated with species presence, assumed to represent the most suitable ecological-niche for the species. The default settings mean the model determined the heuristic estimate of the relative contribution of each variable to species' distribution. Therefore grid cells with the largest logistic value were predicted to be most likely to be able to support adders, given the species assumed ecological niche (Urbina-Cardona and Loyola 2008). However, assumptions related to the ecological niche and variables parameterising the model are discussed below (see section 3.4).

The output map also enabled informed decision making on the most appropriate areas of the Wyre Forest to undertake habitat restoration and the planned adder reintroduction program. Habitat restoration in areas with the lowest probability of occurrence (0.23), shown in red in figure 3.7, is unlikely to be successful because of their unsuitable aspect. Habitat restoration is more likely to be successful in areas with moderate probability of occurrence (0.35 and 0.65), shown as orange and yellow in Fig 3.7. Habitat restoration could also be appropriately targeted between areas with high probability of occurrence (0.77). Areas with a high probability of occurrence are most likely to be the most suitable locations for the adder reintroduction programme. In order to overcome disease risk, and act in accordance with IUCN guidelines on species reintroductions, the predicted occurrence map can be overlaid with the map of known species presence (see Figure 3.9), to ensure newly introduced reptiles are not placed within existing reptile populations. Figure 3.9 shows the Dowles Corridor as a centralised, potentially suitable area for adder reintroduction, as it contains both sites unoccupied by adders and a series of suitable areas linked by moderately suitable areas which could be improved by habitat management. Its central location would allow reintroduced adders to disperse to the other suitable areas to the east, west and north. This area is therefore the most suitable area of Wyre Forest for the planned adder reintroduction program.

Importing MaxEnt's output map into GIS and overlaying current reptile survey sites, enabled spatial comparison of areas where adders have a high probability of occurrence, and current survey areas. Many sites with a 75% probability of occurrence are not currently surveyed. The difficulties of survey work for cryptic species (de Fraga *et al.* 2014) mean expansion of survey work must be accurately targeted. Investigation of some of the areas with a 75% probability of occurrence led to the discovery of three previously unknown individuals. The results have helped to define new survey locations for expansion of current survey work into areas predicted to be highly likely to support reptiles and will therefore determine whether unoccupied areas of suitable habitat represent true absence or lack of detection.

3.4.2 MODELLING ASSUMPTIONS

The evaluation of the model results with adder presence suggests the model is robust. However, assumptions are inherent in the modelling process therefore species distribution predictions are always subject to uncertainty. Potential sources of uncertainty include: clarification of the niche concept; sampling data; model parameterization and model selection and predictor contribution (Beale and Lennon 2012; Araujo and Guisan 2006). How this research has addressed these assumptions and sources of uncertainty is described is sections 3.2.2 and 3.2.3 respectively.

3.4.3 REFINING THE APPLICATION

Data on vegetation type was available within this study, to fine detail, $10m^2$ resolution was used across the study area. Vegetation type classifications were determined by the Natural England management plans and the Forestry Commission Forest Design Plan process. Although these classifications were useful in determining variation in adder habitat suitability, it would have been useful to have an additional layer of data, which described the fine scale details, features and micro topography of the landscape, such as presence of ant hills, tumps, tussocks, log piles, tree stumps and rocks, as these features often provide hibernacula for adders and contribute to the suitability of different habitat types. However, this information is not available and would require detailed survey, beyond the available resources.

Similarly, within the meadows classification, no information was available on the management regime of the meadows. Grazed meadows are unlikely to suitable for adders, because even the low stocking density used in conservation grazing generally results in loss of tussocky structure and conditions required by adders (Edgar *et al.* 2010). Ungrazed meadows may be managed used large machinery, which is often incompatible with reptile presence or they may be un-managed and therefore have developed the tussocky structure favoured by adders and their prey. Some information on meadow management may be gleaned from the output maps, as some of the highly suitable sites highlighted are meadows, other meadows have been scored with a lower potential for the species. This variation is likely to be due to the presence of species distribution data points in some but not all of the meadows modelled.

Walters (2012) found that the predictive ability of MaxEnt's suitability scores tended to increase with more species data, though eventually a plateau was reached. If the models are improving with new data, then the test AUC and test gain should get larger with each data set. It would be interesting to explore the effect of increased survey data on the Wyre Forest model, however despite additional survey work, in 2015 a smaller number of adders were found than in 2014. Therefore additional data was not available.

3.4.4 MANAGEMENT IMPLICATIONS

This research provided a series of scientifically justified habitat management recommendations for Wyre Forest:

- Expansion of reptile survey into all areas considered highly suitable for reptiles by the model (>80% probability of presence).
- Use of reptile friendly vegetation management techniques in areas highlighted as highly suitable for reptiles.
- Changes to ride management on rides highlighted as highly suitable for reptiles.

- Enhancement of habitat for reptiles adjacent to rides with high levels of suitability.
- The creation of two reptile corridors; one in the north, and one in the central area of the forest, as illustrated in Figure 3.14. These *"reptile corridors"* are now managed to support reptile conservation and habitat restoration within these areas will be used to improve connectivity of existing populations.
- Cessation of reptile friendly management techniques on sites with low suitability for reptiles.

This applied research has found MaxEnt's ability to describe which environmental factor has the greatest effect on species distribution, especially useful. Knowing which environmental characteristics affect species distribution has allowed decision makers and land managers to use their limited resources most effectively; taking action to manage the most relevant environmental factors and to understand where management cannot change the suitability of a site to support the species.

The model illustrates the effect of multiple environmental factors, and therefore was able to distinguish between rides and open spaces which would naturally be suitable for reptiles, and south facing open areas with low levels of disturbance or low footpath density. This is difficult to determine from standard open space maps available within the Forestry Commission, and has provided a useful method for determining which rides should be managed for reptiles.

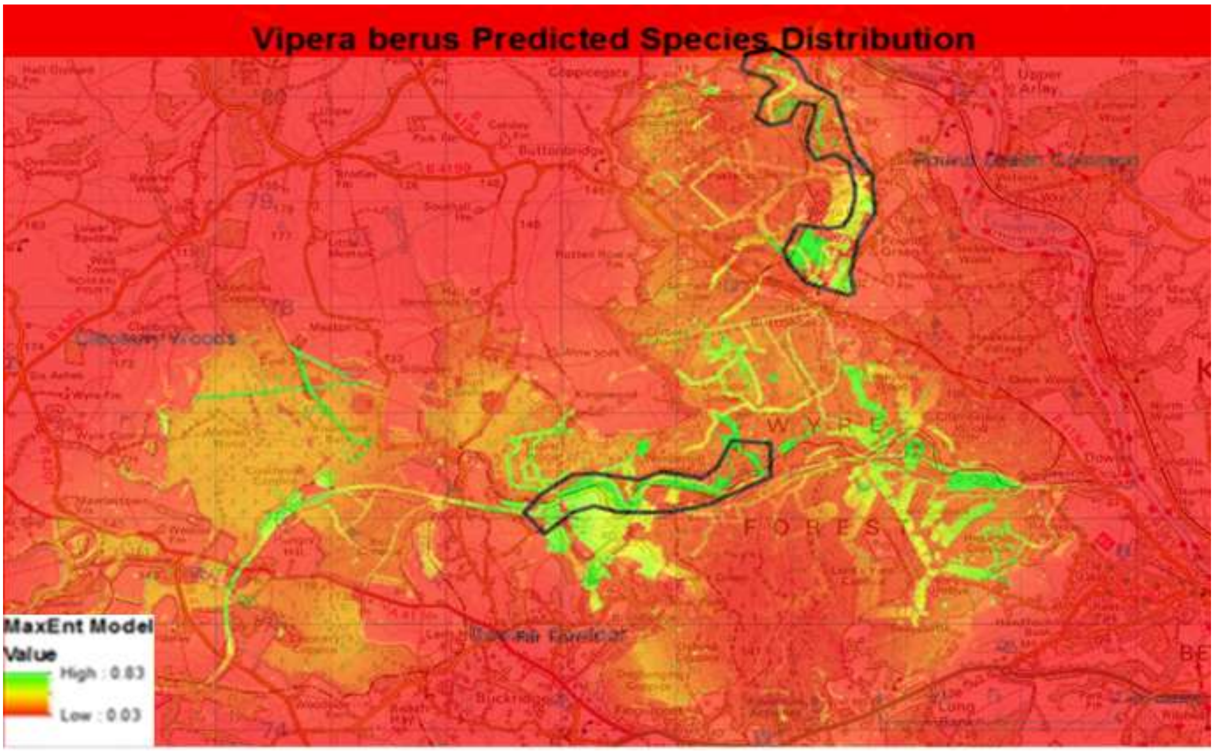

Figure 3.8. Impact of MaxEnt Model Results on Conservation Management.

The areas highlighted in black in Figure 3.14 are now managed as reptile corridors, habitat restoration within these areas will be used to improve connectivity of existing populations.

CHAPTER FIVE
APPLICABILITY OF MODELLING TECHNIQUES

ABSTRACT

This research aimed to explore the use and applicability of ecological modelling techniques within an applied conservation project led by the Forestry Commission. The research methods involved a 33 month micro-ethnography to explore how the implementation barriers and solutions described in the literature, affect the use and implementation of results from landscape permeability modelling research. Within this micro-ethnography the modelling techniques were used to inform a conservation project developed and managed by the Forestry Commission. Subsequently staff were trained to use the modelling tools to support their own work. Chi Square analysis of the results suggests the tools are useful for the organisation, and able to provide relevant, credible data to inform conservation projects. Staff members were keen to adopt the tools and used the results of models to inform conservation planning. The research concludes that most of the barriers described in the literature can be overcome through research design, however time constraints prevented the organisation from permanently adopting the techniques. These barriers could be overcome by two of the implementation solutions suggested in the literature: funding and changes to institutional frameworks to support connections between researchers and practitioners. Fundamentally this research highlights the importance of social capital in enabling effective communication and partnerships between researchers and conservation practitioners.

5.1 INTRODUCTION

Environmental management research is rarely used to inform conservation practitioners decisions (Walsh *et al.* 2015). However, case studies have been used to explore several of the proposed barriers and solutions to the research-implementation gap. Diverse ideas on the reasons and potential solutions to the implementation gap are described in the scientific literature. These are discussed fully in Chapter Two, and can be summarised as issues relating to relevance, interdisciplinarity, access to scientific data, reward, training and resource constraints. Other examples of case study research have facilitated understanding of the conservation research-implementation gap. Case studies have demonstrated that provision of a summary of the literature can change practitioners management decisions (Walsh *et al.*

2015; Hart and Calhoun 2010), which suggests that increased access to scientific literature can improve research implementation and conservation outcomes. However, these studies also suggest that long publication times for articles (average 40.2 ± 1.8 months); subscription-only access (56%); and poor articulation of management implications (19% of articles provided management relevant outcomes), all contribute to why primary scientific literature is little used by conservation managers (Walsh *et al.* 2015). Case studies have also been used to explore the use of scientific research evidence by policymakers. Oliver (2014) demonstrated that scientific data can change conservation policy maker's decisions under certain conditions, namely timely access to research in direct collaboration with policymakers. Relationship and skills building with policymakers, were also found to be the most important factors in influencing the use of scientific evidence within policy making by these case studies (Oliver 2014).

A global review, incorporating case study evidence from Fiji, Central America, the USA, New Zealand, Australia and the UK, citing diverse organisations including Marine Area Networks, the US Department of Agriculture, the US Forest Service, the RSPB, WWF, and the Centre for International Forestry Research, among others, suggested that contrasting perceptions about the salience of research which scientists and practitioners have; conflicting views about what constitutes legitimate information; and how scientific credibility can compromise salience and legitimacy in the eyes of decision makers, creates implementation barriers (Cook *et al.* 2013). Case study research has also suggested that research does not tackle applied topics and therefore lacks relevance to conservation managers (Balme 2014).

Case studies have suggested a variety of institutional frameworks can help integrate conservation scientists and conservation practitioners as a solution to the research-implementation gap (Cook *et al.* 2013). These suggestions are supported by case studies which found that development of conservation research with stakeholders, supports implementation (Home *et al.* 2014; Oliver 2014), and others which demonstrate that consideration of the social processes which influence conservation decisions supports implementation (Ban *et al.* 2013).

In terms of modelling, case study research has concluded that in order for species and habitat models to effectively guide conservation, modellers need to better understand conservation management and policy decision processes, and conservation managers and policy makers need to provide feedback to modellers regarding the use of models to support conservation decisions. This study urged modellers to get involved in real conservation decision-making processes that will benefit from their technical input (Guisan 2013).

For the purpose of this research, a case study is defined as *"In-depth study undertaken of one particular 'case', which could be a site, individual or policy"* (Green and Thorogood 2013). The investigative case study approach was chosen in order to explore '*how', 'what'* and *'why'* questions, concerning the gap between research and its implementation within one particular organisation. The aim was to investigate the barriers to the use of these modelling techniques within the organisation, and whether solutions suggested in the literature could enable the Forestry Commission to adopt these techniques. Additional objectives included seeking insights which could contribute to the theories around the research-implementation gap, and refining understanding of the solutions which can reduce the gap between conservation science and conservation practise.

Research questions were formulated through analysis of the literature and the theoretical issues behind the research-implementation gap. The aims of this research were to:

1. Explore the usefulness of ecological modelling techniques within a conservation organisation, exemplified by the Forestry Commission.
2. Understand the barriers between scientific research and practical conservation projects carried out by the Forestry Commission.
3. Examine whether solutions presented in the literature could overcome these barriers and enable the adaptation of these techniques within the Forestry Commission.

Specific research questions were explored using qualitative research approach (Merriam 2014). This was designed to enable an in-depth exploration of:

- The reasons the techniques are currently not used.
- Staff members experiences of the techniques (described in their own words using their own frames of reference).

- Whether and how the modelling techniques could be adopted by staff themselves within their own work.
- Whether and how the techniques could be adopted by the organisation as a whole.

By maintaining an open-ended approach, information was collected on the organisation itself, its behaviours and values; how these affect the adoption and use of modelling techniques; the setting staff work within; the individuals involved; and social world of the Forestry Commission.

5.2 METHODOLOGY

Two methods were used to explore the implementation gap: a micro-ethnographic case study within a conservation agency and a questionnaire survey to a wide range of conservation agencies across the UK.

5.2.1 DEFINING THE CASE STUDY

This case study research uses an interpretivist, cumulative approach (Yin 2013), to explore the research-implementation gap within the Forestry Commission West District. The Forestry Commission represents a closed, non-public setting (Lofland and Loftland 1995, Hammersley and Atkinson 1995). The West District includes all Forestry Commission land holdings, from the west of Birmingham to Penzance. The inclusion of all parts of the West District allowed access to all levels of management; all staff involved in landscape planning; GIS; and conservation management of Wyre Forest, the study site where the techniques were used. These individuals are the most relevant group of individuals within the organisation to explore the barriers and solutions to the science-implementation gap in conservation management of the study area.

The case study began in May 2012 and ended in February 2015. The author is a former employee of the Forestry Commission, which helped to gain access to the organisation and staff involved in the case study, although 70% of the persons involved within the study were unknown to the author at its outset. Full access was granted via a reciprocal arrangement, in which the modelling techniques were used to support a Forestry Commission led reptile conservation project. Overt access was granted via this agreement, however, during the course of the research overt and covert roles (Atkinson 1981), both active and passive participation (Gold 1958, Bell 1969), total participant, researcher-participant and total researcher roles were used (Gan 1968). Covert roles enabled exploration of the usefulness of the modelling techniques, barriers to their adoption and the potential for their adoption by the organisation. The covert roles sometimes created difficulty in taking notes. In several situations, field notes were overtly taken on the pretext of recording outcomes of meetings, actions or notes during site visits. However, covert notes were taken after seeing or hearing relevant activities. All field notes were written up in full at the end of each day.

The potential uses of the modelling techniques, and their application to the adder conservation project were presented to the Forest District Manager (FDM), who gave permission for the use of the models and the case study. The FDM is the most senior member of staff, who governs all activities in the West District. Field staff responsible for the management of Wyre Forest, were informed by the FDM that these modelling techniques would be used to assist the Wyre Forest adder conservation project and explore whether the techniques could be more widely adopted by the organisation. The GIS manager for the West District, was appointed to oversee the application of the modelling techniques and the case study. He informed all GIS users in the West District of the project and provided names and contact details for all staff who were to be involved in the use of the landscape modelling techniques.

5.2.2 DATA COLLECTION & FIELD WORK METHODS

Data collected was guided by the principals defined by Bryman (2012), in order to support the reliability and validity of the case study. Throughout the case study an interpretivist approach was used, and the research sought to understand individual and shared social meanings, which affected the implementation of scientific research within The Forestry Commission’s conservation activities. Therefore, the evidence collected during this research included all opinions, experiences and beliefs of Forestry Commission staff, as they learnt about landscape permeability and predictive species distribution modelling tools, applied them to their work and explored their usefulness.

The sample design aimed to be as inclusive as possible, to allow equal opportunity for all perspectives to be identified, and be carried out without bias (Ritchie *et al.* 2003;

Onwuegbuzie & Collins 2007). In order to answer the research questions, a representative sample, inclusive of all known constituencies and relevant individuals was required (Merriam 2014). Probability sampling was not used, instead, a purposive sample was used to sample participants in a contextually relevant, strategic way, using participants who are relevant to the research questions (Merriam 2014). Therefore it included the perspectives of five practical field-based staff responsible for conservation activities, four forest planners who undertake strategic planning of landscapes, two ecologists, one GIS manager and eight GIS users involved in the management of the study area. The sample design included staff from several different levels of the management hierarchy within The Forestry Commission. Persons involved in the sample have different roles within the organisation, and were based across the country in three different offices. The sample included all staff relevant to the adoption of landscape permeability modelling and all staff involved locally and nationally in conservation management and forest planning of Wyre Forest. There were no non-respondents and no evidence of attrition (Cheng and Trivedi 2015) within the sample.

The data collection methods included a variety of observational and participatory activities. These were:

I. Telephone discussions
II. Email correspondence
III. Field visits within study area
IV. Semi-Structured Interviews
V. Focus Groups
VI. Observation

Telephone Conversations; telephone helped to elicit the views of staff members and build trust and rapport. Due to the hierarchical structure of the Forestry Commission different levels of management hierarchy were present in each training day and it was not possible to undertake focus groups or training days with only one management level present. In order to allow equal opportunity for all perspectives to be identified, all participants were also interviewed singularly by telephone, so they could express their opinions privately and confidentially. Telephone conversations in particular, allowed staff to express personal opinions and portray their experiences.

Email correspondence; a variety of specific questions were also sent by email to every individual, so they could respond confidentially, without the influence of other members of staff or the management hierarchy. These responses were sought before the focus group days, and before the training sessions, which were carried out in small mixed groups.

Field visits, often aimed at discussing management, or visiting areas highlighted in the modelling process, also supported the creation of an open atmosphere, where participants were able to speak freely and cover both relevant and irrelevant ground, which helped to portray their experiences.

Eleven semi structured interviews were undertaken. Digital recordings of these interviews were not made, as staff were unwilling to be digitally recorded, however detailed notes, including quotes, were taken.

Additionally, three focus groups were held with Forestry Commission staff. These days provided training on the use of the modelling techniques, and overtly explored the use of the techniques, asked for opinions on their suitability and usefulness and explored possible barriers to their use. Training sessions were planned so that field based staff and technical staff were trained separately. Detailed notes were taken during these focus groups, which lasted in total 21 hours. Observations of staff and the organisational culture were ongoing throughout the 33 month long study period, and observations were noted during or after each interaction with participants, with all relevant comments and behaviours recorded.

5.2.3 QUESTIONNAIRE SURVEY

To explore the validity of the findings of the case study, a questionnaire survey was developed. The questions explored whether the issues found within the forestry commission case study, were prevalent within other organisations. The questionnaire was sent electronically to 100 individuals working as conservation practitioners within a wide range of other UK conservation organisations, including the RSPB, Landlife Wildflowers, Wildlife Trusts, Natural England, the Environment Agency, and local authorities. 45 completed responses were received within the allocated timeframe. The full list of organisations from whom responses were received, and an example of the questionnaire can be seen in appendix 5.1.

5.2.4 ANALYSIS AND INTERPRETATION OF DATA

In order to ensure the data analysis was carried out systematically and comprehensively, classifications and typologies were confirmed by multiple assessment. In order to coherently interpret, and analyse the data generated by the research, the data was organised and coded to allow the key issues, those derived from the literature and those emerging from the dataset, to be recognised. An initial coding framework was developed linked to the barriers identified in the literature review. This coding frame was applied systematically to the whole dataset. A framework approach comprising of five stages; familiarisation; identifying a thematic framework; indexing; charting; mapping and interpretation (Stake 2013), was used to manage and analyse the data. Respondent validation, i.e. allowing the participants to check the interpretation of findings, and provide their opinion as to whether these are accurate, has been included in the process to increase scientific rigour.

5.2.5 RELIABILITY & VALIDITY

Reliability and validity help to define the strength and soundness of the research and its results. Reliability and validity have been variously described over the years. '*External validity'* is the degree to which findings of research can be generalised across social settings, and '*internal validity'* describes whether or not there is a good match between researchers observations and the theoretical ideas they develop (LeCompte and Goetz 1982). Reliability and validity have also been described as whether you are "*observing, identifying and measuring what you say you are"* (Mason 1996).

Within this research the approach of Bryman (2012) has been adopted, where reliability and validity are sought through appropriate research design and conduct. The research approach has been transparent, throughout the research process. The European protected species involved in case selection, data collection, the reasons for the particular methods chosen are described in detail. The researcher's background and level of involvement are described in section 5.4.8, so readers can judge whether the researcher has influenced data collection and interpretation. All data was collected by the same individual, the author, using the same approach, in order to ensure the field work was carried out consistently.

Lewis and Ritchie (2003) suggest that reliability depends not only on the way the data is interpreted, but also the likely recurrence of the results. However, the idea of reoccurrence or replication in qualitative research has been criticised. Researchers within the constructivist school, argue there is no single reality to be captured in the first place, so replication is an artificial goal (Hughes and Sharrock 1997; Marshall and Rossman 1999). Replication has been criticised as "*naïve*" due to the complexity of phenomena studied and the inevitable impact of context, which can never be repeated (Lincoln and Guba 1985). Holstein and Gubrium (2008) suggest dynamic, qualitative research can only be conducted effectively in a responsive manner, and therefore studies can never be, nor should be, repeated. While this may be true, robust theories require an element of *saturation* i.e. the point in data collection when no new or relevant information emerges with respect to the newly constructed theory and therefore all available evidence supports the robustness of a theory (Houghton 2013). Within this research, saturation was reached the point the interviewees all began to make similar statements, and when multiple respondents raised the same issues in terms of barriers and opportunities for implementation. Evidence of saturation is also seen in the data provided by respondents to the questionnaire survey. Although the questionnaire survey to other conservation agencies is not a repetition of the case study, it asked many of the same questions to conservation practitioners about the use of modeling techniques, and many of the same issues raised by staff in The Forestry Commission case study, were also raised by questionnaire respondents.

5.3 RESULTS

The results of this micro ethnographic study are presented with background and contextual information, to enable the reader to understand the processes that were followed and how the conclusions were reached. Individual participants remain anonymous throughout. The results are presented chronologically, with answers to the research questions presented as they arose during the study.

5.3.1 INITIAL PRESENTATION OF THE TECHNIQUES

The modelling techniques were presented first in Wyre Forest itself, to the field staff responsible for managing the forest. Amongst field staff, the initial perception of the models was generally poor. Explanation of the modelling processes and assumptions, led to comments about the unnecessary nature of the techniques. Comments included; "*It's obvious where's good for adders*"; "W*e already know what they need, its common sense" and "We don't need a fancy computer to tell us something we already know".* They did not believe the techniques would be useful, and the modelling process was perceived to be time consuming and unnecessarily complex. Therefore, something they were unwilling to encompass into their already busy work schedules. The in-depth nature of the interviews and long time period of the research, enabled the development of understanding as to why Wyre Forest's field staff felt this way about the modelling tools. There was an underlying resentment among some field staff, that they were not responsible for decision making and did not create the management plans for the forest, but were instead only responsible for implementing them. Comments included; "*We know what's needed but it doesn't matter what we think*". Therefore, at least partially, the negative attitudes towards the modelling process, reflected frustration that decisions about the land management, were not based on their own in-depth knowledge of the area they worked in, but on the decisions of others. These 'others' would be viewed as unnecessary, whether they were other staff members, or computer based modelling tools.

The initial reaction of the technical staff to the modelling techniques was strikingly different. Explanation of the modelling processes and assumptions, led to immediate excitement and stirring within the group. GIS users and ecologists immediately recognised the applicability of the tools and talked between themselves, suggesting uses to each other. Comments included; "*it's an option testing process"; "identify objectives within forest plans"; "predict* *the results of different forest plans"; "similar to the planting model"; "target restoration of broadleaf, identify areas for restoration and marry it with data on indicator species*" and "*good at a public consultation*". Multiple questions were asked, which demonstrated staff were envisaging applying these tools within their own work. Comments such as "w*ish we'd had this for Croft*", concerning the development of management plans already completed, indicated that staff perceived using the techniques would have improved their work, or made it easier. Comments such as "*Knocks spots off what Holden's doing*" indicated a competitive spirit, and the sense within the group that if they were using these techniques, their management plans would be better than those produced by staff in other regions. Comments on the usefulness of the techniques included; "*Better than a finger in the wind"* and *"Something to hang your hat on"*. Interviews with these staff suggested the techniques could give them something "*solid"* to base their decision making on. This suggested that planning staff feel some level of discomfort about conservation planning decisions which are largely based on their own subjective judgement, albeit including the views and opinions of other stakeholders and local land managers.

Three landscape modelling tools were presented: MaxEnt as a predictive species distribution tool and two techniques to model landscape permeability: Rule Based and Expert Scored; and Least Cost Path Analysis to explore habitat connectivity. The research aims were: to present the approaches, train Forestry Commission staff to use each of the four techniques, support staff to apply them to their own work to assess barriers to their use and opportunities for their adoption within the organisation. However, after the tools were presented, the GIS manager present, asked staff which they felt would be most useful to their work. After a short discussion staff determined that the Rule Based and Expert Scored habitat suitability modelling and Least Cost Path Analysis were the most useful tools, and the GIS manager decided that staff would be trained only in these methods. The reasons for the rejection of the other technique were clear from the discussion. Staff felt that the predictive species distribution modelling was not relevant to their work. They were more interested in tools which enabled them to explore different management options. Additionally staff felt that the expertise to score the landscape was available in the organisation, and therefore would be a quick process which the ecologists could carry out on behalf of forest planners. There was debate about the utility of the Least Cost Path, two planners remained sceptical about its usefulness, but the ecologists were in favour of using this technique and determined it could be useful for habitat restoration for European protected species.

5.3.2 TRAINING IN USING THE TECHNIQUES

Training was focused on technical staff and ecologists who were potential users of the techniques. Field staff, who are not frequent GIS users, and are not responsible for landscape planning, were not trained in the use of the techniques. However, field staff were involved in the parameterisation of the models. Training sessions were provided on each stage of modelling: parameterisation, model building and running the LCP analysis. During the training sessions, staff's attitudes to the modelling techniques began to change and some of their enthusiasm waned as the difficulties of using the techniques and barriers suggested by the literature became apparent.

5.3.2a Model Development with Field Staff

Field staff would potentially be responsible for implementing model results, but not using the model, therefore sessions focused on understanding what useful information a model could provide, and the types of answers they needed. The rapid decline of the adder in Wyre Forest and the consequent failure of Wyre Forest to achieve favourable SSSI status, has focused attention on adder conservation. In order to implement a conservation project for adders, field staff wanted information on the feasibility and potential for habitat reconnection and the spatial requirements of adders. They were also interested in whether there might be adders in unsurveyed areas of the Wyre Forest.

As the rule based and expert scored models were developed, they were taken back to the field staff to discuss the variables and why these had been included. Field staff were concerned by the lack of constraints in the model and keen to include the impacts of recreation and commercial forestry. This led to the development of an additional model, which included a constraints layer.

5.3.2b Model Development with Technical Staff

The stages of model development were first explained, then staff were split into pairs and used worksheets provided by the author (appendix 5.2), to enable them to work through the model development process for a species of interest. European protected species were chosen, as earlier comments had indicated that these would be the priority species the tools would be used for.

The worksheets to support the development of a rule based model included simple questions, related to rules, including; *"What vegetation types provide food / and shelter?" "How far away are these vegetation types from each other?" "How does the species move?" "What stops it moving across a landscape?" "How many do you need to live together to survive long term?" "Can you identify threats to the species?"*

Similarly, worksheets were used to support the development of the expert scored model. These included simple questions, such as "*Where do they find food?" "What is shelter for this animal?"* to helped them to work out which landscape variables were important for their species, and then rank their importance.

The first problem faced by staff was difficulty answering these questions. There were two ecologists present, and so staff asked the questions to these ecologists. However, the ecologists were not able to answer all of the questions. Talking after the training session, the ecologists described their discomfort during this questioning, explaining how difficult it is within the organisation, being the only ecologists and expected to know everything about every species. Comments included; *"we're a jack of all trades, we can't be expected to know everything"; "I always feel terrible when someone asks me a question and I can't answer it, it's like we don't know anything because it's what we're supposed to be expert (in) but we still don't know"; "it's impossible to know everything about every species but they expect us to know, our subject is huge"; "we can't know it all"*. Their responses made it clear that trying to answer the questions had been difficult and created some frustration, linked to the expectations of other staff, that as ecologists they would be able to answer questions and provide all the data required to build species and habitat models.

The training session on model building lasted just one day, and it was not possible to accurately answer all of the questions required for model building in this time. Therefore, to enable the training to continue the following day, a combination of known values, estimated values, and false values were given for each species. The response of staff to the problem of how much time was required to score the model was twofold.

Firstly they suggested prioritising when and with which species to use the model. Suggestions included "*use it on selective basis*"; "*use it where plans are contentious*"; "*use it for funding bids"; "use it to confirm guesses or see if we're barking up the wrong tree*"; "*got* *to balance the effort, depends how important the species is*". Staff ranked species importance, based on their legislative duties towards biodiversity, European protected species and the Wildlife and Countryside Act as amended.

Secondly, planning staff decided that Forestry Commission ecologists could create a national data set, which planners could access, so that the values needed by any model were available. This dataset could be based on a list of species that forest plans frequently have to take into account, and European protected species. It would provide habitat value scores or resistance scores, for each vegetation type, age etc. It would include data on dispersal distances, barriers to movement, threats etc. Questions within this debate amongst staff included: "*What about small occurring species, should you use it for them because they're rare or not use it because they aren't widely occurring?"; "Or for species that need a proper corridor?"* Staff described an existing database developed and held by the Forestry Commission, which holds species presence records, the inclusion of model relevant data was envisaged as an extension to it. The process was seen as similar to developing species guidance and staff felt it could be done nationally. There was debate about the feasibility of this, and database maintenance, and whether other Forestry Commission regions would use it, but the atmosphere was positive. It was generally agreed by the group that having this data ready would speed up the modelling process, and if other staff were also trained in the modelling process they would be likely to use it. The author was requested to do further training for other districts, if they were in agreement with it. At this point in the process, staff felt that they wanted to use the tools, GIS managers felt that they would be beneficial and that internal resources, available nationally, could be utilised to make model development faster and easier.

5.3.2c Creation of Models in GIS

The training sessions on building the model in GIS produced some surprising results. The level of GIS proficiency varied greatly between planning staff, despite the similarity of GIS use within their roles. Staff were familiar with the use of attribute tables, but not familiar with any of the spatial analysis tools. Spatial analysis tools such as merge, used within the modelling process to create a scored landscape based on compilation, editing and merging of multiple datasets, were new to staff. This was because spatial analysis does not come with a standard GIS licence, it is an additional extension, and therefore was not available to the majority of Forestry Commission GIS users. One training session had to be re-arranged as the spatial analysis tools were not available. In order to use these tools, special permission needed to be granted from the national office within the Forestry Commission, responsible for GIS licencing. Although this enabled the use of the spatial analysis licences for the training sessions, it meant that most staff would not have these tools available when they returned to their offices.

The process of building a model progressed very slowly, as new tools in GIS and new procedures had to be learnt, as well as the new technique of model building. The newness of the tools, and slow speed of model building led staff to question whether habitat modelling was too complex and too time consuming. Comments included; *"if I was in my office I'd never be able to do this, there'd be someone coming in and talking to you or the phone ringing"; "I'd lose what I was doing and have to start again and never finish it!"*

The process of creating a single model, led staff to determine that the technique although useful, would need to be prioritised, and used only for certain rare species and priority areas, not every Forest Design Plan. Staff suggested that if the forest planning process could be streamlined, they would have more time for the inclusion of the modelling techniques. Staff debated whether the technique should form part of forest planning, or be a separate thing, done by someone else, with data saved on an internal server, available for planners to access. Although still positive about the technique, comments reflected attitudes becoming more pragmatic, largely due to time constraints; "*it needs to be balanced, how much effort and how important the species is"; "in a perfect world you'd use it everywhere, but you could use it selectively, to inform or justify things"; "maybe just for controversial plans, or those with loads of public involvement".*

Within the time allocated for each training session (one day), there was insufficient time to complete the stage which had been planned. Further training was arranged and carried out to complete the model building, but this highlighted to staff the time commitment required to undertake the modelling processes. They expressed increased uncertainty about the suitability of the technique and anxiety about their ability to incorporate it into their roles.

5.3.2d Undertaking Least Cost Path Analysis in GIS

The training sessions on Least Cost Path Analysis in GIS highlighted the novelty of the technique and the unfamiliarity of staff with using GIS spatial analysis tools. The procedures of creating shapefiles for the source and destination files were familiar enough to staff, but using the spatial analysis cost distance tool to produce the raster files (the least-cost distance and back link raster) and using these files to run the Least Cost Path analysis, was perceived by staff as difficult and proved time consuming.

Another interesting result whilst teaching staff how to undertake a Least Cost Path analysis was their mixed reaction to its usefulness and application. Ecologists were clear that within woodlands it could be useful for exploring the connections between habitats, and suggested it use for species such as dormice, and a variety of butterfly species including nationally rare small pearl bordered fritillaries *Boloria selene*, dingy skipper *Erynnis tages* and grizzled skipper *Pyrus malvae*. However, planners were much more sceptical about the usefulness of LCP analysis. They proposed that as butterflies can fly, habitat fragmentation is not an issue for them, and that dormice can "*scamper about in trees"* and therefore move around. During this debate, the author retained a neutral position, encouraging both the planners and ecologists to speak by voicing interest in both opinions. It appeared that although ecologists were able to explain that some habitats are difficult or risky for some species, and it was accepted that species prefer certain conditions, landscape planners remained sceptical that some species would be unable to cross certain habitat types, and would therefore be isolated. They were therefore sceptical of the value of the Least Cost Path analysis.

5.3.3 USING THE TECHNIQUES THEMSELVES

The study then examined what happened when Forestry Commission staff use the models themselves, on live projects, in their own offices with their data, i.e. within the Forest Design Plans they were working on. The author was present during this process, both to assist when needed and to record the results. Only two of the techniques were actively used by staff: the expert scored landscape and the Least Cost Path analysis. These two were selected due to time constraints. Staff perceived the information contained in the rule based model to be less detailed and therefore felt an expert scored model could provide them with all the information they needed, and the same or more data than a rule based model.

Step one, model development was undertaken by planning staff, in consultation with Forestry Commission ecologists. During the model development process, conversations with Forestry Commission ecologists revealed that they were more comfortable with the scoring process this time, because they had more time, and so were able to consult the literature and other colleagues for answers. In the words of one ecologist: *"I'm less on the spot, I can email answers and we can talk about it by phone".* When questioned on the ease of accessing the scientific literature, and its usefulness to finding data for model construction, both ecologists expressed frustration at only being able to view abstracts of recent papers.

However, during step two, the model construction in GIS, extra variable classes became apparent and more scoring exercises had to be carried out. This was due to the availability of additional data in the Forestry Commission GIS system. Age class of trees was decided to be equally important as vegetation type, and was therefore included in the models. However, extracting this data from attribute tables, for each vegetation type, proved time consuming and difficult. During the building of the model in GIS, Forestry Commission planning staff required a great deal of support. Most misremembered how to undertake the various spatial analysis operations required. This is to be expected, when using new techniques after a small number of training sessions, however, it highlights the complexity of the process and the GIS software used to undertake it. When staff undertook the operations themselves, the process was extremely slow. After a full day, with most scores already prepared, the model was not complete. Two additional days and several part days were spent building the model. However, after this time several variable layers were still not complete and no overall, scored landscape had been created. Comments recorded during the model building process pointed towards the barriers to using the model: *"There isn't enough time without the phone ringing"; "I forget what stage I'm up to and have to start again"; "Everyone just thinks you've got time to chat and you can't get away from them"*; "*There's too many stages, I keep mixing up the layers".* Several staff, overwhelmed by the process and with other pressing commitments, requested the author create the scored landscapes for them. In one case, this was undertaken to enable the Least Cost Path analysis to be used in a Forest Design Plan with a tight deadline for public consultation. The results of this Least Cost Path were included in the final plan to support the development of a wildlife corridor for Pearl Bordered fritillaries. The inclusion of this Least Cost Path highlights the potential of the techniques to support the work of The Forestry Commission planners.

Less than half of the staff who took part in the training, completed the modelling process and ran the Least Cost Path themselves. Those that did were assisted throughout the process. Other staff did not complete the process. This was because GIS managers determined that enough time had been dedicated to learning the techniques, and undertaking them with the authors support. The staff's time was no longer available to focus solely on the modelling. Support and questioning about the process was continued through email and telephone contact with these staff. However, once staff returned to their normal work schedules, they did not find the time to complete the process.

5.3.4 REACTIONS TO THE MODEL RESULTS

In Wyre Forest, where the models were directly applied to provide scientific guidance to a reptile conservation project, the reactions to the model's outputs were surprisingly positive. Field staff, despite their initial scepticism about the process, and their reluctance to engage with it, were highly interested in the output maps and very willing to discuss the different habitat suitability maps and Least Cost Paths. Their reactions to each of the four techniques are described below.

5.3.4a Reactions to Results of the Predictive Species Distribution Model

Field staff described the results of the Predictive Species Distribution model MaxEnt as least valuable; *"we could have told you aspect is most important for snakes"* was the reaction of one member of staff on learning the results of MaxEnt's jackknife test of variable importance. However, these field staff believed south facing land was most important for reptiles, whereas the results of the analysis suggest that the greatest effect was due to the avoidance for north facing slopes. South, east and west facing areas showed little variability in their impact on the adders predicted distribution. However, field staff were interested in where the MaxEnt analysis predicted adders to occur, outside of currently surveyed areas. These results were deemed sufficiently plausible to warrant checking and three adders, previously unrecorded, were found. Sites with high predicted distribution have subsequently been included in the list of sites for the 2016 reptile survey.

5.3.4b Reactions to Results of the Rule Based Model

The results of the rule based model were shown to land managers and field staff in two stages: firstly the map of each rule, followed by the final rule based model derived output map.

Rule one on suitable vegetation types, provoked little reaction, as staff had previously agreed these vegetation categories. Rule two on habitat fragmentation created an interesting discussion, which promoted the creation of a new rule based model, to explore the effect excluding rides from the suitable vegetation categories. This was undertaken because the models suggested all suitable reptile habitat patches are connected (by rides), making reptile friendly ride management an obvious solution to habitat fragmentation. However, reptile friendly ride management is not possible across the whole of Wyre Forest, due to machinery and timing constraints. A new model was built to explore the effect on habitat fragmentation of current ride management. This request for additional modelling, demonstrated how examination of the results of the models, had changed their mind about the modelling process, to the extent that they wanted more information, and wanted to use the models to undertake virtual management experiments. The credibility granted to the output maps illustrated a phenomenon described by Beck and Suring (2009), who warn that output maps from models may create a greater sense of accuracy than is warranted.

Presentation of the map of rule three presented no significant reaction from staff, they were in agreement with the barriers between populations. Presentation of the rule four map, which determined three hectares as the minimum habitat patch size required to support a minimum viable population of forty individuals, led to a brief discussion, but staff were content that both experts and the literature seemed to agree on these figures. One staff member commented that 3 hectares was also required for woodland birds and this seemed to lend credibility to the figures used in the model and therefore the output map. The map of rule five on disturbance caused no significant discussion, because staff were in agreement with the impact of houses and the public on adders.

When the final rule based output map was presented to staff their reactions were surprisingly hostile. It was apparent that the final map, built from the application of the five rules, surprised staff by how little of Wyre Forest was determined to be suitable for reptiles. Field staff responsible for land management were reluctant to acknowledge that this could be the case, as loss of suitable habitat is an unpopular reason for adder decline amongst land managers. After the final map was shown, a discussion of the model rules began and staff found fault with the rule on habitat size, eventually suggesting that although a big population of adders might need so much space, it was not a requirement for the remaining adders in Wyre. Comments such as *"most of them in the forest are in tiny areas, ride edges, nothing like as big as that and they are fine"* illustrated how staff were avoiding blame for the decline of the species, by suggesting that adders do not need large areas of habitat. This conclusion was based on the logic that for many years they have seen adders, in the same small areas. As the purpose of this research was to understand the science-implementation gap by exploring the barriers and solutions within the Forestry Commission, the author remained neutral but supportive in tone, and suggested that the rules could be changed, and the size rule modified to any appropriate size. Staff were interested to see a new model with this rule, suggesting a high degree of confidence in modelling results.

5.3.4c Reactions to Results of the Expert Scored Model

Three habitat suitability maps based on expert scores were presented, one at a time, to land managers and field staff.

1. The first map was based on a landscape scored and weighted by experts, the environmental variables included were aspect, vegetation type, footpath density, size and proximity to disturbance.
2. The second map used same reptile expert scores, but also included an additional environmental variable, commercial constraints scored by land managers.
3. The third map included aspect, vegetation type and footpath density as scored by experts, but did not include size or disturbance, and incorporated weights based upon a separate MaxEnt's analysis (Chapter 3).

Reactions to these maps were more positive than the rule based habitat suitability map. Although at first, they were considered confusing, *"blimey!"* commented one staff member, referring to the mass of coloured squares. However the logic of green for good, red for danger, was clear to them and in this context they examined each map. Field staff found map two, the map which incorporated their views on constraints, as the most interesting and relevant. In order to prompt discussion of all three maps, the differences between the maps were presented, and people were asked what they thought, which was most realistic, most useful etc.

The familiarity of field staff with the study area meant they were easily able to relate the areas on the map, with the areas they corresponded to in reality. There was a great deal of discussion about "*Wimperhill*" and "*Dowles corridor*", local names for areas identified by the habitat suitability analysis as highly suitable. Field staff found the output maps useful, in fact, having spent around an hour and half in the office, looking at the results of the habitat suitability models, they decided to go outside to assess the potential for habitat creation in areas highlighted by the models as suitable for dispersal and highly suitable. The output maps were taken outside. Whilst comparing the areas identified by the models, with the areas on the ground, field staff were prompted to discuss the usefulness of the modelling technique. Staff asked questions about why certain areas had scored less well than others, and appeared on the output map as unsuitable for adders and an unlikely dispersal route, when standing in the area, it appeared to be suitable habitat. When it was explained that in that particular case it was likely to be due to the unfavourable aspect, field staff were sceptical that it would in reality be unlikely to be dispersed through and stated that they disagreed with the models results. However, for the most part, when visiting areas highlighted as highly suitable, there was agreement about the suitability of the area and agreement that reptile friendly habitat management between these areas would be beneficial.

5.3.4d Reactions to Results of the Least Cost Path Analysis

The habitat suitability scores created by both models were subsequently used as a proximal resistance values within a Least Cost Path analysis. Four Least Cost Paths were presented to field staff. The first on the rule based model landscape, the other three on the three expert scored landscapes described above. Again there appeared to be an assumption of credibility towards the four output maps, each showing a different Least Cost Path. Credibility was reinforced by discussion amongst staff on the similarity of Least Cost Paths. The rule based model path and the landscape including constraints were similar to each other, and the first expert scored path and the final expert scored path, were similar to each other.

The differences between these two sets of maps made sense to field staff, who recognised the avoidance of young conifer plantations in the Least Cost Path route of the landscape including constraints and the use of the former railway line by the Least Cost Path in the rule based landscape. The Least Cost Paths on the two similar expert scored landscape maps both travelled through the forest on a more meandering route strongly affected by aspect. When prompted as to the utility of the maps, field staff found the map including constraints and rule based map most useful. Staff were aware that the results of the models might be used to help determine where to create reptile habitat. If this involved felling conifers, it incurred costs and meant loss of income. The Least Cost Paths preferred by field staff avoided most areas of conifer plantation.

Field staff were very interested in the Least Cost Path maps and again, having spent time in the office examining the maps, they decided to go and walk and drive the four potential Least

Cost Paths, in order to explore the potential for habitat creation. It was already understood by field staff that they would be required to create open areas of suitable reptile habitat, a minimum of 3 hectares in size, no more than five hundred metres apart. The Least Cost Path maps enabled staff to look along these routes and decide where to create these habitat areas. Walking the routes of the Least Cost Path, staff came across open areas, favourably scored by the habitat suitability analysis as either dispersal or suitable habitat, which were slightly (<20 m) off the route of the Least Cost Path. Site managers decided to create new reptile habitat by increasing the size of existing open areas. This illustrated that despite apparent interest in the model outputs, site managers chose a pragmatic solution, based on their own decision making, rather than relying entirely on the recommendations of the model.

5.3.4e Technical Staff's Reactions to Model Results

Staff who completed the model construction process, and viewed the results of the model on their own data, found them useful. Comments from staff included: *"It backs up what you think"; "It gives you a reason for your decision making"; "It's good to show external partners why you're doing what you're doing"; "Its transparent, you can take people through the European protected species and justify management decisions"; "I can test the effect of PAWS restoration in different areas"; "I can use it to target habitat restoration where the model suggests potential can be enhanced".* Comments from staff viewing Least Cost Paths included: "*Not what we expected, but shows us where to punch through and connect rides*".

However, after creating a model using his own data and running the Least Cost Path analysis, one member of staff was disappointed by the results and became sceptical of the modelling tools. This was because the Least Cost Path largely followed rides, and therefore he felt the analysis had been time consuming and the answer was common sense. This highlights the need for sufficiently complex input data, to gain useful results from the model. In this case the landscape was very simplistic, constructed of large areas of conifer with high resistance values, and a ride network with a low resistance value.

5.3.5 SEMI-STRUCTURED INTERVIEW RESULTS

Eleven semi structured interviews were undertaken to explore specific barriers and solutions to the science-implementation gap. Every interviewee cited time and data constraints as a barrier, linked to both data requirements and data availability. Additional barriers reported included: lack of trust in the process (2), conflict with other priorities (2), process not meeting enough management needs (1), increase in existing workload (6), lack of access to training (2), organisational culture impediments (1), complexity of the modelling process (3) and modelling assumptions (1).

Possible solutions, discussed in terms of enabling staff to use the modelling techniques, illustrated that removal of time constraints, would have the greatest benefit to enable staff to use the tools. This was cited as a solution by seven staff members. Training and budget support were both cited as solutions by five interviewees. Three members of staff suggested some kind of implementation framework would help. Other solutions included organisational encouragement, policy support, partnership with a university and increased simplicity of models.

Interviewees were asked to rank the relevance of the techniques to their work, although the results were variable, permeability modelling and Least Cost Path were ranked as '*very*' useful by the majority of participants. Rule based modelling was ranked as less useful than expert scored modelling and species permeability modelling was ranked as '*moderately*' useful. The most useful applications of the Least Cost Path modelling were cited as *"exploring networks and linkages at a landscape scale"; quantifying opportunities"* and *"where there is a conflict of interests"*.

The most useful applications of the permeability modelling were described as "*for European protected species"; "for removing guesswork in conifer removal and habitat creation"; "clear and transparent process"; "strategic planning tools"; "for option testing"* and *"justifying management decisions"*. The most useful applications of the predictive species distribution modelling were: *"determining where to concentrate efforts"* and *"connecting ecological theory with practise"*.

5.3.6. QUESTIONNAIRE SURVEY RESULTS

In response to question 1: ***Does your role include conservation management / planning?***
All 45 respondents stated they were involved within conservation planning and management.

Question 2 sought to understand which scientific tools practitioners used: ***Which scientific or other techniques do you use to support your decision making?***

All respondents stated that they used scientific or other techniques do you use to support their decision making. The techniques most commonly used by practitioners were survey 98% (n44), stakeholder consultation 82% (n37) and best practise guidance 80% (n36).

Table 5.1 Results of Question 2

Decision Making Tool	Number Using	% Using
Survey	44	98%
Policy documents	29	64%
Best practise guidance	36	80%
Stakeholder consultation	37	82%
Species modelling	9	20%
Scientific Journals	14	31%
GIS	19	42%
Landscape modelling	11	24%

A Chi-Square was performed on the results to determine whether the variation in practitioner's choice of decision making tool was significant. The test statistic is 749.40, significantly larger than the expected chi-square distribution (24.322) even when p = 0 .001, 7 df. Therefore the null hypothesis, that all decision making tools are equally popular is rejected.

See appendix 5.3 for all Chi-Square calculations.

Questions 3 and 4 assessed practitioner's awareness and use of the modelling techniques used within this research. ***Are you aware of the uses of these techniques? Do you currently use any of these techniques?***

Table 5.2 Results of Questions 3 and 4

Modelling Type	No' aware of the techniques	% Known	No' using the technique	% Used
Species Specific Rule Based Modelling	16	35%	7	15%
Landscape Permeability Modelling	20	45%	16	35%
Predictive Species Distribution Modelling	31	70%	20	45%
Least Cost Path Modelling	11	25%	9	20%

Chi-Square tests were performed to determine whether the variation in practitioner's knowledge and use of decision making tools was significant. The Chi-Square assessing variation in practitioner's awareness of the different tools found the test statistic of 43.49 significantly larger than the expected chi-square distribution (16.266) 3 df, with a p value of 0.001. Therefore the null hypothesis, that all decision making tools are equally well known is rejected.

However, the Chi-Square examining variation in practitioner's use of the different modelling tools found the test statistic of 11 to be smaller than the expected chi-square distribution (16.266) when p = 0.001, 3df. Therefore the null hypothesis, that all decision making tools are used equally cannot be rejected. This reflects the high level of use of rule based modelling by the individuals who were aware of the technique.

Question 5 attempted to explore whether respondents felt additional modelling tools, beyond what they currently use, could support their management and decision making: ***Do you feel use of any of the techniques you don't currently use, could support your conservation management decision making?***

71% (n 32) of respondents felt they didn't know if additional tools could help them, or stated that they might be occasionally useful.

Question 6 explored barriers to use of the techniques: **What prevents you from using the techniques?** The question encouraged respondents to tick as many as options as were applicable and included an 'other' category for their own suggestions.

Table 5.3 Results of Question 6

What prevents you from using the techniques?	**Number**	**%**
Not aware of the techniques	24	54%
Usefulness of technique unproven	9	20%
Lack of training in use of technique	18	40%
Lack of access to scientific literature	4	10%
Not relevant to my role	2	5%
Belief workload will be increased	0	0%
Organisational culture impedes use of technique	0	0%
Lack of trust in results or modelling process	4	10%
Lack of interaction between scientists and conservation managers	7	15%
Time constraints	11	25%
Funding constraints	9	20%
Assumptions of the model	2	5%
GIS software not available	0	0%
Data requirements	13	30%
Data availability	9	20%
Complexity of techniques	7	15%
Not a priority within my organisation	9	20%
Other *(please state)*	0	0%

The barriers most commonly cited by practitioners as preventing them from using the techniques were not being aware of the techniques (n 24) and lack of training in use of technique (n 18).

Question 7 asked participants about implementation solutions: **Would any of the items below enable or encourage you to use these techniques?** The question also encouraged respondents to tick all applicable options and included an 'other' category for their own suggestions. The solutions most commonly cited by practitioners as potentially enabling or encouraging practitioners to use these techniques were "*Usefulness of technique proven* " 54% (24), "*Provision of training in techniques* " 49% (22) and "*Increased budget*" 49% (22). The Chi-Square assessing variation in applicability of solutions to practitioner's use of the tools presented in the literature, found the test statistic of 754.43 significantly larger than the expected chi-square distribution (36.12) even when p = 0 .001, 14 df. Therefore the null hypothesis, that all solutions suggested in the literature could encourage the use of tools equally is rejected.

Table 5.4 Results of Question 7

Would any of the items below enable or encourage you to use these techniques?	No' of Respondents	% Respondents
Awareness of techniques	18	40%
Usefulness of technique proven	24	54%
Training in techniques	22	49%
Access to scientific journals	15	33%
Provision of time to use techniques	18	40%
If organisation encouraged use of these techniques	13	30%
Their ability to support management decision making	7	15%
Increased time available	16	35%
Implementation frameworks	2	5%
Increased budget	22	49%
Policy support for techniques	9	20%
Simplification of technique	7	15%
Partnership with university	13	30%
Support from researchers	9	20%
Other	0	0%

Question 8, the final question was open ended and asked participants for their opinion on what would enable conservation research to support conservation practitioners: **What do you think would enable conservation research to support conservation practitioners?**

The answers were coded and grouped into the six categories defined within the literature review, these are discussed in section 5.4. The most common responses were funding, access to relevant data, partnership work and specific responses about research topics which would benefit practitioners. These included more research on: insects to enable justification of invertebrate survey; bird collision with buildings; building design; habitat associations of invertebrates; bat foraging behaviour in terms of temporary roosts; dormice movements; fish migration; and human disturbance impacts.

5.4 DISCUSSION

The results of the micro ethnographic case study and questionnaire survey are discussed in terms of the barriers and solutions described by the literature to the science-implementation gap (relevance, interdisciplinarity, access to scientific data, reward, training and resource constraints). Data from the questionnaires and semi structured interviews, observation, field visits, phone and email conversations within the case study was coded, based on these themes, to enable discussion of the data and contribute to the development of these theories.

5.4.1 RELEVANCE

Relevance appeared as a potential barrier on several occasions during the research, discussed here in chronological order.

Field staff demonstrated high levels of scepticism towards the relevance of the modelling tools. This was due to their perception of knowing the forest very well, and therefore a modelling tool was irrelevant and not necessary to assess habitat suitability in the forest. This presents an obvious barrier to use of a tool and implementation of its results. However, despite their initial perception, field staff found the results of the tools relevant and subsequently used them to make habitat management decisions.

When technical staff were introduced to the modelling techniques, the relevance of the Least Cost Path (LCP) technique was questioned by planners who were sceptical about the ecological theory which Least Cost Path analysis is built on. This highlights how for tools to be adopted, end-users need to accept the underlying science, assumptions and theories which have led to their development. Without this the tools risk being perceived as inaccurate, and therefore irrelevant, to practitioner's work, which could present a significant barrier to their implementation.

An interesting occurrence, linked to the relevance of model results was highlighted when field staff walked the routes of the Least Cost Path (LCP). They decided to create some of the new reptile habitat by increasing the size of existing open areas, which were within 20m of the LCP, rather than placing these new open habitats along the exact route of the LCP illustrated by the model. Staff used the models results as a basis for pragmatic decision making on the locations for habitat creation. However, they did not feel restricted by the results, or that the new habitat needed to be exactly along the LCP. This is appropriate firstly because using a different approach, such as least cost corridor, the areas chosen would have been within a 30-50m wide corridor and secondly because models are designed to be useful tools, not straightjackets. Not implementing their exact recommendations does not make models irrelevant, but demonstrates how a flexible approach, including practical considerations can make research implementation more likely.

One member of technical staff questioned the usefulness, and therefore relevance, of the results of the LCP after using it on his own data set, which was too simplistic to yield a useful analysis. Although understanding of how the LCP functions makes this result predictable, the disappointment highlighted that when using a modelling tool, especially when it is perceived to be complex, users can have very high expectations, believing the model able to answer almost any question and provide definitive guidance. In reality, models are simply additional tools, designed to explore options and assist decision making, and the caveats and assumptions of the model need to be considered when examining their outputs.

There was a significant difference in how the relevance of model outputs were judged by technical and field staff. Technical staff, having used the technique and gone some, or all of the way to producing their own outputs, were aware of the limitations of the data and model assumptions. They regarded the outputs as useful, but were able to question them. However, field staff, who had been sceptical about the need for modelling and questioned the relevance of it, but had not used the techniques themselves, demonstrated a high level of trust in the model outputs. They appeared to find the output maps highly credible. Despite explanations of the assumptions in the process, field staff were strongly influenced by model outputs. In this, the case study supports the findings of other studies, such as Beck and Suring (2009) that output maps often create more certainty than they may warrant.

The importance of relevance as an implementation barrier was indirectly inferred by the questionnaire survey responses from conservation agencies. The scientific techniques most commonly used by practitioners were survey 98% (n44), consultation 82% (n37) and best practise guidance 80% (n36), suggesting these are the most relevant data sources for conservation practitioners.

Overall, relevance of the techniques did not seem to be a barrier within the case study, analysis of interview data illustrated that staff ranked the techniques as '*very*' (80%) to '*moderately*' (20%) useful. It is important here to note that the aims of the model and the research questions were developed based on the needs of Forestry Commission staff, therefore the research itself was designed around applied questions and inherently relevant to staff. Relevance is usually presented as a barrier by the literature because most conservation research does not source questions from practitioners and therefore, is not designed around their information needs and is unlikely to be relevant to conservation practitioners.

5.4.2 INTERDISCIPLINARITY

Interdisciplinarity presented little barrier to the use of the models by Forestry Commission staff due to the design of the research which . Staff felt able to access skills from other disciplines when they needed them. Forest Design Planning is already interdisciplinary in nature: planners, ecologists, archaeologists, foresters, local historians and local interest groups work together to develop the plans through long term consultation and development processes. The familiarity of planners with drawing experts from other disciplines into their decision making processes, was apparent in the suggestion by planning staff that Forestry Commission ecologists should provide data for the modelling process. Planners were confident the data could be made available by persons with different expertise to themselves. Model development would therefore be multidisciplinary, staff envisaged creating a centrally accessible database of species data. There were no apparent barriers to the use of ecologists to supporting planning staff, this was considered normal practise, showing evidence of multidisciplinary approach to problem solving which has been suggested as a solution to the implementation gap by other authors (Wendt and Starr 2009; Likens and Lindenmayer 2012).

Interdisciplinarity was touched on within one interview, when partnership with universities was raised as a solution to help the organisation adopt the techniques. This was explored more fully with all participants in conversation during model development sessions. All participants felt that this had potential to address their specific research questions and would support implementation of model results, if it enabled others to build and run the models for them. 30% of questionnaire respondents from other conservation agencies also suggested partnership with university would encourage the use of modelling tools. The idea of partnership between a conservation agency or land manager and scientists within a university is suggested by numerous authors as a solution to increasing relevance of research, improving science communication and supporting implementation (Tallis *et al.* 2010; Agrawala *et al.* 2001; Miller 2001). This case study provides additional evidence to support the theory that interdisciplinary partnerships, in which research aims are developed by diverse scientists and practitioners working together, could help overcome the research-implementation gap.

Questionnaire responses from conservation practitioners cited social issues such as land ownership, funding constraints and *willingness to conserve* (Knight 2008), as important in their work, highlighting the need for interdisciplinary science, in which conservation project aims incorporate both social and ecological understanding. This supports theories which suggest implementation requires the inclusion of social data in modelling (Redpath *et al.* 2013, Knight et al. 2008).

5.4.3 COMMUNICATION & ACCESS TO DATA

Access to scientific literature was raised as a barrier within both the case study and questionnaire survey. Within the case study, only three members of staff had heard of any of the techniques, and no one had any experience of using them, despite them being well established with the research community. Access to scientific literature as a barrier was also seen in the frustration of ecologists trying to provide data for the models. Forestry Commission ecologists only have access to freely available, open source journals and the Forestry Commission’s own journal, not all existing published research. Journals requiring a subscription, which include some of the most highly regarded, such as Journal of Applied

Ecology and Biological Conservation, are not available to conservation practitioners, although some allow content to be viewed once it is older than 1 or 2 years. Not being aware of the techniques and lack of access to scientific literature were cited by 54% (n 24) and 10% (4) of questionnaire survey respondents as barriers to use of models. Similarly, 33% (n 15) cited access to scientific journals as solutions which would encourage their use of scientific tools. The potential for access to scientific information to support implementation may also suggested by the finding that predictive distribution modelling was both the best known modelling technique 70% (n 31) and most frequently used technique 45% (n 20). Although this may suggest knowledge of the techniques increases their use, LCP modelling was least well known 25% (n 11), however, it was not the least used technique.

Communication as an implementation barrier also became apparent in a way not described in the literature; related to how open-plan office structures change communication patterns, to create difficulty for staff carrying out complex, time consuming tasks, which require a high level of concentration. During the case study staff described the reduction in quiet time necessary for concentrating on difficult tasks: "*if I was in my office I'd never be able to do this, there'd be someone coming in and talking to you or the phone ringing"; "then I'd lose what I was doing and have to start again and never finish it".* This may be an underestimated barrier to the use of complex scientific tools in conservation organisations, which due to budget constraints often operate in small, overcrowded or open plan offices.

The case study also highlighted communication in terms of social capital, and partnerships between universities and conservation agencies as a possible solution to the research-implementation gap. Forestry Commission staff had difficulty finding the data required for model parameterisation, and they did not have the time resource to use the modelling techniques themselves. Time limitations and financial barriers such as computer licences, could be overcome by partnership projects, in which novel, applied research is undertaken to improve conservation management and provide data. The development and success of such partnerships requires effective communication and high levels of social capital (Lauber *et al.* 2011).

5.4.4 REWARD

Within the case study, lack of reward became apparent as a barrier due to the perceived increase in workload using the models would cause. More than half of the staff involved cited this as a barrier during interviews. Reward was also highlighted indirectly, by the potential for partnerships between universities and conservation agencies to overcome the research-implementation barrier. Currently there is little reward for academics to engage with conservation practitioners because the time taken to build partnerships may act as a disincentive (Burns *et al.* 2014). Although partnerships and applied projects, can lead to publishable work, partnership work is slower than independent work, and therefore may offer a competitive disadvantage to academics. Additionally, interdisciplinary work, developed in partnership with scientists and professionals from a range of diverse sectors is less likely to be published (Tress & Fry 2005). However, research funders are increasingly requesting '*impact case assessments'*, in which grant applicants must describe how their research will be useful. Funders requesting, evaluating and publishing these '*conservation* outcomes' may increase the implementation of conservation science, but these do not require the involvement of conservation agencies, the formation of research in partnership with conservation professionals, or addressing applied conservation problems. Examination of the impact case assessments published by Research Councils UK and the University of Oxford illustrate that even research with potential to be applied to real world problems is still largely undertaken without the direct involvement of conservation agencies (Oxford university 2015; Research Councils UK 2015). So much so, that one academic created a conservation agency in order to implement his work (Research Councils UK 2015). Until research is rewarded for its implementation and funders require a percentage of research to be carried out in partnership with practical conservation agencies, applied conservation research will remain a minority research practise.

5.4.5 TRAINING

Without training the techniques are too complex to be adopted by conservation organisations. Training support was cited as an implementation solution by only five interviewees, however, during the case study it was apparent that training was essential for all staff, as none were able to use the tools, interpret the results or understand the limitations and assumptions without training. Training in the use of techniques was also cited by 49% (n 22) of questionnaire survey respondents as likely to increase their ability or willingness to the modelling techniques. This supports the findings of other authors who also suggest training could help enable research implementation (Knight *at al.* 2006; Gerhardinger *et al.* 2011; Newing 2010).

Interestingly however, the case study and results of questionnaires to conservation organisations, reveal that provision of training in the tools is not enough. Conservation organisations (due to their limited resources) undertake a training cost:benefit analysis; the perceived benefits must be greater than the time and resource cost. Conservation managers may limit training (as seen in the Forestry Commission case study) or not permit staff to undergo training, if the benefits are unknown: for example because there is insufficient evidence on the applied use of the tools or no knowledge of the tools. 40% (n18) of conservation practitioners cited awareness of techniques and 54% (n 24) suggested having the usefulness of technique proven, would encourage their use. This supports the work of Hall and Fleishman (2010) who suggest that cost of implementation should be assessed in real-world conditions. Such "*real-world assessment"* would provide an evidence base of applied research using the techniques, and illustrate which situations the benefits of the techniques outweigh their costs, thereby making them more likely to be implemented.

5.4.6 RESOURCE CONSTRAINTS

Budget support was cited as an implementation solution by five staff within the case study and during interviews and increased budget cites by 49% (n 22) of questionnaire respondents. Financial constraints meant the GIS Spatial Analysis tools necessary to use modelling tools, were not available to Forestry Commission staff, even though it is large and well funded in comparison to most other UK conservation organisations. This highlights that despite budget constraints being raised by less than half the interviewees, it is a significant implementation barrier.

Time was also raised as a severe resource constraint. 100% of staff in the case study and 35% (n 16) of questionnaire respondents suggested lack of time is an implementation barrier. Staff suggested that if the forest planning process could be streamlined, they would have more time for the inclusion of the modelling techniques. They debated whether modelling should be a separate job for somebody, with data provided to forest planners. Although positive about the technique, concerns about using and implementing the models mainly reflected the time constraints staff face. The long time period it took Forestry Commission staff to complete the model building in GIS was due other elements of work intruding into time allocated for modelling, mistakes were made, the techniques were unfamiliar. However, model development, building and running is a slow, time consuming process, therefore, its inclusion, into already full existing roles, is unrealistic without significant support or reduction of other work.

5.4.7 CAVEATS

This case study was focused on the implementation of specific conservation modelling techniques, rather than the general implementation of all types of conservation research.

As a former employee it is possible the author's opinions of the organisation could bias the results. However, great care was taken throughout the case study and analysis of data, to remain aware of biases and personal beliefs, in order to prevent these from affecting how data was coded and interpreted. It's also certain that the attitude of the person who presented the modelling techniques and trained staff in their use, would affect the way the techniques were perceived by staff, and their enthusiasm towards them. However, the very different reaction of the two groups of staff, field staff and technical staff, suggests that the techniques were delivered in a neutral way, without bias, and the reactions and attitudes of staff reflected their own understanding of them, and their relevance to their role in the organisation, rather than the attitude of the person presenting them.

This research was carried out within a single organisation. Although all staff involved in GIS and conservation management were included in the case study, this still represents a small, inclusive sample. Lack of access to staff, budget and time constraints prevented this research from covering all Forestry Commission districts. However, further work could assess whether these barriers are present across the entire organisation.

5.4.8 CONCLUSION

This research demonstrated empirically that the modelling techniques can provide useful scientific data for conservation projects carried out within a real organisation. The results of the models were implemented in Wyre Forest to increase connectivity by creating new reptile habitat and to support habitat connectivity within a Forest Design plan in Holman Forest. The tools were acknowledged as highly relevant and useful within the organisation However, none of the tools were adopted by the organisation. Forestry Commission staff were not able to incorporate using modelling tools into their work because of time constraints.

Two of the solutions in the literature: funding and changes to institutional structure, may be able to overcome time constraints, which proved to be an insurmountable barrier to adoption of the tools in this case study.

Increased funding has potential to overcome the time constraint barrier through employment of persons able to use scientific tools on behalf of conservation practitioners. Within the Forestry Commission, currently subject to budget cuts, and within most charitable conservation agencies, funding permanent, internal scientific posts may not be a realistic option. It is likely that conservation agencies able to afford internal science departments (e.g. RSPB) already have these, and those which do not are unable to afford them.

Changes to institution structure to increase contact between conservation researchers and practitioners is suggested by Cook *et al.* (2013). This research concludes that such changes to institutional structure and research institution conservation agency partnerships have the capacity to overcome time constraints. However, it is stressed here that the case study provided strong empirical evidence for the importance of social capital, without which formal links or embedding scientists in conservation organisations may not lead to implementation. The author established professional but friendly relations with all Forestry Commission staff involved in the case study to facilitate communication. The social capital this developed had highly significant benefits and directly enabled the implementation of results. The Forestry Commission has an internal department which also undertakes landscape permeability modelling (see Watts *et al.* 2014). Much of this research is related to applied conservation issues, however, it is not currently used with the Forestry Commission West District. No staff or GIS managers involved in the case study were aware of the modelling research undertaken by their own organisation. No staff had used any of the Forestry Commission's modelling research in their work. The existence of published work, from within the same organisation, which fails to inform conservation practise is a powerful illustration that without social capital and direct personal engagement, research is unlikely to be implemented. Numerous researchers have demonstrated that good relationships between scientists and decision makers creates the social capital (trust, respect and cooperation) required for implementation (Lauber *et al.* 2011; House 2010; Gibbons *et al.* 2008; Farley *et al.* 2010) and Leith *et al.* (2014) argue that is it possible to identify "*appropriate processes, institutions, objects (e.g. tools, information products) and relationships"* which enable research implementation. This research concludes that social capital is a fundamental and essential part of the communication required for research implementation.

Social capital provides the high level of support required by conservation professionals in order to use and adopt scientific tools. The author was able to work with the organisation through every step of the process '*hand-holding'* staff, in order to build acceptance of the tools and trust in results, and finally to train staff in the use of the tools. Without this support implementation is unlikely to have occurred. The necessity of high levels of support to change behaviour is well recognised in other fields (Houghton 2013; Cohen 1983; Beer 1990; Davenport 1998; Young and Jordan 2008; Romer and Hornik 1992; Noe 1986). The level of support provided within the case study could be replicated by interdisciplinary partnership with a research institution or the institutional frameworks suggested by Cook *et al.* (2013).

The case study also illustrated that all the barriers suggested in the literature could potentially prevent implementation and adoption of the models. However relevance; interdisciplinarity; communication and access to scientific knowledge; training; and reward did not present problems due to the design of the case study. To illustrate: questions were sourced from practitioners, thus were inherently relevant. The research involved ecologists, foresters, planners, social and economic constraints and therefore prevented the common problem of results not being implemented because they have not been developed through interdisciplinary partnerships which acknowledge the complexity of real-world conservation. Communication and training were enabled through the placing of a scientist (the author) into a conservation organisation, and crucially the building and maintenance of high levels of social capital. Reward was also inherent within this research because the author benefitted from undertaking the research through its contribution to this thesis. This suggests that research design could overcome many potential barriers to implementation and provides evidence that many of the solutions suggested in the literature can contribute to implementation. Sourcing of research questions from conservation practitioner is suggested by many authors (Matzek et al. 2014; Sayer *et al.* 2013; Laurance, *et al.* 2012; Milner-Gulland *et al.* 2010; Farley 2010; Sutherland *et al.* 2004, 2009). The potential for interdisciplinary research to support implementation is also frequently highlighted (Matzek et al. 2014; Barmuta *et al.* 2011; Redpath *et al.* 2013). The benefits of adaptive management (Benson and Stone 2013) were also demonstrated because implementation of results relied on changing and adapting models according to needs as they developed.

Adoption of techniques is often the aim of modelling studies which develop techniques applicable to conservation problems such as habitat fragmentation. However, the results of this research suggest *model results* are more likely to be implemented, than the tools themselves adopted. The preferred solution of Forestry Commission staff was for a research agency to use the tools on their behalf and supply them with results. This provides further support for the importance of relationship building with conservation practitioners, and the sourcing of research questions from them to improve implementation of research. A further important implication of this is that scientists could increase research implementation by using techniques to solve specific problems faced by practitioners, instead of focusing on encouraging the use of techniques or refinements to techniques. It is likely the development of increasingly sophisticated techniques, would be supported by the use, adaptation and subsequent development of techniques to resolve applied problems.

The validity of these conclusions was assessed in two ways. Firstly, they were discussed with staff involved in the case study to see whether or not they agreed with the interpretation of the findings. Staff agreed that links with research scientists could help overcome the time constraints. All staff agreed that communication, social capital and adaptive management (which incorporated different scales and objectives) helped implementation.

Secondly, to help assess the reliability and potential generalisation of the results of this case study research, a questionnaire based on its findings was designed and distributed to other conservation agencies in the UK. As described above, many of barriers to implementation seen within the Forestry Commission were also cited by other conservation organisations. The solutions with the greatest potential to support the Forestry Commission's use of the techniques: funding, partnership with research agencies and support from researchers were respectively suggested by 49% (27), 30% (n 13) and 20% (n9) of questionnaire respondents from other conservation organisations.

5.4.9 RECOMMENDATIONS FOR FURTHER RESEARCH

The findings of this case study suggest that further research to develop an evidence base for the tools, may support their implementation**.** 54% of responses from a diverse range of conservation organisations, suggest that conservation practitioners would be more likely to adopt the modelling techniques if there was clear evidence available for their usefulness. Therefore, further research, applying the techniques within conservation projects, would help to create an evidence base to convince practitioners of their usefulness, applicability and relevance. This evidence base might also provide support, in terms of cost:benefit analysis, training conservation staff in the use of scientific techniques, such as modelling.

Further research into the type of organisational structure most effectively able to support communication and the development of social capital between researchers and practitioners might also support implementation of conservation science and research into social capital: What communication styles best support development of trust, respect and cooperation? How often must communication occur to maintain social capital?

In addition, case studies within some of the conservation agencies which took part in the questionnaire survey, would allow detailed exploration of their answers and assessment of whether the issues in the Forestry Commission are wide spread.

Another case study within the Forestry Commission itself, exploring the use and adoption of other research techniques, could help assess the reliability and replicability of this study's conclusions on the use and adoption of landscape permeability modelling techniques.

CHAPTER SIX
CONCLUSION

6.1 INTRODUCTION

Landscape Permeability and Predictive Species Distribution modelling are well established within conservation research and proposed as tools to address numerous applied conservation problems (Teixeira *et al.* 2014; Klimek 2014). However, the persistence of the research-implementation gap means few conservation agencies in the UK actually use these tools to guide their work (Guisan 2013). The literature describing the reasons for the research-implementation gap stretches from the development of conservation science (Soule 1986) to the present day (Gossa *et al.* 2015), yet it is inconclusive, with a wide range of implementation barriers described as causes for the gap and numerous diverse solutions proposed to overcome it.

This research aimed to investigate whether Landscape Permeability and Predictive Species Distribution modelling research could benefit an applied *Vipera berus* conservation project run by the Forestry Commission, an organisation not currently using these tools. It also sought to understand the effect of the research-implementation barriers and solutions described in the literature on implementation of modelling results and the adoption of these tools. This chapter provides a synthesis of the empirical findings of the study, with respect to the individual research questions, and describe the implications for conservation practice and conservation research policy of this research. In addition it describes opportunities for further research, in light of both the limitations of this study and the implications of its findings.

6.2 SUMMARY OF FINDINGS

The main empirical findings are presented within the respective empirical chapters: 3. Modelling *Vipera berus* in Wyre Forest; 4. Landscape Permeability Modelling; and 5. Case Study: Applicability Of Modelling Techniques. Here these empirical findings are synthesised and discussed in terms of how they contribute to the existing understanding of the research-implementation gap.

- The first objective of this study was to determine which environmental variables explain adder distribution in Wyre Forest and locate adders in unsurveyed areas. The results of the model demonstrated that adder distribution is primarily based on avoidance of north facing areas, and secondarily to vegetation type. Disturbance and footpath density had little effect on adder distribution in Wyre Forest. Modelling identified and mapped sites with a 75% probability of adder occurrence which are not currently included in the annual reptile survey. This led to the discovery of previously unknown adders, and the model data was used to redefine the locations covered by the annual adder survey.

- The second objective of this study was to evaluate habitat suitability and connectivity in order to inform habitat restoration and adder reintroduction in Wyre Forest. Model results enabled evaluation of habitat suitability, and illustrated considerable similarity in the quantity and location of habitat defined as suitable. Expert-derived and rule based models suggested 100ha and 112ha respectively. The expert-derived model identified precise locations of optimal habitat for adder reintroduction and dispersal habitat between suitable habitat for habitat restoration.

- The third objective of this study was to explore how applicable the results of ecological modelling exercises are in a UK conservation agency setting, as exemplified by the case of Forestry Commission. The results demonstrated that the modelling exercises were applicable to the Forestry Commission's adder conservation work. Results were used to inform and change conservation management of Wyre Forest to benefit the species. Analysis of interview data illustrated that 80% of Forestry Commission staff ranked the techniques as '*very*' useful.

- The final objective of this study was to explore the barriers and solutions to research implementation and adoption of techniques. Most barriers described within the literature were encountered and it was clear that these barriers could potentially prevent the implementation of modelling results and adoption of the techniques in the organisation. However, due to the research design these did not prevent implementation of modelling results.

- The research's results demonstrate resource constraints, specifically time, are the main barrier to the Forestry Commission adopting the modelling techniques.

- Implementation of modelling results was more important to staff than the adoption of the tools themselves. Forestry Commission staff's preferred implementation solution was for a research organisation to undertake modelling on their behalf and provided them with data and solutions to the applied problems they face within their work.

- Two of the solutions suggested in the literature: funding and changes to institutional structures to connect scientists and practitioners, have potential to support research implementation in the Forestry Commission because they could both overcome the time constraints which prevented the organisation adopting the tools.

- This research suggests that research design can overcome the implementation barriers described in the literature and suggests that the majority of the research-implementation barriers, concerned with relevance, interdisciplinarity, training, communication and access to scientific knowledge, are not in reality barriers, but the *effects* of research which is developed and undertaken without the involvement of conservation practitioners.

- Possibly the most significant finding was the importance of social capital, without which links between scientists and conservation organisations do not lead to research implementation.

6.3 EVALUATION OF THE METHODOLOGY

Here the three ecological modelling tools; species distribution modelling, rule based and scored landscape permeability modelling, and the two social research methods; case study and questionnaire, are evaluated in terms of their ability to answer the research questions, provide insight into the research implementation gap. In addition, the external validity of the research, findings of other studies, data quality and software limitations are discussed.

Predictive Species Distribution modelling was a satisfactory tool and able to achieve the first objective of the research. Understanding of how these environmental characteristics affect adder distribution led to the designation of two reptile corridors in Wyre forest, and allowed land managers to use limited resources more effectively by understanding where management could and could not improve habitat suitability. The model results were therefore able to inform where to create habitat and where adder reintroduction could be most successful. However, the methodology is complex, time consuming, requires high level GIS skills. There were issues over data availability, as valuable data for reptile distribution modelling, such as hibernacula locations, vegetation structure, microtopography and meadow management were not available. Despite this, the models appeared to be robust and accurately predicted reptile occurrence in Wyre Forest. Validation via a persistence evaluation illustrated a strong spatial overlap between areas predicted to be suitable where reptiles are currently found, and areas predicted to be unsuitable where reptile populations have been lost.

The Landscape Permeability and Habitat Suitability modelling tools were satisfactory and able to achieve the second research objective. The results of these modelling tools had several management implications, which were subsequently implemented. These included; the identification of priority rides for reptiles, changes to ride management, and the creation of new reptile habitat patches 3 ha in size spaced 500m apart along the route of the Least Cost Path. One of the advantages of the modelling tools was their flexibility, which enabled exploration of a variety of habitat management options, and proved very valuable for land managers since it directly supported implementation of results. However, both modelling processes require advanced GIS skills. Rule based modelling is less complex, and can be undertaken more rapidly than the expert scored approach. Both approaches were able to identify the extent and arrangement of potentially suitable habitat, and suggested similar amounts of suitable habitat exist. The rule based approach was able to specifically identify barriers and connectivity more precisely than the expert scored model. However, it could not define optimal or dispersal areas within suitable habitat, because it categorizes the landscape in a simplistic, binary fashion into suitable or unsuitable habitat. Whereas the scored approach was able to identify five habitat categories including optimal, suitable, dispersal, unsuitable and high risk, through its more complex scoring approach, and therefore provided the data required by land managers more effectively than the rule based modelling approach.

Case studies are the "*preferred strategy when 'how' or 'why' questions are being posed, when the investigator has little control over events, and when the focus is on a contemporary phenomenon within some real-life context*" (Yin 1994). The case study technique was able to explore the barriers and solutions to research implementation within the Forestry Commission, it enabled the development of a detailed understanding of the organisation and the effects of implementation barriers and solutions within it.

The main disadvantages of case studies are; that the data collected cannot necessarily be generalised, bias in data collection or the so called "*Pygmalion effect"* whereby researchers influence results (Jussim 2015), and it is also very difficult to determine definite cause and effect from case studies. In order to overcome difficulties of construct validity within the case study and understand the wider applicability of the case study findings, a questionnaire based on the results of the case study was developed to explore whether the same implementation barriers and solutions could affect other UK conservation agencies. The questionnaire method provided valuable results which supported the validity of the case study's conclusions and suggests the findings may be generalisable to other organisations. For example, within both the case study and the questionnaire, highly significant implementation barriers included not being aware of the techniques (54% n 24) and lack of training in the technique (40% n 18).

However, questionnaires have several disadvantages when compared to case studies. The questionnaires were distributed by email, therefore questions could be interpreted differently by respondents, and the balance between open and closed questions to encourage potential respondents to complete questionnaires meant that all answers were not fully explained. Therefore the reason for a trend may remain unclear, for example, the reasons for practitioner's choice of modelling tool were not determined by the questionnaire data.

The implementation of modelling results from this research, within an organisation which was unaware of the modelling research carried out by its own internal research department and therefore not using this to inform their work, despite this work being published in highly regarded journals (see Stevenson-Holt and Watts *et al.* 2014; Moseley *et al.* 2013; Bocedi *et al.* 2014; Eycott *et al.* 2011), provides powerful empirical evidence for the importance of interpersonal communication and social capital in research implementation. This research suggests that social capital is crucial to research implementation. One of the major findings of the case study; the value of direct communication between conservation practitioners and scientists, and the critical importance of social capital for successful communication and research implementation, is also validated by the findings of other authors over the last 15 years (Guerrero *et al.* 2013; Bodin and Crona 2009; Hahn *et al.* 2006; Carberry *et al.*, 2002; Guston *et al.* 2000).

External validity for the importance of social capital is also provided by the questionnaire results. The most frequent suggestions of questionnaire respondents to increase their implementation of modelling results or encourage adoption of modelling tools, were all based on increased communication between practitioners and scientists. These included: "*usefulness of technique proven"* 54% (24); "a*wareness of techniques"* 40% (n 18); and *"training in techniques"* 40% (n 18). These findings illustrated the same phenomena as seen in the research of Hart and Calhoun (2010), in which face to face communication of research results led to implementation, whereas publication in highly regarded journals did not lead to research implementation, or even awareness of the research. Therefore, the findings of this research support the argument made by other authors (Cook *et al.* 2013; Addison *et al*. 2013), that publication in scientific journals is not enough to support implementation of results. Similarly to other research, this research proposes scientists should initiate a proactive dialogue with conservation organizations (see Laurance *et al.* 2012; Milner-Gulland *et al.* 2010). Other authors have also recommended scientists use additional communication methods to reach wider audiences (Milner-Gulland *et al.* 2012; Cook *et al.* 2013). Studies have also suggested communication between scientists and decision makers is particularly critical in the case of adoption of modelling tools and implementation of results (see Schwartz *et al*. 2012; Addison *et al*. 2013).

This finding of this case study regarding the relevance and applicability of the research questions i.e. developed in conjunction with practitioners, if the results are to be implemented, supports the findings of other authors who suggest that sourcing questions from practitioners supports the implementation of research (see Bruelle *et al.* 2015; Matzek et al. 2014; Dicks *et al.* 2014; Bloor *et al.* 2013; Sutherland et al. 2011, 2009).

This case study found the models' ability to explore different management options most useful to practitioners, and led to practitioners implementing the results. The wider applicability of this is suggested by its similarity to the findings of Smith *et al.* (2014), who also suggest conservation research should compare the effectiveness of management interventions in order to be implemented.

The other significant implementation solution raised by the case study was additional financial resources. This was in order to provide more time, via recruitment of additional staff members to either undertake research or reduce staff workload, therefore increasing capacity to implement modelling results or adopt the tools. Provision of time to use techniques was also cited by 40% (n 18) of conservation practitioners in the questionnaire survey as likely to support adoption of modelling tools, and 49% (n 22) suggested increased budget. These findings highlight the importance of time and resource constraints for conservation practitioners, which suggests that research implementation solutions need to address these barriers in order to be successful. Other authors have also found extra financial resources to support implementation (see Burns *et al.* 2014; Williams *et al.* 2012 and Lauber *et al.* 2011).

The findings of the case study led to the conclusion that implementation barriers can be avoided by research design because barriers are created by the current conservation research paradigm of autonomous science, in which conservation research is normally developed without partnership with conservation agencies. The questionnaire results support this conclusion, 54% (n 24) of respondents suggested "*usefulness of a modelling technique being proven"* as an implementation solution. Undertaking modelling studies in partnership with conservation agencies to answer applied questions relevant to UK conservation problems, would build an evidence base to support their use, thereby proving the usefulness of the techniques. This would also impact directly on all of the highest scoring implementation solutions cited by practitioners, including "*usefulness of technique proven"* 54% (24); "a*wareness of techniques"* 40% (n 18); and *"training in techniques"* 40% (n 18), partnership with university 30% (n 13) and support from researchers 20% (n 9).

6.4 FURTHER RESEARCH

As this study focused on one organisation, the results may not be widely transferable to other organizations, despite validation of results via the findings of the questionnaire survey. Therefore, further research to explore whether time constraints are a significant barrier to adoption of scientific techniques or research implementation in other conservation organisations would be valuable to assess the validity of this study's conclusions. Due to the limitations of the study period, only one in depth case study was carried out, further case studies using modelling techniques in other organisations are recommended.

The questionnaire survey asked 16 other organisations (see appendix 5.1) about the use of landscape permeability and species distribution models, but did not train them in their use, therefore respondents were not aware of the time required to use the tools. It is therefore possible, that similarly to the Forestry Commission, if these practitioners were trained in their use, time constraints might also prove an adoption or implementation barrier, thus placing further weight on the importance of partnerships between conservation organisations and researchers. Further research could investigate this.

For the last 80 years, numerous successful industries, including aviation, communications, computing, advanced materials, weapons systems and biotechnology have been demonstrating that science is implemented when it is targeted towards specific needs and supported by communication networks between the multiple sectors involved. Further research to explore how frequently the research undertaken by partnerships between conservation agencies and research institutions is implemented, would be extremely valuable to test the conclusion of this study.

Further research to determine what constitutes an effective framework for these research-conservation agency partnerships would also be useful. Research into how to most effectively generate effective, replicable communication networks between research and conservation agencies, could also be useful. However, communication networks could be modelled on the effective networks which already exist in other industries such as biotechnology or aviation.

This research suggests partnerships between conservation agencies and research institutions could also not only enable the implementation of results, but also enabling training in scientific techniques for conservation practitioners. Case studies to explore this could help identify whether training is sufficient in some cases to enable adoption of modelling tools as well as implementation of modelling results.

The findings of this research provide support for other solutions proposed by the literature, including sourcing questions from practitioners, changes to institutional structures, increases in funding, and reward for applied work with direct conservation benefits, cases studies to explore how successful these solutions are when applied, would be useful and might provide research design frameworks which support implementation.

Further research into social capital, how it is best established and maintained, how frequent communication needs to be in order to maintain it etc. could encourage its acceptance and enable busy researchers and practitioners to believe social capital is not too time consuming or difficult to create.

University staff could engage with conservationists when funding calls on different topics are opened, to develop applied projects within these topics. University staff could encourage Doctoral and MSc students to contact conservation organizations and work with them to develop applied research topics. Conservationists could be invited to present their research needs to students in guest lectures. Pietri *et al.* (2013) also suggest that graduate students should foster links to practitioners from within their academic institutions.

Much modelling research uses modelling tools theoretically with an emphasis on modifications to tools (Guinotte and Davies 2014; Chauvenet *et al*. 2015; Lavers *et al.* 2014). Ostensibly this research is carried out in the hope that improving tools, or demonstrating their usefulness to theoretical questions, will promote their understanding and encourage conservationists to use them to address the questions they need answers to. However, this research proposes that a change in perspective could enable greater implementation research. Modelling research could focus on the implementation of research results, rather than adoption of the tools. This case study suggests that despite the literature describing a tool able to explore habitat connectivity, conservation managers are unlikely and unable to teach themselves to use a modelling tool to answer their specific habitat connectivity questions.

Almost 30 years of survey data is available within Wyre Forest, however, only the most recent ten years data was used to train the model. This was because the vegetation type and land use in Wyre Forest is rapidly changing, and survey records older than 10 years, will not accurately represent the relationship between species presence and current landscape features. Further investigation could train the Wyre Forest MaxEnt model using fewer years of data and compare this to the results of ten years of data. This could reveal important caveats on the use of predictive species distribution modelling for determining conservation strategies within rapidly changing landscapes, with common pressures like changes in disturbance level and vegetation type.

The usefulness of the modelling techniques to the Forestry Commission in the adder conservation case study, their wider work, and the implementation of the modelling results within the Forestry Commission's conservation management, leads to the following recommendations for modelling research in an applied context:

- Use modelling tools to answer *applied* conservation questions.
- Involve conservation practitioners in *all stages* of research design and the modelling process, most importantly in model parameterisation.
- Experiment with changes to models according to land managers needs. These are likely arise during the modelling process. Be prepared to change and re-run models based on modelling results, to facilitate discussion and implementation of credible results.
- Explain practical implications of modelling results to land managers so they can be used to support pragmatic conservation management decisions.

6.5 IMPLICATIONS

The results of this research suggest the theoretical debate on the research-implementation gap needs to be revisited, in order to understand whether all implementation barriers are in fact consequences of research design and the current research paradigm, or whether any genuine research-implementation barriers exist.

If all the barriers proposed in the literature can be overcome by research design based on partnership with conservation practitioners, this would fundamentally change the current understanding of the research-implementation gap. If accepted, this understanding would place responsibility for implementation of research into the hands of researchers, creating an obligation to ensure research design revolves around applied questions developed in partnership with conservation agencies. This suggestion is supported by the findings of other authors, who suggest research frameworks which embed research into applied conservation projects support implementation (see Lennox and Cooke 2014; Cook *et al.* 2013; Hall and Fleishman 2010; Hart and Calhoun 2010; Tappeiner and Walde 2006).

Although some *"blue sky"* conservation research might still be appropriate, an acceptance of implementation barriers as due to research design, would require changes in the requirements of research funding to go beyond the current need for an impact statement, to insisting on partnership with conservation agencies to ensure relevant research and implementation of results.

If social capital is as important as suggested by this research, this has important implications for scientific training. Communication skills are an essential prerequisite for the creation of social capital, which implies that communication training should be an essential part of scientific training programmes. Several authors have pointed out that communication, trust building, leadership and "*doing conservation*" skills are not currently part of scientific training, and stressed the need for conservation scientists to learn such skills to facilitate communication and implementation (see Burns 2014; Allen and Reyers *et al.* 2013; Kenward *et al.* 2011; Farley *et al.* 2010; Manolis *et al.* 2009; Knight *at al.* 2006; Tainter 2001; Weber and Word 2001).

The current research paradigm is based on the assumption that autonomous research is the most effective way to pursue knowledge and can produce implementable results. This position assumes the scientific community is "*an autonomous, self-regulating market, able to identify and pursue the most efficient lines of knowledge generation."* Scientific knowledge is perceived to "*accumulate in a metaphorical reservoir from which society can draw to solve its various problems"* (Sarewitz and Pielke 2007). However, empirical studies of the relationship between research and societal application suggest this is not true. Longitudinal surveys on the origins of technological innovation, demonstrate continuous feedback networks between academic and industrial scientists, research administrators, corporate executives, policy makers and consumers (Sarewitz and Pielke 2007). Research exploring the relationships between industries and universities, also illustrates how the priorities of "*pure science"* are often, in reality, aligned with the needs of industry. This alignment is not due to chance, but due to the communication networks between the multiple sectors involved in technological innovation (Crow and Tucker 2001). Scientists working within these networks still have considerable autonomy to pursue knowledge, but their priorities and directions are strongly influenced by collaboration with engineers and managers in product development and application.

Historical studies of innovation also provide evidence against the autonomous science argument. So called "*technological frontiers*" frequently preceded knowledge of the underlying fundamental science, therefore in many areas, demand for improved theoretical understanding of technological applications has driven fundamental science (Rosenberg 1994). Post World War II science and technology policy made strategic decisions about investments in science, in support of specific areas of societal application, including communications, computing, advanced materials, aviation, weapons systems and biotechnology (Sarewitz and Pielke 2007). From the creation of agricultural research stations in the mid-19th century, to the continued advance of human biotechnologies today, decisions to focus scientific research on technological application have affected society in terms of economic growth, agricultural productivity and military power. Over ten years ago, evidence from health related research illustrated how targeting research towards specific needs reduced the gap between research and its application (Lerner 2001; Morgen 2002).

The current paradigm of conservation research as an autonomous science creates a cultural and communication divide between universities and conservation agencies. This research suggests that conservation science should imitate the behaviour of other applied sciences and create communication networks with the relevant industry i.e. conservation practitioners, in order to develop relevant science and enable implementation. These communication networks could be modelled on the existing networks between universities and other industries, to enable them to support ongoing, reciprocal flows of information at all stages of research (Cook *et al.* 2013). These networks would require institutional and policy support. Perhaps most importantly, this paradigm shift requires changes in the thinking of both conservation practitioners and scientists. Willingness to learn and recognise how science can improve their work by conservation practitioners, and partially giving up research autonomy and directly engaging in communication and partnership building by researchers, in order to solve complex, political, social, multifaceted conservation problems.

The barriers to this *"post-normal science"* (Farley 2010), in which conservationists and conservation scientists are involved in development of research aims, are also partly due to the current structuring of reward systems within universities and scientific journals. Currently scientists are rewarded, in terms of promotion, tenure and peer regard, according to the number of publications in peer reviewed journals they produce (Burns *et al.* 2014).

Research funders have recently begun to make descriptions of research impacts part of applications, require academics to make "*impact case statements*" and some funding opportunities require collaboration (UK REF). However, there is no insistence on collaboration with conservation practitioners, most collaboration is still between research institutions and based on non applied research projects. Policy and funding support would be needed to develop an alternative to this which focused reward on applied conservation impact and implementation. Knight *at al.* (2006) and Hart and Calhoun (2010) propose that academics should be rewarded for involvement in conservation management processes and implementation of their work. As Hall and Fleishman (2010) explain, field testing results in the real world is the translation of scientific understanding into metrics of performance which validate research. This research supports these suggestions and proposes policy change within journals and universities to change the current reward systems into those which support implementation. Although several authors have suggested most conservation scientists are not seriously committed to implementation (Balme *et al.* 2014; Arlettaz *et al.* 2010; Laurance *et al.* 2012; Knight *et al.* 2008; Putz and Zuidema 2008), the popularity of Sutherland's "*UK Questions"* (which still hold the records as the most downloaded paper ever from any British Ecological Society journal), and 2009 research "*Global Questions"* (the most downloaded paper in Conservation Biology in 2009), suggests that many scientists do want their research to support conservation practice. Therefore, changing the reward system is likely to enable large numbers of scientists to begin to work with conservation practitioners and support research implementation.

Other authors have made similar suggestions for the direction of conservation research, such as ensuring it is problem-oriented (McNie 2007), identifies the end-users of research (Hulme 2014), long term and applied (Likens and Lindenmayer 2012; Meijard and Sheil 2007), focused on comparative management studies (Smith *et al.* 2014), evaluated under field conditions (Hall and Fleishman 2010), based on empirically relevant economic mechanisms (Diamond and Saez 2011), and includes identification of the processes, institutions and relationships which connect science and decision-making (Leith *et al.* 2014). This research agrees that these factors could help support implementation, but suggests that all these would flow naturally from communication networks and partnerships between research and conservation organisations.

6.6 CLOSING STATEMENT

Current species extinction rates are 1,000 times higher than natural background extinction rates (De Vos *et al.* 2015). Conservation practitioners have many questions of pressing concern, answers to which could enable effective conservation action. Conservation research could play a vital role in making conservation activities more effective and increasing the resources available to it. The conservation research-implementation gap has been debated for over thirty years with little improvement seen. This research suggests this is because the described implementation barriers are not in reality barriers, but the effects of research developed without the involvement of conservation practitioners, a practice perpetuated by the current research paradigm based on autonomous science.

It is the conclusion of this research that research implementation requires the urgent adoption of what is already normal practise in other applied sciences; namely partnership with the conservation industry. This would support the development of communication networks, similar to those between applied university research and industry, which enable the building of social capital and support ongoing, reciprocal flows of information at all stages of research and therefore enable its implementation.

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