UNDERSTANDING THE ROLE AND VALUE OF EXPERIENCE FOR ENVIRONMENTAL CONSERVATION

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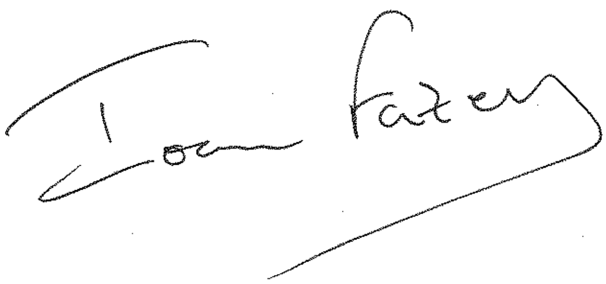
To Della and John Fazey

for their love and support

STATEMENT OF ORIGINALITY

This thesis is presented as a collection of linked papers with the aim of informing environmental conservation research and practice about the role and value of experience. The thesis relies on information from a number of non-biological disciplines including clinical medicine, philosophy, systems science, phenomenography, and cognitive psychology. Data collection, analysis, and write-up for the main chapters and Appendix 1 were for the most part conducted by myself, and the contribution of collaborators did not extend beyond a normal supervisory role. However, the breadth of the thesis would not have been possible without discussion, ideas, feedback on earlier drafts, and guidance from a number of individuals. To acknowledge such assistance, individuals have been listed at the beginning of each chapter as co-authors in the order of the magnitude of their contribution. (See acknowledgements for a more detailed account of their assistance).

This thesis is my own work except where otherwise acknowledged (see Acknowledgements).



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PREFACE

This thesis is an exploration of the nature of environmental conservation and how more effective conservation practice can be achieved. Much of the context of the thesis stems from a desire to develop a personal understanding of the relative contributions of science and experience for informing conservation management. This desire grew from my own previous experience of conservation work where there were always difficulties obtaining relevant information and translating it into a form in which it could be applied effectively. In many cases, significant gaps in information meant that relying on experience and good judgement was often the only possible way forward.

While the thesis concentrates on developing understanding about the nature, role and value of experience, an additional personal aim was to broaden my understanding about conservation issues generally, and of other disciplines and research methods. To represent the personal development of understanding about conservation and experience, chapters are presented in the order in which they were written or data collected. The thesis is therefore not intended to be a linear progression through theory, data collection, analysis and interpretation of results. Instead, chapters have been written as stand-alone pieces of work, and were generally completed before beginning the next chapter. Later chapters would not have been conducted without insights from previous ones, and diagrams in some of the sections are used to clarify interconnections between chapters. Because the thesis relies on insights from a wide range of disciplines, it does not conform to the traditional biological scientific study.

All of the main chapters, including the synthesis, have been written with publication in mind: Chapters 2-3 are in press; Chapters 5 and 7 have been submitted to journals; and Chapters 4, 6 and 8 are in preparation and will be submitted by April 2005. In addition, Appendices I-III are publications that have been written during the course of the PhD. These papers do not relate directly to the central theme of the thesis, but they have contributed to my understanding about environmental conservation and the development of appropriate conservation theory. Because the main chapters are intended to be stand-alone pieces of work which were written with particular journals in mind, the chapters have minor stylistic differences. For example, some chapters use U.K. spelling and others American, and chapters may use either the term "environmental conservation" or "conservation biology". Because the chapters stand-alone, some repetition between chapters was unavoidable.

SUMMARY

To facilitate the implementation of research, recent studies have suggested that environmental conservation should adopt an evidence-based approach from clinical medicine and public health (Pullin and Knight 2001, Pullin *et al.* 2004). In this approach, scientific research is systematically reviewed and disseminated through organisations dedicated to the process. Strong emphasis is placed on the integration of experimental research. While the proponents of the evidence-based approach acknowledge the importance of experience for decision-making, there has been limited discussion about how experience should be incorporated into the decision-making process. To achieve greater integration, an important first step is to determine the nature, role and value of experience for environmental conservation. To achieve this step, a broad range of topics has been explored in this thesis. This has involved drawing insights and understanding from a wide range of non-biological disciplines, including clinical medicine, philosophy, systems science, phenomenography and cognitive psychology.

The nature of environmental conservation was examined through a review of publications in three prominent conservation journals (Chapter 2), and by comparing conservation with clinical medicine to ask if an evidence-based approach could assist the review and dissemination of conservation research (Chapter 3). These first two studies in the thesis suggest that while experimental evidence is important, to take into account the complexity of environmental systems, environmental conservation also often needs: (1) greater acknowledgement of uncertainty; (2) a holistic and inter-disciplinary approach; and (3) stronger links between research and practice. The evidence-based approach could have many significant benefits for conservation, but would need to be complemented by other approaches, such as adaptive management or the appropriate application of experiential knowledge.

Another key issue for conservation is how people theorise and build understanding of environmental systems. Therefore, the nature of formal conservation theories (Chapter 4) and how practitioners apply them (Chapter 5) was explored. These two studies suggest that: (1) theories, by necessity, are summaries of a complex world and therefore all theories have limitations; (2) multiple concepts are necessary to guide conservation action; (3) the human mind significantly affects the theories we accept (Chapter 4); and (4) when practitioners

make decisions, formal theory is combined with the rest of an individual's educational, research, work and environmental experience (Chapter 5).

Taking into account issues raised in preceding studies (Chapters 2-5), a case study elicited the extensive implicit knowledge of seven on-ground managers of the large and complex Macquarie Marshes wetland system in south-eastern Australia (Chapter 6). Detailed scientific research and data for the wetland were lacking, yet there was extensive on-ground experiential knowledge about the impediments to achieving effective conservation of the wetland. In addition, an experimental approach would have been unable to capture the complexities of the conservation issues (Chapter 6).

The on-ground managers were interested in finding ways to articulate their deep understanding of conservation issues to ensure that adequate attention was given to the ultimate causes of the conservation problems, and not just to dealing with the symptoms of the problems. A series of semi-structured interviews and a workshop informed the development of a conceptual model to communicate the impediments to achieving effective conservation of the wetland to a wide audience. The wetland is undergoing dramatic changes as a result of water extraction for irrigation. The conceptual model highlighted the strong and complex positive feedback that was continually reinforcing the potential for policy and/or management by water agencies to favour the interests of the irrigation industry. While action on many levels and scales was required, without major governmental intervention and a shift in the prevailing worldviews of the water agencies and the public, the health of the Macquarie River and the wetland was likely to continue to decline.

The case study (Chapter 6) highlighted the notion that extensive research and/or management experience of an environmental system has considerable value for informing conservation practice, and that finding ways to articulate such knowledge was important. Given that many practitioners rely on their experience when making decisions, a next step was to determine how practitioners could learn better from their experiences and apply experiential knowledge more appropriately. By reviewing some of the literature from cognitive psychology and phenomenography on how people learn, a way of thinking was presented to help researchers and practitioners develop expert understanding of environmental systems in an adaptive and flexible way (Chapter 7). To do this, individuals need to: (1) vary and reflect on their experiences and become adept at seeking out and taking different perspectives; and (2) become proficient at making balanced judgements about how or if an experience will change their current working representation of the environmental system by applying principles of "good thinking". Such principles include those that assist individuals to be open to changing their current way of thinking (e.g. the disposition to be adventurous) and those that reduce the likelihood of making erroneous interpretations (e.g. the disposition to be intellectually careful). A key finding was that while experiential knowledge is different to knowledge derived from experiments, they are complementary, and both are important.

Finally, the studies in the thesis were integrated in a discussion about the role and value of experience in relation to evidence-based conservation (Chapter 8). A conceptual model was used to demonstrate how expertise in learning from experience, defined by a person's capacity to seek out and take different perspectives and to be open to how an experience might change their current way of thinking, influences the development of understanding about environmental systems. An evidence-based approach provides an important springboard for increasing emphasis on reviewing, planning and reflecting on conservation actions. Therefore, in addition to making research more accessible to the wider conservation community, the approach could also facilitate the development of a practitioner's personal understanding of environmental systems.

There are five general conclusions arising from the thesis about the role and value of experience for environmental conservation:

(1) Because personal experience will often play a dominant role in decision-making, developing our capacity to learn from our experiences - including the experience of research - will have a significant influence on the effectiveness of conservation decisions;

(2) While an expert's implicit knowledge is qualitatively very different from explicit knowledge, both are important and complementary;

(3) Some experiential knowledge can be expressed quantitatively, but making implicit knowledge explicit changes its nature because it is no longer linked to the rest of an expert's personal knowledge;

(4) Synthesizing and communicating research is essential to help prevent people from heading down potentially erroneous ways of thinking;

(5) There is no single definition of expertise. It is difficult to compare one expert with another as their knowledge is built from a unique set of experiences. However, it takes considerable time to develop the form of expertise that is typically discussed in the education literature. When referring to "expert knowledge", it is therefore important to be clear about the basis and extent of this knowledge, and the degree to which the knowledge is relevant.

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Chapter 1

INTRODUCTION

1.1 Background

"Conservation" can be considered to be the "management of human use of the biosphere that provides the greatest sustainable benefit to current generations while maintaining its potential to meet the needs of future generations" (UNEP 1992). This definition embraces "preservation, maintenance, sustainable use, restoration and enhancement of the natural environment" (UNEP 1992). Thus, the academic discipline of environmental conservation primarily aims to inform society about threats to the natural environment and biodiversity, and how to alleviate those threats and manage environmental systems appropriately.

Given the extent of the global environmental crisis, there have been suggestions that environmental conservation is failing in its duty to inform practitioners about the conservation of biota. Whitten *et al.* (2001) argued that enough is often known about conservation problems to take immediate action, such as to halt illegal logging or large-scale loss of native vegetation. Instead of more priority setting, planning, and assessment exercises, they suggested that greater emphasis should be placed on on-ground action (Whitten *et al.* 2001).

Determining what makes research useful depends on personal opinion and values. Nevertheless, irrespective of whether it is considered to be relevant, environmental conservation has serious problems disseminating and implementing research (Pullin and Knight 2001). It takes longer for conservation journals to publish their results than other biological journals (Kareiva *et al.* 2002), and practitioners rarely apply the research when compiling management plans (Pullin *et al.* 2004).

The problem stems, in part, from the inaccessibility of research. With substantial amounts of conservation and environmental publications "hidden" in the grey literature or in obscure journals, practitioners may be unaware that the information exists (see Pullin *et al.* 2004).

Yet, even if it were accessible, practitioners working in a real world of time and resource constraints are unlikely to use it unless it is presented in a form where its relevance can be easily judged (see Ely *et al.* 1999). As a solution, it has been suggested that environmental conservation adopt the "evidence-based approach" from clinical medicine and public health, where research is systematically reviewed and disseminated through organisations dedicated to the process (Pullin and Knight 2001). Such processes are important because they also provide mechanisms where researchers can be informed about the relevance of the research to practice (Waddell 2001).

Appropriate research is necessary to prevent "superstitious learning" by individuals and organisations, where erroneous connections between cause and effect can occur (Levitt and March 1988). However, environmental systems are often dynamic, complex and context-specific, and data are usually lacking. In such situations, it is often the degree of personal experience that counts most when making conservation decisions (Woodwell 1989). While the proponents of an evidence-based approach acknowledge personal experience is important (Pullin and Knight 2001, Pullin et al. 2004), there has, so far, been limited discussion about how experience should be incorporated into the decision-making process. To achieve greater integration, an important first step is to determine the nature, role and value of experience for environmental conservation.

1.2 Objectives and Aims

This thesis aims to develop a better understanding of the role and value of experience for environmental conservation. To do this, five main topics are addressed:

- *Section A:* Understanding environmental conservation (Chapters 2 & 3);
- *Section B:* Developing and applying formal conservation theories (Chapters 4 & 5);
- *Section C:* Capturing implicit knowledge (Chapter 6);
- *Section D:* Learning better from experiences to develop expert understanding of environmental systems (Chapter 7);
- *Section E:* Synthesis: Understanding the role and value of experience for conservation research and practice (Chapter 8).

Fig. 1.1 provides a schema for the links between chapters. The process is not a traditional linear progression through theory, data collection, and interpretation of results. Instead, to avoid making prior assumptions about the role and value of experience, each chapter was largely conducted one step at a time. The chapters are presented in the order in which data were collected or in which they have been written to represent the development of understanding about the research topic. In recognition of the need for accessible research, chapters have been written as independent pieces of work, each with a clear contribution to the discipline of environmental conservation. Nevertheless, chapters later in the thesis would not have been conducted without the direction from previous ones.

In Section A, the nature of environmental conservation and issues surrounding the dissemination and application of research are explored to provide the context within which the role and value of experiential knowledge can be examined. Chapter 2 reviews the research published in three conservation journals, and discusses the relevance of the published research to policy and management. Chapter 3 explores whether conservation practice could be improved by applying the evidence-based approach characteristic of clinical medicine and public health to facilitate the review and dissemination of conservation research. By comparing clinical medicine and environmental conservation, the role of different types of evidence for informing practice is considered.

Given the complexity and uncertainty of conservation issues, another key issue is how we think about, theorise and build understanding of environmental systems. Because formal theories are primarily built from our personal understanding, they are strongly influenced by our experiences (e.g. Lakoff and Johnson 1999). Section B therefore explores the nature of theory, how our cognitive capacities influence our acceptance of certain theories, and how practitioners apply formal theory. Chapter 4 considers the challenge of developing theories that have a practical focus, but which do not mislead scientists and practitioners. Chapter 5 then explores how practitioners apply conservation theory in real world settings, based on an exploratory study of planners and implementers of conservation programs of the New South Wales National Parks and Wildlife Service (NPWS), south-eastern Australia.

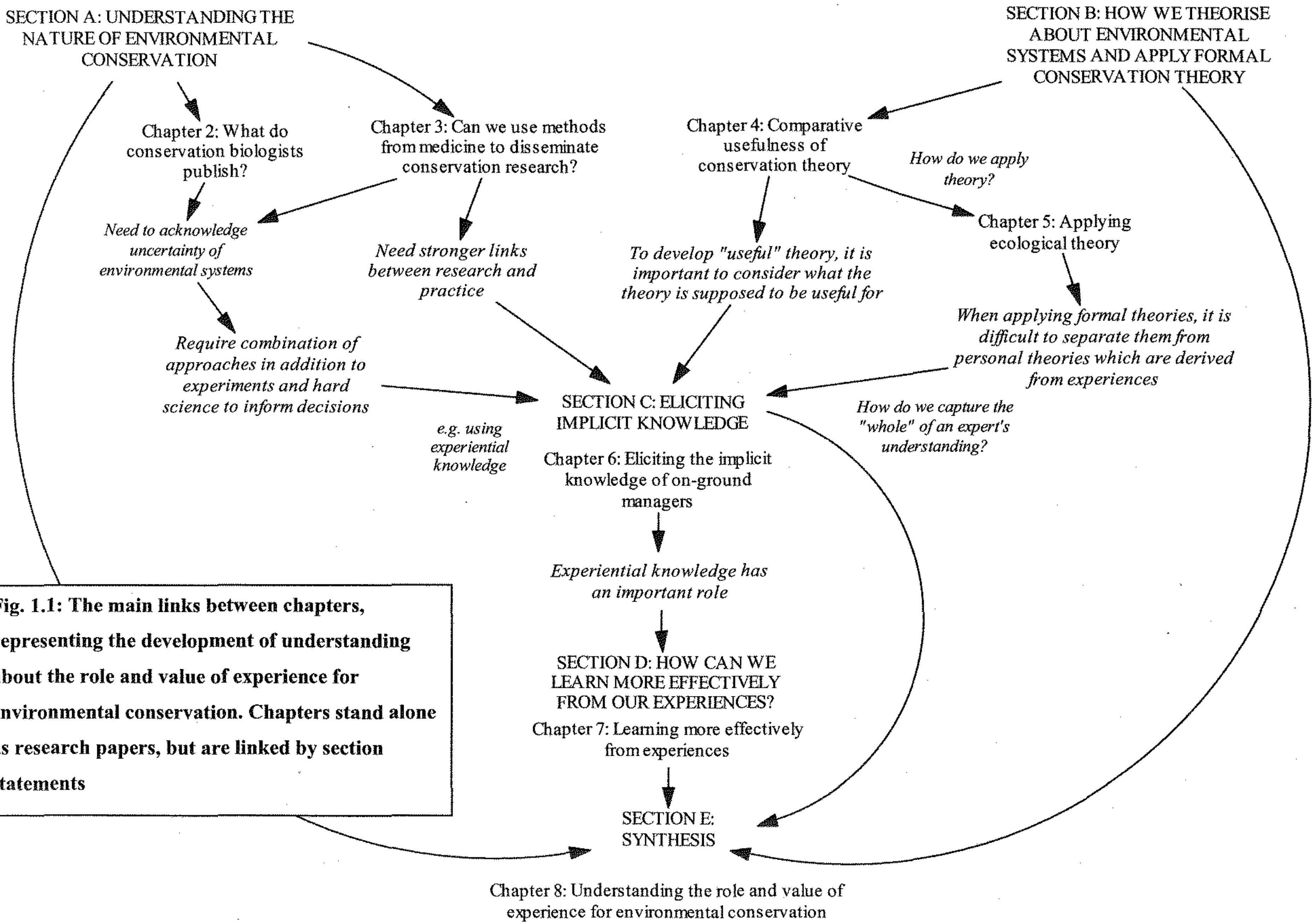


Fig. 1.1: The main links between chapters, representing the development of understanding about the role and value of experience for environmental conservation. Chapters stand alone as research papers, but are linked by section statements

Many practitioners have considerable experience of particular environmental systems, and in the absence of appropriate research, experiential knowledge can be valuable for informing conservation practice (e.g. Robertson and McGee 2003, Martin *et al.* in press). However, the nature of experiential knowledge means that it can often be difficult to articulate (Polanyi 1958). Thus, finding ways to capture and present such knowledge is an important issue for environmental conservation. In Section C, Chapter 6 applies a method specifically designed to elicit the experiential knowledge of on-ground conservation managers working in a complex and dynamic wetland system in south-eastern Australia. To articulate the understanding of the managers, a conceptual model of the dynamics of the system is developed and presented, taking into consideration insights about conservation theory from Chapters 4 and 5.

Because practitioners rely heavily on experiential knowledge (Pullin *et al.* 2004), Section D explores how we can find more effective ways to learn from our experiences. Chapter 7 examined how we can learn better from, and make the most of our personal experiences, and learn how to apply experiential knowledge more appropriately. Research from phenomenography (studies of what expert teachers and learners can tell us about learning) and cognitive psychology is reviewed and discussed within the context of developing expert understanding of environmental systems.

Finally, Section E (Chapter 8) presents a conceptual model that explains how expertise in learning influences our capacity to learn from experiences to develop expert understanding about environmental systems. The model is a synthesis of understanding derived from previous chapters. Its implications for understanding the role and value of experience for environmental conservation are discussed in relation to evidence-based conservation.

1.3 Approach

This thesis is an exploration of a number of different issues and topics, which lead to a better understanding of the nature, role and value of experience for environmental conservation. While no single or specific research method has been applied throughout the thesis, each chapter is influenced by three main considerations:

1) In recognition of the inter-disciplinary nature of conservation biology (Soulé 1985, Hunter 2002), where possible and appropriate, chapters should: (a) draw on knowledge from outside the biological disciplines; (b) engender collaboration with researchers or practitioners from other disciplines; and (c) integrate different types of information.

2) Chapters should have an underlying practical focus, and thus should: (a) be an independent piece of work; (b) provide a clear message to conservation researchers and practitioners who may not be familiar with material from other disciplines; and (c) be accessible to a wide audience (i.e. written in a format amenable for publication).

3) Bearing in mind considerations (1) and (2) above, chapters should make use of the most appropriate method for the research task. Methods employed include quantitative methods, theoretical research, and qualitative methods (including interviews, grounded theory, causal loop diagrams and workshops).

1.4 Definitions

Definitions of key terms are provided within each chapter. However, the term "environmental system" is used throughout the thesis. We take Newell and Wasson's (2002) definition that a "system" is "something composed of discernible parts that interact to constrain each others behaviour", where the "characteristic behaviour of that system arises from the internally generated forces imposed on parts of the system by (other) parts of the system".

By "environmental system" we are referring generally to the social, biological and physical components that drive a system's dynamics.

SECTION A:

UNDERSTANDING ENVIRONMENTAL CONSERVATION

To understand the nature, role and value of experience, it is first necessary to gain an understanding of the nature of the discipline of environmental conservation, and how research and other types of information are used in environmental management. Chapter 2 reviews an extensive body of literature from three conservation journals, and discusses the relevance of the research published in the journals to policy and management. Chapter 3 asks whether the application of some of the mechanisms adopted in medicine and public health would benefit conservation practice. The chapter compares the types of evidence available in conservation and medicine, and points to some of the difficulties when integrating scientific studies with other, more qualitative, types of evidence.

Chapter 2

WHAT DO CONSERVATION BIOLOGISTS PUBLISH?

Citation: Ioan Fazey, Joern Fischer, David B. Lindenmayer, D.B. (2005). What do conservation biologists publish? Biological Conservation.

2.0 Summary

We provide an overview of publications from three prominent conservation journals (*Biodiversity & Conservation, Biological Conservation and Conservation Biology*) published in 2001 (n = 547 papers). We found a wide breadth of studies of different topics from different climates and habitats and across a range of spatial scales. Most studies were quantitative (89%) and used inferential statistics (63%). Research was biased towards vertebrates, forests, relatively pristine landscapes, and towards studies of single species and assemblages rather than communities or ecosystems. Despite assertions in the literature that conservation is synthetic, eclectic and multi-disciplinary, few studies were truly cross-disciplinary (13%). In addition, few studies investigated the loss of native vegetation (2%), or specifically studied introduced (4%) or non-threatened species (4%). 20% and 37% of studies had high relevance to policy and management respectively. However, only 12.6% of studies actively went out to test or review conservation actions. Although many topics are covered in the literature, improvements are possible. We suggest 1) broadening the number of habitats, taxonomic groups and scales studied and 2) providing closer and clearer links with other disciplines and research approaches, and with policy and management.

2.1 Introduction

People have been engaged in conservation activities for centuries, i.e. ever since human reasoning began to extend the idea of deferred gratification ("save this fruit to eat tomorrow rather than now") (Hunter 2002). Over the last 150 years there have been significant changes in western conservation ethics and values. During the 19th century and first half of the 20th century, the careful use of natural resources was advocated mainly for the need for spiritual satisfaction or for the conservation of limited resources for future human use (Calicott 1990). More recently, there has been increasing recognition of the need to care for the function and integrity of natural processes and systems, and that all components of nature have intrinsic value (Callicott 1990).

With changing values there have been dramatic increases in organisations, institutions and programs interested in serving a conservation ethic. Some of the earlier prominent ones include the International Union for the Protection of Nature established in 1948 (now the IUCN World Conservation Union), the International Biological Program (1968-1974), and journals like this one (first published in 1968). Such organisations greatly assisted the development of an academic discipline specifically devoted to the conservation of biota and contributed to early definitions of what constituted the study of biological conservation (e.g. Polunin 1968).

Research in numerous disciplines, including biology, ecology and wildlife management greatly contributed to increased understanding about nature conservation. However, many felt that a new discipline was required to bring different components of research together (Jacobson 1990). In 1978, the First International Conference on Conservation Biology was held at the University of San Diego, followed by the ensuing publication of the book *Conservation Biology* (Soulé & Wilcox 1980).

In 1985, the landmark paper "What is Conservation Biology?" was published (Soulé 1985). This paper was significant because it attempted to define a new field of inquiry characterised by few disciplinary boundaries. Soulé (1985) argued that the eclectic, synthetic and multi-disciplinary nature of conservation biology resulted because all components of human activity (law, economics, sociology etc.) are ultimately linked to the state of Earth's biological diversity. Some of the most important points from Soulé's paper are summarised in Table 2.1.

In this paper we provide a snapshot overview of conservation research. To do this we investigate four main themes: an overview of topics, habitats, taxa, and the ecological, temporal and spatial scales of the research. We also investigate these four themes with regard to the relevance of the research for informing policy and management. Our aim is not to make major comparisons between journals, as most people will already be familiar with the biases or preferences of a particular journal.

Table 2.1: Key aspects defining conservation biology (from Soulé 1985).

Aspects defining conservation biology:

- Conservation biology is a crisis discipline.
- Tolerating uncertainty is often necessary.
- Given incomplete knowledge, conservation biology is a mix of science and art requiring intuition as well as information.
- Conservation is synthetic, eclectic and multi-disciplinary with dependence on biological and social science disciplines.
- Conservation biology is holistic: Processes need to be studied at macroscopic levels, and reductionism alone cannot lead to explanation of community and ecosystem processes.
- Conservation biology is based on a number of underlying functional and normative postulates suggesting rules for action.

Functional Postulates:

1. Many species constituting natural communities are products of co-evolutionary processes.
2. Many ecological processes have thresholds below and above which they become discontinuous, chaotic or suspended.
3. Genetic and demographic processes have thresholds below which non-adaptive, random forces begin to prevail over adaptive, deterministic forces within populations.
4. Nature reserves are inherently disequilibrial for large, rare organisms.

Normative Postulates:

1. Diversity of organisms is good.
2. Ecological complexity is good.
3. Evolution is good.
4. Biotic diversity has intrinsic value.

2.2 Methods

2.2.1 Choice of journals

Our survey covers three international conservation biology journals: *Biodiversity & Conservation* (B&C), *Biological Conservation* (BC) and *Conservation Biology* (CB). The journals were selected on the basis that they were the highest impact biological journals with '*conservation*' in their title. These are some of the longest standing journals publishing conservation research. They have all been heavily involved in the promotion of conservation biology and together provide a good representation of the global scientific literature in conservation biology. While the review of only three of many journals that are fully or partially devoted to conservation will influence the results of this study, sampling a larger number of journals with fewer papers from each is problematic. This is partly because in some of the more ecologically-oriented journals (e.g. *Journal of Animal Ecology*) it can be difficult to decide if a publication should be included as a paper that is devoted to conservation biology. Other conservation related journals are often quite specific to particular issues (e.g. *Restoration Ecology*), to a specific region (e.g. *Pacific Conservation Biology*) or to particular taxa (*Invertebrate Conservation*). We were careful to ensure there were no special issues of the journals that would highly skew the results (there was only one special issue which we account for in the analysis – see section 3.3.1). Thus, while the choice of the journals for this survey will influence some of the results, we believe the journals we focused on will provide a good overview of the most widely read international publications specific to the discipline of conservation biology.

The three journals reflect a range of different types of publications and editorial policies. The 2001 impact factors for the three journals were 2.78 for CB, 1.69 for BC, and 1.31 for B&C (ISI Web of Knowledge).

2.2.2 Data collection

With the exception of letters and book reviews, we read all publications in the three journals from 2001 (total n = 547; comprised of B&C = 124, BC = 210, CB = 213). Other sampling protocols would have been possible, but our aim is to provide a snapshot overview rather than a historical trajectory of the discipline. Therefore, an actual review of one year, with a large number of papers was considered informative. Numerous questions were asked of each paper, such as the habitat type and species studied. Questions and different categories (e.g. forest or marine) were derived inductively by reading the first 100 papers from 2001 (equal proportions from each journal relative to their overall proportion). These papers were re-read once appropriate questions had been determined. Many of the questions and categories are self-explanatory. Those requiring precise definition are presented in Table 2.2.

Table 2.2: Questions and categories requiring detailed definition.

Questions	Categories
Type of publication:	Categories include: *Essays and comments*, *reviews*, and *individual studies* (i.e. qualitative and quantitative studies)
Mode of inquiry:	*Natural experiment* = studies which have some elements of true experiments, e.g. those comparing data before and after intervention or that use an unaltered site as a control (see Diamond 1986).
Topic overview:	*Wider context of conservation biology* = papers that specifically engage broader discussion about conservation other than just focussing on the biological e.g. community participation, ethics etc.
Threatening process:	*Disturbance* = species affected by presence of humans (e.g. birds on beaches).
	Effects of take = hunting, harvesting or fisheries bycatch.
	Habitat change = loss of native vegetation, effects of logging, grazing etc.
	Habitat fragmentation = *edge effects*, *studies of isolation/connectivity*, or '*general fragmentation*' (studies that do not isolate different fragmentation processes).
	Effect of small population size = allee effects, inbreeding etc.
	Multiple = more than one threatening process or where threatening processes are discussed generally
Climatic zone:	Zones are based on Hutchinson *et al.* (1992).
Habitat modification:	The degree to which the study site has been altered by processes other than fragmentation. Categories include: *Low* (e.g. relatively pristine and undisturbed), *medium* (e.g. areas that have been selectively logged or grazed), *high* (e.g. urban areas that have very little vegetation remaining) or *multiple* (more than one category).
Landscape structure:	*Small fragments* = <100ha, *large fragments* = 100-1000ha, *natural* = >1000ha
Species status:	Whether research is conducted solely on *non-threatened*, *threatened* or *introduced species*. '*Multiple*' refers to studies that include species from more than one status category.
Highest organisational level:	Categories include: *Individual/population*, *assemblage* (multiple species but from one taxonomic group e.g. birds), *community* (across a range of taxonomic groups or where interactions between species from different taxonomic groups are specifically studied), *ecosystem* (across a range of communities). When a study covers multiple categories, the highest level was noted.
Largest spatial scale:	Categories include: *Local* (<1km^2), *landscape* (1-100km^2), *regional* (multiple landscapes), *continental* (across continent or multiple continents). Where a study covers multiple categories, the largest scale was used.

Research can inform a wide spectrum of conservation activities along a continuum from broad political debates about the direction that society should be taking to more specific on-ground action. To determine the degree to which publications were relevant to conservation activities at different points on this continuum, we asked whether publications had high relevance to policy or management (HRP and HRM respectively). We take 'policy' to be the result of "the interaction of values, interests and resources, guided through institutions and mediated through politics" (Davis *et al.* 1993), and consider 'management' to be the administration and control of specific conservation actions, such as the development of management plans or mitigation measures. Each publication was assigned a score between zero and three for the degree to which it aimed to inform policy and management. The score was based on 1) objectives of the study, 2) the degree to which it considered policy or management in the introduction and discussion and 3) the clarity with which it delivered its conservation message. A paper was considered to have high relevance if it had a score of two or more. Because HRP and HRM were assessed separately, a paper with HRP could also have HRM.

The classification of publications was inevitably subjective, but we made every effort to retain consistency throughout the survey. To maintain consistency, the primary author (IF) assessed all papers. Due to the large amount of data gathered, we have been selective in the data we have presented. We do not present data on the countries where research was conducted. This is covered elsewhere (Fazey *et al.* 2005-a [Appendix 1]). Similarly, we do not review theory in the conservation literature as it has been reported in With (1997). Means are reported with standard errors.

2.3 Results

2.3.1 Overview

2.3.1.1 General

On average, it took 3.9 (+/-0.13) years from the last year of data collection for a paper to be published. There was no difference between journals for years to publication, although the difference was close to being significant ($F_{325} = 2.47$, $p = 0.09$ B&C: 3.5 (+/-0.8), BC: 3.8 (+/-2.3) and CB: 4.3 (+/-0.3)).

The majority of papers were individual studies (85%), with the remainder being essays/comments (8%) and reviews (6%). CB had relatively fewer individual studies (72%) compared to B&C (95%) and BC (95%). B&C and BC had no comments/essays. All three journals had a similar proportion of reviews (B&C: 7%, BC: 5%, CB: 7%). The majority of studies collected some of their own data - i.e. were not only relying on existing data sets (79%) and 89% were mainly based on quantitative data. 63% of articles used inferential statistics, but only 8% of individual studies were true experiments and 18% were natural experiments.

2.3.1.2 Topics studied

Papers considering the threats to biodiversity dominated the literature (40%) (Fig. 2.1a). B&C had the greatest proportion of papers devoted to biodiversity surveys and studies examining the causes of species distributions (B&C: 26%, BC: 5%, CB: 1%). BC had a higher proportion of papers devoted to studies of species biology (BC: 28%, B&C: 5%, CB: 6%). CB had higher proportion of papers that considered the non-biological wider context of conservation (CB: 25%, B&C: 7% and BC: 1%). Of all publications in the three journals, 14.1% explicitly proposed, developed or tested conservation theory.

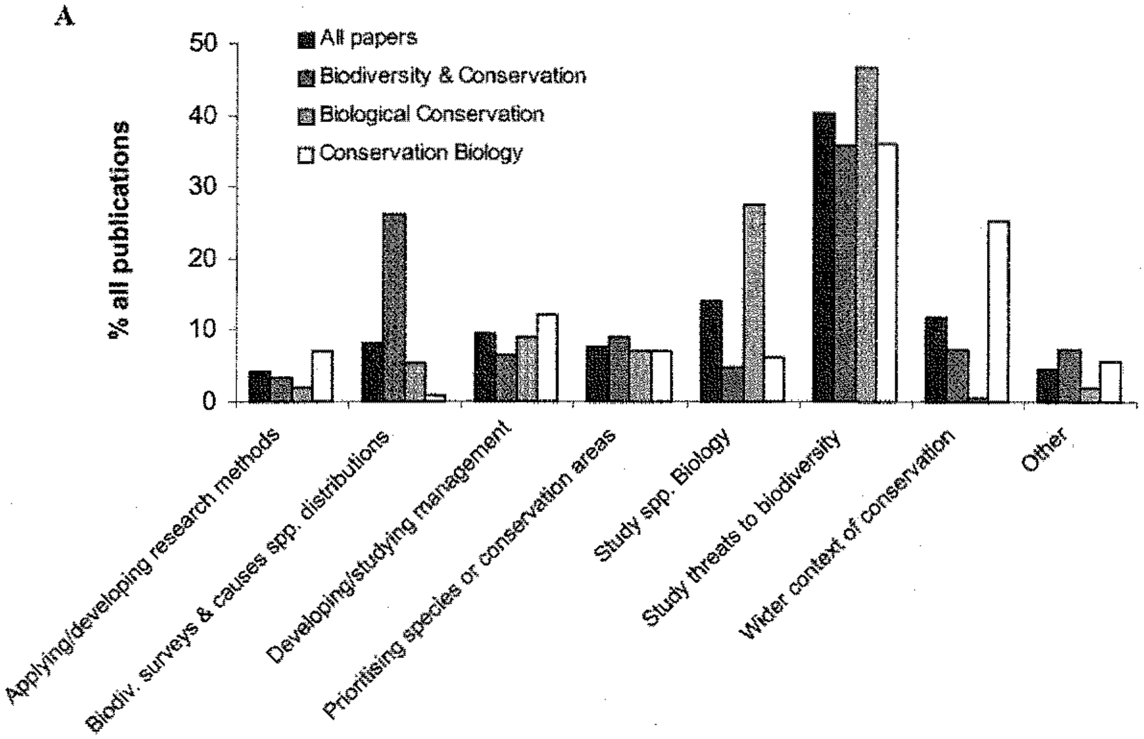
2.3.1.3 Threatening processes

71% of all papers considered at least one threatening process (Fig. 2.1b). The most common categories were multiple (18%), habitat change (13%), and habitat fragmentation (11%). Loss of native vegetation was rarely studied directly (2% of all papers). Of the 61 papers on habitat fragmentation, 36 considered general fragmentation, 13 edge effects and 12 isolation/connectivity.

2.3.1.4 Cross-disciplinary research

13% of all papers (n = 73) were cross-disciplinary, i.e. they included both a biological and non-biological discipline. The non-biological disciplines included: Economics (n=8), Education (n=6), Health sciences (n=4), History (n=8), Policy (n=24), Sociology (n=12), Multiple (n=4), and Others (n=7).

A



B

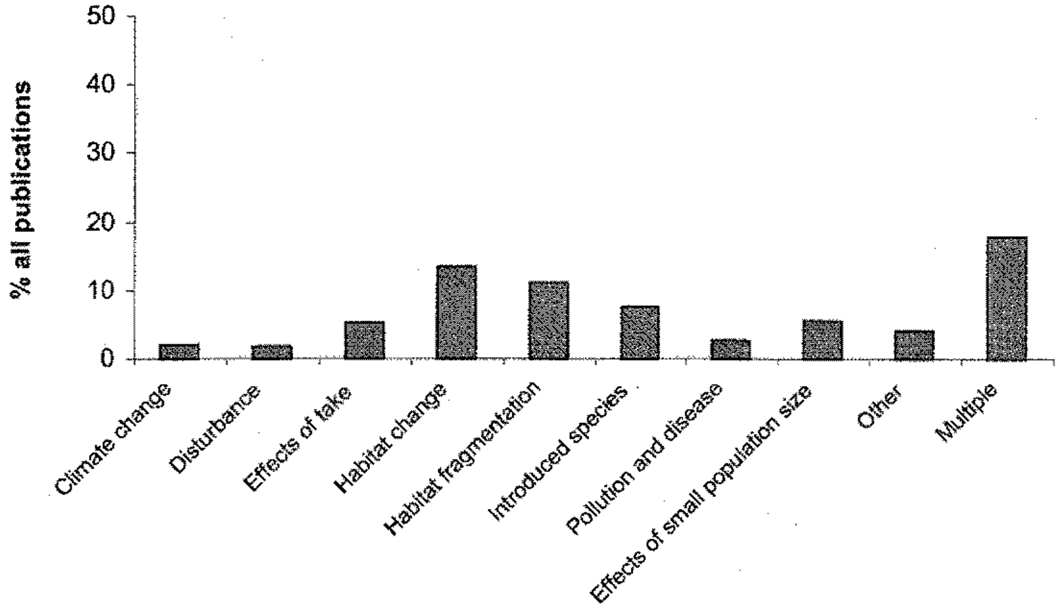


Fig. 2.1: Proportion of all publications (n = 547) and journals for: a) different conservation topics, b) different threatening processes considered in a study. The categories for papers where the threatening process could not be identified are not shown.

2.3.2 Habitats

2.3.2.1 Climatic zone and habitat type

Studies were conducted across a range of different climatic zones: Cold to very cold (13%), cool (19%), warm (16%), hot (14%) and multiple (15%). Fewer studies were conducted in high montane and dry warm to hot regions (1% and 5% respectively)(e.g. arid zones in Australia and Africa).

Studies were dominated by those conducted in multiple habitats (21%) or in forests (20.5%). Habitats least represented were deserts (0.7%) and montane (1.6%), with others being more evenly represented: e.g. agricultural (2.4%), scrub (2.7%), coastal (3.7%), wetlands (4.4%), grasslands (4.8%), marine (4.9%), aquatic (5.5%), woodland (6.4%).

2.3.2.2 Degree of habitat modification

Studies were biased towards habitats with low modification. Of the 283 studies where habitat modification could be identified, 54% were conducted exclusively in low-modified (e.g. intact forest, relatively pristine habitats), 8% exclusively in medium-modified (e.g. grazed woodlands, selectively logged areas), 2% exclusively in highly modified habitats (e.g. urban), and 36% considered habitats with multiple modification classes. Even when papers from the multiple classes were added to the other classes, the total number of papers considering low, medium and highly modified habitats were 251, 106 and 41 respectively, i.e. studies were still strongly biased towards habitats with low modification.

2.3.2.3 Landscape structure

Studies were biased towards large natural habitats (Fig. 2.2). There were 341 papers where landscape structure was relevant or could be identified. Of these, a higher proportion were conducted in natural landscapes (45%) compared to large fragments (7%), small fragments (12%), studies that considered the matrix with large and small fragments (10%), multiple classes (22%) and islands (4.4%).

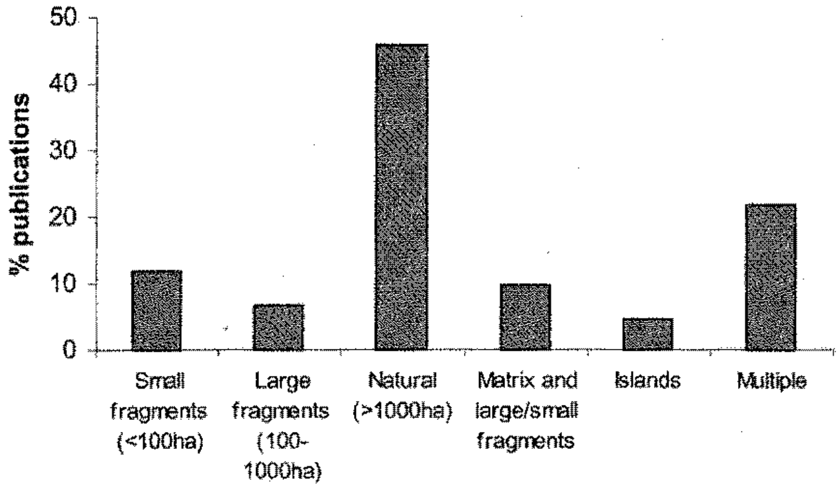


Fig. 2.2: Proportion of publications conducted in different landscape structure classes (n = 341). Publications where landscape structure was not possible to determine were excluded.

2.3.3 Taxonomic groups, number of species, and their status

2.3.3.1 Number of species and species status

Some studies dealt with large numbers of species (mean = 64.5, +/- 7.9) but most dealt with relatively few (median = 5).

Of the 436 papers where species status could be identified, studies of threatened species (42%) were far more common than those of non-threatened (4%) and introduced species (4%). 50% of studies included species with more than one status. Of these, only 7% specifically studied introduced species and 31% studied non-threatened species. 60% of the studies which included more than one species status were on a wide variety of species, such as biodiversity surveys where species status was not a primary consideration of the study. In addition, a special edition (in BC; Issue 1, Vol 99) of research from New Zealand on introduced species skewed the results, accounting for 9 out of 32 papers that specifically studied introduced species. Thus, even when studies where more than one species status was included and special editions were taken into account, there were still few publications that specifically set out to study introduced or non-threatened species.

2.3.3.2 Taxa

Most taxonomic groups were relatively well represented except fish, fungi and lichens (Fig. 2.3). Birds and mammals were particularly well-represented (31% of all individual studies).

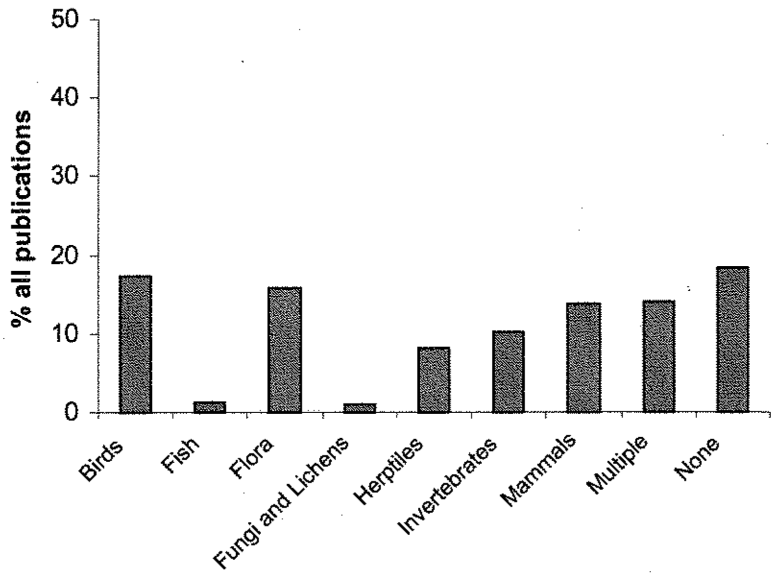


Fig. 2.3: Proportion of all publications (n = 547) and the proportion of publications in different journals for the taxonomic group studied.

Of the 73 papers studying invertebrates most studied arthropods (52 papers, with 33 studying insects, and 19 studying all other arthropods). Non-arthropod invertebrate taxa were poorly represented (6 studies on corals, sponges and echinoderms, 8 on molluscs, and 7 on multiple invertebrate taxa).

2.3.4 Ecological, spatial and temporal scale

2.3.4.1 Organisational level

More publications were conducted at the individual or population level than other organisational levels (Table 2.3). Fewer studies at higher organisational levels were experimental or natural experiments (Individuals/populations: 44%, assemblage 31%, community 22%, ecosystem 3%) or used quantitative data (Individuals/populations: 83%, assemblage 94%, community 78%, ecosystem 34%).

2.3.4.2 Largest spatial scale considered

There was a relatively even distribution of studies at different spatial scales except for the continental scale, which had a lower proportion (Table 2.3). There were more true experiments or natural experiments at the local scale (66%) than at the landscape (23%), regional (12%) or continental (0%) scale. There also were more studies that used quantitative data at the smaller scales (local 93%, landscape 88%, regional 73%, and continental 50%).

Table 2.3: Spatial and temporal scale of studies

	Scale		%
Highest organisational level (n = 479)	Individual/populations		54%
	Assemblage		22%
	Community		17%
	Ecosystem		7%
Largest spatial scale (n = 470)	Local		36%
	Landscape		26%
	Regional		34%
	Continental		4%
Temporal scale	N yrs. the study spanned (n = 376)	Mean: 12.3 (+/-2)	Median: 2
	N yrs. data collected (n = 352)	Mean: 4.9 (+/-0.5)	Median: 2
	N intervals or seasons per year (n = 347)	Mean: 1.5 (+/-0.1)	Median: 1

2.3.4.3 Temporal scale

Although the mean number of years a study spanned was considerably higher than the mean number of years of data collection (means of 12.3 and 4.9 respectively), the median was the same (median = 2, Table 2.3). This suggests that, most studies covered a short time span. Similarly, most studies did not collect data over different intervals or seasons throughout the year (Table 2.3). Differences between journals for number of years of data collection were significant (F_{351} = 3.53, p = 0.03) with B&C having 2.9 (+/-0.53) years, BC 4.9 (+/-0.75) years and CB 6.7 (+/-1.34) years.

2.3.5 Policy and management

2.3.5.1 Relevance to policy and management

37% of publications had a high relevance to management (HRM) and 20% a high relevance to policy (HRP). 25 publications had both HRP and HRM.

2.3.5.2 Differences between studies with HRP and HRM

Publications of HRP had a higher median number of species than papers of HRM (medians of 21 and 2 respectively). More publications of HRP were cross-disciplinary (34%) compared to publications of HRM (7%).

There were 279 publications where both threatening process and relevance to policy/management could be determined. There were differences in the proportion of studies for each threatening process that had either HRP or HRM (Fig. 2.4). For studies with HRP, 'multiple' and 'effects of take' categories had the highest proportions (Fig. 2.4a). For studies with HRM, 'disturbance', 'effects of take', 'habitat change', and 'other' categories had high proportions while 'habitat change' had the highest actual number of studies with HRM (Fig. 2.4b). 'Habitat fragmentation', 'introduced species' and 'multiple' categories had relatively low proportions, although overall habitat fragmentation had a high actual number of studies (Fig. 2.4b).

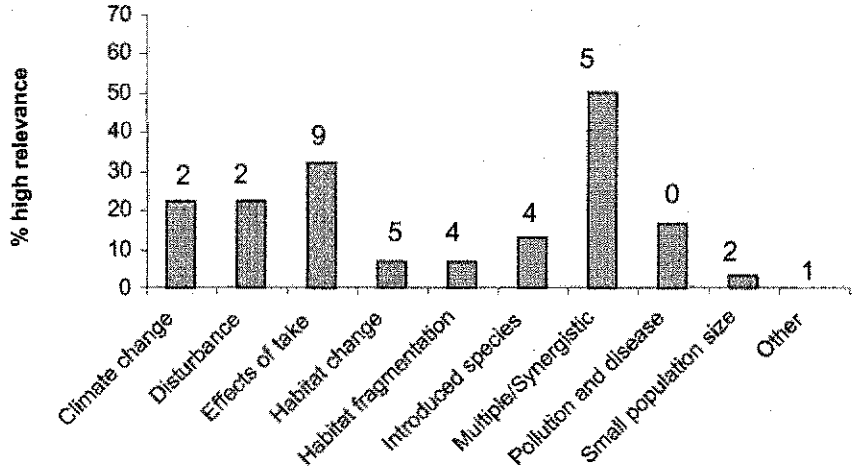
The proportion of publications with HRP was relatively high for studies that considered multiple habitats (26%) compared to montane (11%), agriculture (8%), marine (8%), wetlands/riparian (6%), woodlands (6%) and grasslands/savanna (4%). Publications with HRM were relatively even across habitat type, although scrub (53%), wetland (57%) and woodlands (55%) had proportionately more publications with HRM compared to studies in aquatic (31%) and desert (25%) habitats.

Fungi/lichens and invertebrates were poorly represented in the papers with HRP and HRM. There were no HRP studies for fungi/lichens and few for invertebrates (6%) compared to birds (11%), herptiles (12%), flora (13%), fish (14%), and mammals (16%). There were also few studies with HRM for fungi/lichens (20%), herptiles (27%) and invertebrates (31%) compared to birds (51%), fish (57%), flora (44%) and mammals (47%).

2.3.5.3 Testing conservation actions

12.6% of publications tested or reviewed a specific conservation action. Actions most frequently tested were translocation (n = 10), restoration (n = 10) and other types of species recovery efforts (Fig. 2.5).

A: Policy



B: Management

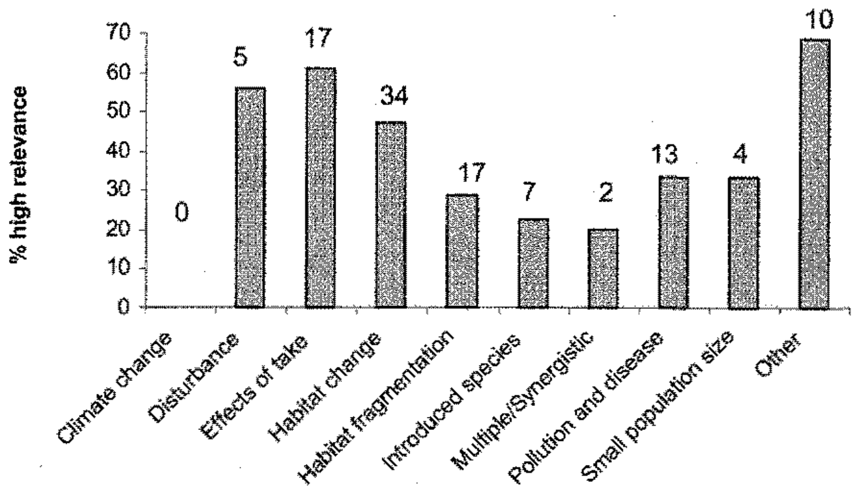


Fig. 2.4: Proportion of papers for each threatening process with: a) high relevance to policy and b) high relevance to management. The total number of papers where threatening process and policy/management relevance could be determined was 279. Numbers above each bar give the actual number of publications with high policy/management relevance.

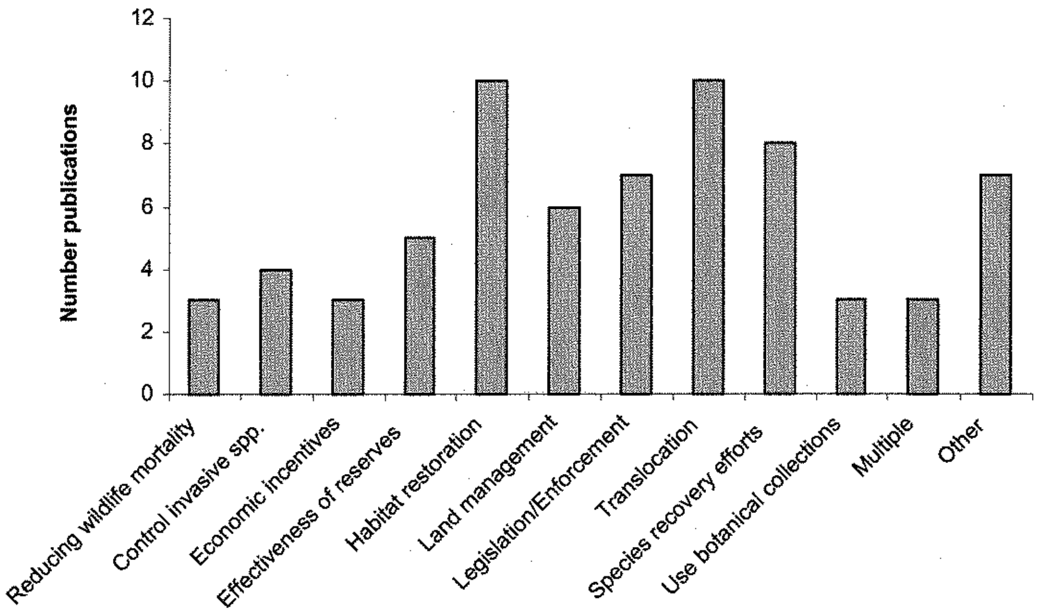


Fig. 2.5: Number of publications that tested or reviewed a specific conservation action. Total n = 69.

2.4 Discussion

2.4.1 Publication type

Conservation biologists study a diverse range of topics covering numerous scales, regions, habitats and taxa. The variety of research suggests that academics, students and practitioners have a wide breadth of knowledge and experience to guide conservation action. While the three journals had differences in the type of studies they published, these differences tended to complement each other (Fig. 2.1a).

Although most studies considered at least one threatening process, it was striking that only 2% of all publications specifically addressed the loss of native vegetation (Fig. 2.1b), the greatest threat to biodiversity (Fahrig 2003). For example, in Australia 6,878 square kilometres of native vegetation are being cleared each year equating to 50 rugby fields per hour (QCC *et al.* 2001), killing approximately 100 million native mammals, birds, reptiles and 190 million trees (Cogger *et al.* 2003). The dearth of research on the loss of native habitat could be due to three reasons: 1) It may be considered to be an uninteresting subject –

once the vegetation has gone what is there left to study? 2) More complex aspects of the problem such as broad ecosystem impacts, extinction debts and accumulative effects of piecemeal loss of vegetation (e.g. through development) may be considered too difficult to address directly. 3) Since they often occur together, some people assume that fragmentation studies include both the loss and subdivision of native vegetation, despite the distinct differences between the two processes (Fahrig 2003). Thus the current literature may give an impression that the loss of native vegetation is less important than it actually is, which may contribute to claims that it is failing to address today's problems (e.g. Whitten *et al.* 2001).

2.4.2 Habitat

There have been numerous recent calls for more emphasis on studies in modified landscapes, given the vast proportion of the world's landmass is outside reserves (Daily 2001; Fischer *et al.* in press a [Appendix 2]). Human demographic predictions also suggest rural areas will increasingly be abandoned and more people will move to coastal and urban environments. Hence, a greater understanding of how to protect and manage riparian, wetland and coastal ecosystems and restore marginal, abandoned land will be required (Young 2000; Luck *et al.* 2004). Despite these calls we found that few studies were conducted entirely in areas under intense human pressure (agricultural landscapes, coastal and urban areas). This was also reflected in data on landscape modification and structure (Fig. 2.2), suggesting that conservation biology is dominated by research in relatively intact habitats.

2.4.3 Taxonomic group

Research in conservation biology is dominated by vertebrates, with work on birds and mammals constituting a high proportion of all studies (Fig. 2.3). This bias is already well documented (e.g. Clark & May 2002; Baldi & McCollin 2003) and is also reflected in the allocation of resources and in the value the public places on different taxa (e.g. Czech *et al.* 1998). Surprisingly little research was conducted on introduced species, despite their importance as a threat to biodiversity (Novacek & Cleland 2001).

2.4.4 Ecological, temporal and spatial scale

Single species and genetic studies are essential for conservation, yet practitioners are increasingly being asked to manage multiple species and habitats (T. Soderquist, personal communication). Our data suggest that conservation biologists are tackling some of the difficult research questions at landscape or regional scales (Table 2.3). However, despite Soulé's (1985) assertion that conservation biology is holistic (Table 2.1), our data suggests that more work may be required on the conservation of communities and entire ecosystems (Table 2.3).

2.4.5 Relevance to policy and management

Conservation biology is an applied discipline that aims to inform practitioners about how best to understand and manage species and habitats. We found 37% and 20% of studies had HRM and HRP respectively. Whether this is a sufficiently high proportion is difficult to judge, and depends on how one values pure or applied research. However, while authors believe their work is being used to guide management and policy (Flaspohler *et al.* 2000; Ormerod *et al.* 2002), a recent survey by Pullin *et al.* (2004) found that only 23% of practitioners 'always' or 'usually' used scientific publications when compiling management plans. The survey strongly suggests that the majority of conservation actions remain experience-based and rely heavily on traditional management practices. The limited application of primary research may be due to 1) the lack of accessibility of research or 2) that it is not considered to be relevant to conservation practice.

2.4.5.1 Is research accessible to practitioners?

Pullin *et al.* (2004) found evidence that practitioners did not access primary research because it is too time consuming to locate, access and read. Pullin *et al.* (2004) strongly advocate that conservation adopt the evidence-based concept developed and used in medicine and public health which aims to promote the use of the best available evidence to make decisions. In this approach strong emphasis is placed on reviewing studies and making them accessible (Sacket *et al.* 2000), including using new fora to guide the production and dissemination of systematic reviews (Fazey *et al.* 2004 [Chapter 3], Pullin and Knight 2003).

Our study supports Pullin and Knights's (2001, 2003) hypothesis that research may not be readily accessible to practitioners. First, it takes considerable time for results to be published following the last year of data collection (3.9 +/- 0.13 years), and conservation journals take longer to publish articles than other ecological journals (Kareiva *et al.* 2002). Making new information rapidly available is important for any crisis discipline, and there have already been calls for reviewers to turn articles around more quickly (Meffe 2001).

Second, only 6% of all studies were reviews. Concise reviews are essential because no individual can retain all information and be expected to make reliable conclusions from it (Sacket *et al.* 2000). In clinical medicine reviews are now much more highly valued, and their value is beginning to be reflected in incentives for their production (Fazey *et al.* 2004 [Chapter 3]).

Third, many of the conclusions of the papers we read were not sufficiently clear with respect to how they might influence policy and management. Authors and editors could do more to ensure it is clearly communicated as to how their work relates to practice, e.g. by providing short sections in the abstract and discussion. This has been beneficial in other applied disciplines like clinical medicine (e.g. *British Medical Journal*) and has already been demonstrated to be effective in some ecological journals (e.g. *Journal of Applied Ecology;* Ormerod *et al.* 2002).

2.4.5.2 Is the research relevant?

'Relevance' refers to whether something is "closely connected or appropriate to the matter in hand" (OED 2002). Thus whether a published article is relevant is context dependent, and certain types of information will be more relevant for some conservation issues than others.

The necessity for a range of types of information is highlighted by the differences between studies with HRP and HRM. Publications of HRP were more likely to include a non-biological discipline and tended to concentrate more on multiple species and habitats compared to publications with HRM, which were often species or habitat specific. The differences reflect the broader nature of policy with regard to guiding conservation action. Because cross-disciplinary studies often integrate different types of knowledge, they are also often more qualitative or integrative than single disciplinary biological studies. Our results therefore suggest that such studies clearly have a role to play in providing policy advice about conservation issues.

The lack of studies with HRM for multiple species also raises the question of whether conservation biology is adequately providing sound management advice to protect biodiversity at broader organisational levels despite the absence of detailed knowledge of each species' biology and habitat requirements (see Section 2.4.4). This problem is clearly highlighted by the debate about the usefulness of theoretical approaches and frameworks that rely on environmental surrogates for achieving conservation outcomes (e.g. Simberloff 1998). On the one hand such theory may be flawed (e.g. focal species approach, see Lindenmayer *et al.* 2002; umbrellas and flagships, see Andelman & Fagan 2000). On the other hand, practitioners may resort to less than perfect theory because they are faced with threats that require immediate action (e.g. Hess and King 2002).

There is a distinct lack of application of theory in conservation research and practice (With 1997) and little consensus on how to apply ecological theory for the conservation of communities and ecosystems (Knight 1998) or at landscape scales (Hobbs 1997). This problem is due in part to the lack of integration of ecological theory (Pickett *et al.* 1994), and there is a need to identify or develop theory to guide practice in a way that is not misleading but which is still useful to managers working in complex systems in a real world of time and resource constraints. To achieve this we will need a greater understanding of: 1) what makes a theory useful, 2) how practitioners apply formal theory (if they apply any at all), and 3) the way people think and make decisions (Anderson 2001). To answer these questions, conservation biology will need to apply research methods from the social sciences and refer to knowledge from other disciplines such as psychology, phenomenology and philosophy (e.g. Anderson 2001). We will never have perfect theory that is completely practical, explanatory and predictive. Multiple approaches will therefore always be required for conservation management (e.g. Lindenmayer & Franklin 2003).

Studies investigating the effectiveness of interventions are often highly relevant to practitioners, yet we found that only 12.6% of studies specifically set out to test or review conservation actions. We also found that conservation approaches most tested or reviewed tended to be those most amenable to experimental or pseudo-experimental methods, e.g. translocation, habitat restoration and species recovery efforts. In these cases, it is possible to identify a desirable outcome (e.g. an increase or decrease in population size) and compare the situation before and after intervention or use some natural standard as a control. However, many interventions (e.g. legislation, economic incentives or those involving multiple species and habitats) are less easily tested and reviewed directly (Fazey *et al.* 2004 [Chapter 3]).

In medicine, the evidence-based concept revolutionised practice because it emphasised the importance of testing the effectiveness of interventions (Pullin and Knight 2001). Thus while methods employed in the evidence-based approach have the potential to provide many real significant benefits for conservation (Fazey *et al.* 2004 [Chapter 3]), it does tend to promote research on aspects that are most amenable to testing. In conservation, many problems require non-biological solutions because the causes of conservation issues often stem from the unsustainable nature of human activities (Harcourt 2000). Thus, adoption of the evidence-based concept requires care. Importantly, given the nature of conservation issues, conservation biology needs to ensure that it does not become preoccupied with management solutions that make good experimental studies when more novel or complex ways to treat the real causes of the problem are necessary. For example, translocation of an endangered species faced with urban development is usually considered by ecologists to be a last resort. Yet, it is now so often used in the U.K. as a mitigation strategy that it is becoming accepted as an effective mitigation measure at the expense of searching for more innovative ways to prevent the need for translocation in the first place (I. Fazey, *personal observation*).

2.5 Caveats

This paper provides a snapshot of research in conservation biology. Having only covered literature from three journals published in one year means that some care needs to be taken when drawing conclusions as research topics found to be lacking in this study may be covered by other journals. It is also difficult to determine whether conservation biologists should devote more time and resources to certain topics, as most research is in some way relevant to real world problems. We have therefore taken a conservative approach when making recommendations by only concentrating on the topics and issues found to be most lacking.

2.6 Conclusion

Experimental approaches must continue to inform conservation practice and be integrated with all the other types of information and evidence available to guide decisions. Experiments must also be applied within a coherent theoretical framework that actively acknowledges the uncertainty involved in making decisions (e.g. Whelan *et al.* 2002). Nevertheless, in the end, it is important that conservation biology continues to strive to find ways to manage biodiversity that focus on lasting and healthy ecological interactions rather than just focusing on the parts of communal structures in isolation (Freyfogle & Newton 2002). To do this, we will need effective research that is relevant to practitioners, but we will also need the experience from practitioners to inform us about what they think makes accessible and useful conservation research.

2.7 Acknowledgments

IF and JF were supported by GSS grants from the Australian National University. We thank one anonymous reviewer and B. Davis for reviewing the manuscript and for providing constructive comments.

Chapter 3

CAN METHODS APPLIED IN MEDICINE BE USED TO SUMMARISE AND DISSEMINATE CONSERVATION RESEARCH?

Citation: Ioan Fazey, Janet G. Salisbury, David B. Lindenmayer, John Maindonald, Robert Douglas (2004). Can methods applied in medicine be used to summarise and disseminate conservation research? Environmental Conservation. 31 (3): 190-198

3.0 Summary

To ensure that the best scientific evidence is available to guide conservation action, effective mechanisms for communicating the results of research are necessary. In medicine, an evidence-based approach assists doctors in applying scientific evidence when treating patients. The approach has required the development of new methods for systematically reviewing research, and has led to the establishment of independent organizations to disseminate the conclusions of reviews. Such methods could help bridge gaps between researchers and practitioners of environmental conservation. In medicine, systematic reviews place strong emphasis on reviewing experimental clinical trials that meet strict standards. Although experimental studies are much less common in conservation, many of the components of systematic reviews that reduce the biases when identifying, selecting and appraising relevant studies could still be applied effectively. Other methods already applied in medicine for the review of non-experimental studies will be required in conservation. Using systematic reviews and an evidence-based approach will only be one tool of many to reduce uncertainty when making conservation-related decisions. Nevertheless an evidence-based approach does complement other approaches (for example adaptive management), and could facilitate the use of the best available research in environmental management. In medicine, the Cochrane Collaboration was established as an independent organization to guide the production and dissemination of systematic reviews. It has provided many benefits

that could apply to conservation, including a forum for producing and disseminating reviews with emphasis on the requirements of practitioners, and a forum for feedback between researchers and practitioners and improved access to the primary research. Without the Cochrane Collaboration, many of the improvements in research communication that have occurred in medicine over the last decade would not have been possible.

3.1 Introduction

Pullin and Knight (2001) recently proposed a framework based on evidence-based practice in clinical medicine and public health to revolutionize the way conservation management is conducted. Conservation practitioners intervene with the aim of improving the health of ecological systems just as doctors try to improve the health of their patients. Conservation interventions include the restoration of habitats (Pywell *et al.* 2002) and populations (Raesly 2001), mitigation of human activity (Cosgrove & Hastie 2001), removal of invasive species (Craik 1998) and controlling rates of species harvestings (Soerhartono & Newton 2001). Practitioners also intervene using legislation (Salvatori *et al.* 2002), economic incentives (Richards 1996; Musters *et al.* 2001) and landscape planning (Lutz & Bastian 2002; Meegan & Maehr 2002).

Although ecological studies can be useful for guiding such interventions (Ormerod *et al.* 1999, 2002; Flaspohler *et al.* 2000), there are relatively few direct studies of the effectiveness of interventions in the literature. Only 12.6% of 547 studies published in 2001 in three prominent conservation journals (*Biological Conservation*, *Conservation Biology* and *Biodiversity and Conservation*) specifically tested or reviewed an intervention. Only 6% of the 547 publications were reviews of conservation research (Fazey *et al.*, 2005-b [Chapter 2]).

Summarizing and disseminating conservation research is the first step towards achieving effective implementation. Most information flow involves a passive process of diffusion through journals rather than by proactive dissemination involving information targeted for the intended audience (Lomas 1993). Conservation managers find serious problems with the research literature; it is voluminous, has little coherence and is of varying quality (I. Fazey, D. Lindenmayer, personal observation 1990-2004). Journals are obscure or expensive, and reports and environmental impact statements are generally accessible only to those for whom the work was originally intended. While some individual scientists do work hard to disseminate their findings, it is more often left to the practitioner to locate, synthesize and assess the relevance of information.

A recent study in clinical medicine found doctors did not use 'evidence' if they could not access a relevant piece of information within two minutes (Ely *et al.* 1999). We believe that similar problems exist in conservation. Without accessible information, practitioners will inevitably fall back on personal experience or subjective judgements. The value of experience in solving environmental problems cannot be understated (Woodwell 1989), yet we can still do much more to ensure that existing research is readily available to practitioners and encourage them to use it.

3.1.1 Can conservation biology learn from medicine?

Since the 1970s, there have been major improvements in the accessibility of science to medical researchers, doctors and patients. Systematic methods for identifying, selecting and critically appraising the primary literature and associated data have been developed to mitigate the biases that can occur when individuals review information. Organizations have also been formed to guide the production and dissemination of these reviews. The best known of these organizations is the Cochrane Collaboration (CC), which was established in 1993 to oversee international collaborations that review the systematic reviews, assess and develop the methods for reviewing data, and address issues of communicating science to doctors and patients.

The approach adopted in clinical medicine and public health has become known as 'evidence-based medicine' (or 'evidence-based practice'). This approach can be defined as 'the integration of best research evidence with clinical expertise and patient values' (Sackett *et al.* 2000). It aims to review evidence as objectively as possible for the effectiveness of a specific practice, and ensure that practitioners understand and apply the results of research. It is not about making decisions based solely on scientific data; clinicians still have to integrate the data with other individual patient factors (Chalmers 1993).

Pullin and Knight (2001) have suggested that conservation management adopt a similar approach. So far there has been no detailed discussion about whether an evidence-based approach would be appropriate for conservation. In this paper we expand the debate and highlight how the methods and organizational structures in medicine could assist communication between researchers and practitioners. We address three main questions. (1) Can we systematically review evidence for conservation management? (2) Is an evidence-based approach appropriate for conservation management? (3) How can we make results from systematic reviews widely accessible?

3.2 Q1: Can we systematically review evidence for conservation management?

3.2.1 Systematic reviews in medicine

The purpose of a systematic review is to use explicit methods to identify, select and critically appraise relevant research and to collect and analyse data from the studies that are included in the review. Statistical methods (meta-analysis) may or may not be used to analyse and summarize the results (Glasziou *et al.* 2001). In medicine, most reviews of basic science are published in scientific journals, whereas systematic reviews of the effectiveness of healthcare procedures are generally published through organizations such as the CC or in specialist publications. Systematic reviews have begun to be applied to other basic sciences, such as ecology (Gates 2002), but have not yet been used to assess the effectiveness of conservation management interventions (Pullin & Knight 2001).

There are three main components that typically make reviews 'systematic' (as applied in medicine; Clarke & Oxman 1999). The first is the method that is used to find relevant studies in the literature, such as the choice of databases, whether journals are to be searched by hand, or if studies published in other languages are to be considered. The second is the way in which studies from the searches are chosen for inclusion in the review and the criteria that are used to do this. Once the criteria have been defined, it is usually expected that at least two independent reviewers read each study because this dramatically reduces the bias associated with deciding whether it should be included. The third component is the process by which evidence from the separate studies is critically appraised, such as using statistical methods (see Gates 2002 for a detailed account of how systematic reviews differ from traditional narrative reviews and meta-analyses in an ecological context).

Systematic reviews published by the CC are reviewed in a similar way to journal papers, although the process is more rigorous. A formulated question, protocol for the methodology and the completed review are all assessed in separate stages by the most relevant editorial board before the review is published. A section on the implications for research and practice are mandatory and the authors must state any conflicts of interest that may have influenced their judgements, including personal, political, academic or financial (Clarke & Oxman 1999). Reviews are not published if there are strong conflicts (for example a pharmaceutical company funding a review of one of their own products).

3.2.2 Types and quantity of evidence in conservation

While there are similarities between medicine and conservation management, there are also fundamental differences (Tables 3.1 and 3.2). Medicine primarily concentrates on the health of one species with a global distribution, whereas conservation management is often concerned with the well-being of multiple species and habitats that are usually restricted in range.

These differences affect the type and quantity of information available for synthesis and review. The more controlled the conditions of the original studies, the more robust the review conclusions will be. In medicine, the CC deals only with reviews of clinical trials that have been carried out under the most robust experimental conditions, in other words randomized controlled trials (RCTs). Such experimental conditions are rarely attainable in conservation biology. Some study designs, such as natural experiments that compare situations before and after an event, or that use a natural standard as a control (see Lindenmayer *et al.* 2001), have characteristics similar to true experiments (Diamond 1986). The use of these designs is increasing in conservation, and there are also opportunities for collecting more evidence from interventions that we use to manipulate environmental conditions.

Despite these opportunities, there is proportionately much less evidence from studies conducted under controlled conditions in conservation management compared to medicine. This is partly because obtaining adequate replication is difficult (Eberhardt & Thomas 1991), as in the case of replicating wetlands with specific vegetation communities when assessing the effect of water level management (see La Peyre *et al.* 2001). There are also problems in measuring desirable outcomes, and even if they can be measured, there can be disagreements on what constitutes a successful intervention. For example, the eradication of rabbits on Round Island, Mauritius, resulted not only in the positive outcome of the regeneration of endemic tree and reptile species, but also in the spread of the previously sparse exotic grass *Chloris barbata* (North *et al.* 1994).

One much discussed issue in the medical literature is whether experimental units in the primary studies (usually patients) have been randomly assigned to treatments. Randomization is the only means for controlling for unknown and unmeasured differences between comparison groups as well as those that are known and measured (Kunz & Oxman 1998). In experimental design, unpredictability is therefore introduced by using random allocation to protect against the unpredictable bias that can occur in non-randomized designs. Failure to include randomization can result in either an increase or a decrease in the effect of an intervention (Kunz & Oxman 1998).

Statistical and methodological improvements have helped to eliminate some of the biases that affect conclusions of systematic reviews that are based on observational (non-randomized) studies (Benson & Hartz 2000). However, introducing some element of randomization in the primary studies where possible is important. For example, in the Tumut fragmentation 'natural' experiment, Lindenmayer *et al.* (1999) included elements of randomization by enumerating a large number of eucalypt forest patches, and then randomly selecting from them.

Table 3.1 Similarities between medicine and conservation management.

Subject	*Similarity*
Overall aim	Common goal of doing more good than harm
Applied science	Interaction and communication between researchers and practitioners is essential to achieve effective outcomes
Intervention	Procedures and interventions are common, and are essentially experiments in progress
Monitoring outcomes	Essential for informing future practice
Crisis discipline	Decisions are often made in the absence of perfect information
Experience	Has an important role and is widely used by practitioners

Table 3.2 Differences between medicine and conservation management.

Subject	***Medicine***	***Conservation management***
Overall aim	Benefit of trying to improve the health of a person is rarely contested	Benefit of conserving biodiversity is often contested
Types of evidence	Often experimental and easier to control potential explanatory variables	Rarely experimental and usually difficult to control explanatory variables
Sample sizes	Easier to obtain large sample sizes	Harder to obtain large sample sizes
Outcomes	Can be easier to define and measure	Usually harder to define and measure
Number of species	Concentrates on well being of single species	Deals with multiple species and habitats that are often restricted in range
Problem	Conclusions of studies can have global implications	Conclusions of studies are often landscape or problem specific
Funding and resources	Significantly greater than conservation, with strong interest from the private sector	Much less funding than in medicine, with relatively little interest from the private sector
Influence of politics	Generally supportive	Often negative
Practitioners and consumers of information	Distinction between researcher, practitioner and consumer is often clearer (i.e. doctors = practitioner, patient = consumer). This makes it easier to tailor information to them	Practitioners and consumers are varied and difficult to identify. Practitioners could be farmers, policy makers, conservation biologists, foresters etc. However, a farmer may also be considered to be a consumer

In environmental conservation, a huge range of variables may drive an issue. Directly controlling for the variables or controlling for them indirectly by using randomization may be very difficult. However, this is also the case for many areas of medicine (such as epidemiology or neuropsychiatry), which have difficulties conducting experiments to identify whether an action truly causes a phenomenon (van Reekum *et al.* 2001). In these cases various criteria have been used to help pull together different strands of observational evidence and provide a process and framework upon which to build a balanced judgement. A number of different sets of criteria for inferring causation have been proposed, the most well known of which are the criteria published in response to the issue of whether smoking causes lung cancer (Hill 1965). The criteria include assessing the consistency, strength, specificity, temporal relationship and coherence of the association (Fox 1991, and references within). Applying such criteria has greatly influenced the use of observational data in medicine and public health and has direct relevance to conservation management.

A system that ranks the ability of the original study to control for bias is also used to synthesize less robust studies (NHMRC [National Health and Medical Research Council] 2000). Similar systems could be applied to evaluating conservation procedures that include a wide range of evidence, including anecdotal and expert opinion (Pullin & Knight 2001). Expert opinion and experience will always be an important part of making decisions; the goal has to be to use the best available scientific evidence. Adopting such an approach encourages researchers to develop and use more rigorous experimental designs wherever possible in order to improve the ranking of the evidence they collect.

Despite some clear differences between medicine and conservation, we see no reason why attempts could not be made in conservation management to begin to use more of the techniques applied in medicine that help to objectively synthesize and apply what may initially appear to be disparate types of evidence. This includes using at least some of the components of systematic reviews. Conclusions from such reviews may not be as robust as those that synthesize randomized experimental data, but would be an improvement on more traditional reviews that do not acknowledge the many sources of bias associated with them (see Gates 2002).

3.2.3 Are the types of questions about conservation interventions amenable to systematic review?

In medicine, considerable emphasis is placed on formulating questions that systematic reviews can answer. Precise questions allow focused reviews. Producing systematic reviews therefore necessarily lends itself to a reductionist approach. In ecology, such reductionism emphasizes the structural aspects of natural systems and focuses on individual species and population dynamics of species within isolated ecosystems, compared to more holistic approaches that focus on macro-level functional aspects (de Leo & Levin 1997).

Fully controlled experiments are likely to be most appropriate for answering specific questions. However, in some cases it may be impossible or inappropriate to isolate conservation interventions if they act synergistically, such as in the use of multilateral accords, declarations and actions to reduce seabird mortality in longline fisheries (Gilman 2001). Thus, finding solutions to conservation problems often requires a more integrated or interdisciplinary approach (Ludwig *et al.* 1993) that takes advantage, where possible, of any experimental evidence.

To illustrate the problem of systematically reviewing specific questions of conservation management, we consider the effectiveness of wildlife underpasses constructed under roads for amphibians in the Northern hemisphere. Wildlife underpasses are often used to mitigate the detrimental effect of roads that kill individual animals (Lode 2000) and fragment and reduce the viability of populations (Hels & Nachman 2002). There are many questions about the effectiveness of underpasses for amphibians that could be reviewed. Some of these might be: (1) does a particular frog species use the underpass? (2) For amphibian species, do underpasses, compared to having no underpasses, reduce mortality? (3) For an amphibian species, do underpasses increase the viability of the metapopulation in the long term?

When faced with a development application for a road, a review of question (1) could provide some information for an environmental impact statement. Similarly, it may be possible to review studies that ask if underpasses reduce mortality (question 2). However, while knowing if wildlife underpasses maintain the viability of frog populations is the most useful question (question 3), it may also be the least practical. Tunnels may maintain viability in some cases, such as when there are relatively stable populations on either side of the road, but not in others where other factors may be influencing population viability. These issues are further complicated when multiple species are considered, because roads have different impacts on species (de Maynadier & Hunter 2000) and underpasses provide variable benefits (Clevenger & Waltho 2000).

Sackett *et al.* (2000) make the distinction between knowing the evidence, and applying the evidence in a particular circumstance. Reviews are essential simply because no individual can retain all information and hope to be able to deduce reliable conclusions from it. Although we need more systematic reviews of conservation science, the example above illustrates that there will still be significant issues in deciding how they would apply to individual circumstances. In medicine, methods are being developed to improve on the integration of questions and different types of evidence where answers to multiple questions are required to guide decision-making (see NHMRC 2000). Such methods would also be necessary for the application of systematic reviews of conservation management.

3.3 Q2: Is an evidence-based approach appropriate for conservation management?

Because of the complexity of ecological systems, even if the likely outcome of an intervention is known, there will often be a high degree of uncertainty that cannot be predicted even with the best scientific evidence (Table 3.3). For example, while a review of introducing grazing on lowland heaths in the United Kingdom (UK) found that higher stocking rates generally increased plant species richness, the precise effects on species composition varied widely between sites (Bullock & Pakeman 1997). Without near-perfect information, conservation-related decisions will often rely heavily on value-based judgements (Dovers *et al.* 2001) and expert judgement (Woodwell 1989). Thus, to confront uncertainty, a number of complementary approaches (such as quantitative risk assessment, safe minimum standards and the precautionary principle) will always be required (Mooney & Sala 1993).

Table 3.3 Degrees of uncertainty (Modified from Dovers 2001).

Degree of uncertainty	*Definition*
Identified risk	Sufficient information exists for believable probability distributions to be assigned to possible outcomes of future states (e.g. intervening to trap introduced American mink that are predating on breeding colonies of terns nesting on an island; Craik 1998)
Uncertainty	Although we are confident of the direction of the likely change, we cannot assign probability distributions to future states (e.g. releasing a virus to control rabbits; Cooke & Saunders 2002)
Ignorance	We cannot be confident of the direction of likely change and where threshold effects and likely surprises lurk (e.g. the impact of altering sediment flux washed out of estuaries onto coral reefs; McCulloch *et al.* 2003)

Adaptive management is one such approach that is promoted in conservation. While an evidence-based approach using reviews of the literature asks if there is prior evidence for an intervention, adaptive management aims to learn through the continued reflective process of reviewing management decisions. In this respect adaptive management actively acknowledges uncertainty because it tries to learn from it, while an evidence-based approach does not do this directly.

Unfortunately, adaptive management is rarely well structured and implemented (Taylor 1997), and while one of the claimed benefits of adaptive management is that practitioners are forced to work closely with researchers, there is no mechanism for ensuring such cooperation (Allan & Curtis 2003). Ensuring that reviews of research are available to practitioners will therefore always be an important part of conservation.

As in medicine, it is likely that many reviews of conservation management would find little evidence to support or reject the use of a certain procedure. For example, in the UK, translocation is a common mitigation strategy for reptiles and amphibians faced with habitat loss as a result of economic development. The intervention is expensive, but there are few studies that have assessed the effectiveness of the approach, and translocation is often used without full awareness of its limitations (cf. Seigel & Dodd 2002). Many management actions are also not monitored (Block *et al.* 2001), and any review that highlights the lack of available information strengthens the argument for the collection of more and better evidence. Adopting an evidence-based approach could thus complement and work with adaptive management that requires monitoring to be effective. The results of adaptive management projects could feed into an evidence-based approach to ensure that results are widely available. An evidence-based approach will therefore be appropriate for conservation, as long as it is not applied in isolation from other approaches.

3.4 Q3: How can we make results from systematic reviews widely accessible?

3.4.1 The Cochrane Collaboration

There is no point in conducting reviews if they are not accessible to researchers and practitioners or if the implications of the reviews for conservation management are unclear. In medicine, it was recognized that an organization was needed specifically to guide the production and dissemination of systematic reviews. The international non-profit CC now includes 49 international editorial review groups for different areas of medicine, 11 groups that investigate the methods for reviewing information and disseminating their findings, 15 Cochrane Centres that support the CC worldwide, and consumer networks that ensure the information provided is continually relevant and useful. Reviews are available from the Cochrane Library on compact disk or via the Internet. In some countries access is free, such as in the UK and Australia, where there is government sponsorship. Cochrane Centres are usually funded by their respective governments, while the majority of individuals making up the editorial and working groups do so voluntarily, or as part of their existing jobs in academic and health care institutions.

3.4.2 Why is an independent organization devoted to disseminating reviews important?

The CC was set up to be an independent organization with guiding principles that allow it to disseminate information in an unbiased and non-political way. The principles aim not only to maintain the core principles of science, such as rigour and objectivity, but also to promote the accessibility of science to society. The ten principles are: collaboration, building on the enthusiasm of individuals, avoiding duplication, minimizing bias, keeping up to date, striving for relevance, promoting access, ensuring quality, maintaining continuity and enabling wide participation (Cochrane Collaboration, http://www.cochrane.org).

There have been many direct and indirect benefits of an independent organization that guides the production and dissemination of systematic reviews (Table 3.4). Recognition for synthesizing activities has increased, and conducting a systematic review is now considered to be an important part of an academic's portfolio and postgraduate research. Reviews have highlighted the limits of current information and there is now greater emphasis on publishing studies with null results and obtaining more and better evidence. There have also been major improvements in accessibility of the primary literature through free comprehensive search databases, journals and databases of clinical trials (such as PubMed, http://www.ncbi.nlm.nih.gov/entrez/).

Access to data, primary studies and reviews are currently limited in conservation. This is either because of the physical difficulty of accessing the research or because it is not produced in formats that are clear, concise and understandable. Current incentives do not encourage collaboration and synthesis activities, and academics face strong disincentives for applied research that may not be as new, exciting or publishable as pure research. Conservation journals have a longer time from submission to publication than other ecological and evolution journals (Kareiva *et al.* 2002), and access to them is limited if an individual is not affiliated with a large institution that can afford a wide range of journals or expensive search databases. The conclusions of conservation-related reviews are also likely to be biased by primary studies with positive results (cf. Jennions & Moller 2002) and practitioners may be using interventions despite unpublished studies that have found them to be unsuccessful.

Table 3.4 Summary of the benefits of the CC for medicine that could also apply to conservation management.

Direct benefits	*Other benefits from reviewing and disseminating reviews through the CC*
Forum for the development of methods for reviewing evidence	Global collaboration
Forum and process for disseminating research to practitioners	Reviews clarify limits to current research and knowledge
Forum and process for feedback from practitioners to researchers	Greater accessibility to primary research
	The collection of more and better evidence
	Greater inclusion of null results in the literature
	Highlights the importance of an applied discipline to the wider community
	Encourages incentives for synthesising information

It is essential for conservation to find mechanisms that demonstrate its importance to the wider community. In medicine, the CC has influenced more than just research and direct practice. Reviews have been used by patients, in parliamentary reviews, commissions and inquiries, and have facilitated the transparency of medical science in the public arena (J. Salisbury, personal observation).

3.4.3 Are there existing organizations like the CC in conservation?

We are unaware of any organizations or programmes in conservation with the same objectives and principles as the CC. Some conservation organizations have principles similar to the CC (Table 3.5). Some systematic processes aim to review information and make reliable conclusions from it in a similar fashion to the application of the results of systematic reviews in medicine, for example designating risk status of species (Shank 1999) or assessing the loss of individuals and habitat of endangered species (Smallwood *et al.* 1999). Some conservation-related journals are dedicated to reviews (such as *Annual Review of Ecology and Systematics)*, aim to make research results more understandable to practitioners (such as *Frontiers in Ecology and Environment* published by the Ecological Society of America and *Conservation in Practice* produced by the Society for Conservation Biology) or aim to make quality science freely accessible to society (such as *PloS Biology* http://www.plosbiology.org). Some learned organizations might provide guidance based on reviewing information (for example briefing papers produced by the Fisheries Society of the British Isles, http://www.le.ac.uk/biology/fsbi). However, there are no organizations with the same principles of collaboration, altruism and independence as the CC, which directly aim to develop methods for reviewing studies of conservation management, guide the production of the reviews and widely disseminate their findings at low cost or free of charge.

Table 3.5 Examples of conservation organizations and programmes that aim to achieve similar outcomes or are based on similar principles to the CC.

Organization	*Aim*	*Web address*
Tropical Ecology Assessment and Monitoring Initiative (TEAM)	Network of international field stations using standardized research protocols to monitor biodiversity and track changes in tropical forest ecosystems	www.teaminitiative.org
Web-based conservation Knowledge Management System (KMS)	Public system for searching, organizing and sharing data and other resources including publications	www.cabs.conservation.org/cabskms
Synthesis and Analysis of Local Vegetation Inventories Across Scales (SALVIAS)	Network of ecologists, conservation biologists, biogeographers, botanists and computer programmers interested in understanding large-scale patterns of plant diversity. Assembles, maintains, disseminates global database of local vegetation	http://eeb37.biosci.arizona.edu/~salvias
UK's National Biodiversity Network (NBN)	Database to make wildlife information widely and freely accessible to support decision-making. The independent NBN Trust facilitates the building of the network	www.nbn.org.uk
Australian Virtual Herbarium	On-line botanical information resource providing access to data associated with scientific plant specimens in Australian herbaria	www.chah.gov.au/avh
Global Biodiversity Information Facility (GBIF)	Encourages, coordinates and supports the development of worldwide access to biodiversity data held in natural history museum collections, libraries and databanks	www.gbif.org
National Biological Information Infrastructure (NBII) and Towards Best Practice (TBP) eForum	The USA node of the GBIF. It includes an interactive discussion forum for engaging in moderated debates of submitted best practices.	www.nbii.gov and www.nbii.gov/datainfo/bestpractices
World Conservation Union (IUCN)	Global organization that aims to provide advice, guidelines and conduct conservation programmes (see text for more details)	www.iucn.org

Perhaps the conservation organization most similar to the CC is the World Conservation Union (IUCN). The IUCN is a collaboration of a large number of scientists dedicated to providing advice and guidelines. It includes more than 10 000 internationally recognized scientists and experts from more than 180 countries that volunteer their services, and has approximately 1000 staff members. Its mission is to 'influence, encourage and assist societies throughout the world to conserve the integrity and diversity of nature and to ensure that any use of natural resources is equitable and ecologically sustainable' (IUCN 2001, p. 3).

One of the key objectives of the IUCN is to develop information management and communication systems to ensure the accessibility of accurate data, information and knowledge to guide conservation action (IUCN 2001, p. 59). However, the IUCN does not currently produce reviews in the same way as the CC because its main focus is to provide information on biodiversity rather than on reviews of management action *per se*. Despite these differences, as a well-respected global and independent organization with extensive networks of expertise, the IUCN may be well positioned to be an umbrella body to guide the production of systematic reviews of conservation interventions.

3.5 Achieving better communication between researchers and practitioners

We believe that the accessibility of primary research for conservation managers is currently inadequate. Conservation biologists who wish their work to be of relevance to the world's environmental problems should ensure that their research is understandable and widely accessible. Greater incentives for reviews and finding more effective ways to disseminate them will be a necessary part of this process. Practitioners will not waste time sifting through primary literature that has not been well synthesized and will be in a better position to implement conservation strategies that are based on evidence of effectiveness rather than on opinion or trial and error.

Although it will not be possible to use precisely the same methods as those of the CC that review tightly controlled experimental data, many of the systematic components can be used for reviews of conservation management. Some of these methods can be used immediately, including being more specific in how studies are searched for and the criteria used for deciding whether a study should be included in a review. This would highlight the current difficulties of accessing primary research and may prompt improvements in database access. Stating the implications of reviews for research and practice is now a standard procedure in many medical journals, and editors of conservation-related journals could also encourage this (as in the *Journal of Applied Ecology*).

We acknowledge that conservation will attract less funding than medicine and public health (Noss 2000). Consequently, further discussion and debate will be needed to determine precisely how the conservation biology scientific community can contribute to providing sound advice to practitioners given its current resource limits. For example, there are similar organizations to the CC that are smaller and less well resourced, such as the non-profit Campbell Collaboration (http://www.campbellcollaboration.org) that aims to help people make well-informed decisions about the effects of interventions in the social, behavioural and educational arenas. It is important to recognize that systematic reviews in medicine and the CC were driven predominantly by the enthusiasm of a few people, headed by Iain Chalmers in Oxford, UK. Most of the expense of the CC supports the Cochrane Centres, while the library of reviews is predominantly funded by the non-profit returns from its wide-scale use. It may, for example, require relatively little funding for researchers to form editorial review groups to work on selected conservation topics. Many collaborations of scientists already exist and may be able to act as editorial groups (for example the Declining Amphibian Task Force, http://www.open.ac.uk/daptf/index.htm). In the experience of medicine, once the process of systematic reviews took hold and the limits to current information became apparent, the work of reviewing research attracted more support from outside the medical profession.

Despite the many advantages of the CC it is important to recognize there are still substantial gaps with respect to getting good quality research evidence into medical practice (Waddell 2001). Summarizing research is a necessary first step, and one in which researchers must play an important role, but more effort will be required to ensure that well-attested science is implemented. Because there are rarely single answers to conservation issues, and many of the problems are social or political rather than purely biological, we will need effective methods to integrate and implement a wide variety of different types of information. Thus, introducing a CC-like organization in conservation would not m*eet all* of conservation's information needs, but would be an important step to achieving the more effective use of science in management.

3.6 Acknowledgements

The paper is the result of numerous discussions with a wide range of practitioners and academics from both the medical and environmental sciences. Some of the ideas expressed in this paper were also the result of a one-day symposium in June 2002, which addressed the broader issue of evidence-based environmental management (Salisbury & Fazey 2002). We thank J. Fischer and A. Felton for valuable comments on earlier versions of the manuscript. Ioan Fazey was supported by an Endowment for Excellence scholarship from the Australian National University.

SECTION B:

DEVELOPING AND APPLYING FORMAL CONSERVATION THEORY

In the previous section, Chapters 2 and 3 suggested that to take into account the complexity of environmental systems, environmental conservation often needs: (1) to acknowledge uncertainty; (2) a holistic approach; (3) an inter-disciplinary approach; and (4) stronger links between research and practice. Even if research can be reviewed and disseminated, the systematic implementation of scientific research with other types of knowledge (such as personal experience) will be a major challenge.

Given the complexity and uncertainty of environmental systems, a key issue is how people think about, theorise and build understanding of these systems (Chapter 2). In Chapter 4, the problems of trying to develop practical theories that are not misleading are considered, and discussed in relation to assessing formal conservation theories. An attempt is made to provide a way of thinking about conservation theory to advance the debate about its application in a real world of time and resource constraints. In Chapter 5 ways that practitioners apply conservation theory in a real world setting are examined by focusing on an exploratory study of conservation planners working with the New South Wales Parks and Wildlife Service, south-eastern Australia.

Chapter 4

COMPARATIVE USEFULNESS OF CONSERVATION THEORY

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Comments on this paper from reviewers have recently been received. They have suggested that the paper is currently lacking philosophical depth, and have suggested that some of the points we raise are trivial. It was not intended that a deeply philosophical account of the nature of theory be produced, and instead the aim was to present a different view of theory that takes into account the way in which people summarise and understand the world. In the revised edition (which is in progress and is not presented in the thesis), the aim is to clarify how the metaphorical basis to the way we think (see Lakoff and Johnson 1980, 1999) has direct relevance to the issue of assessing conservation theory and to the points made in the current version of the paper. Further, while some of the points raised in this chapter may appear to be simple, they are not trivial. Despite the important implications of some of the issues that are raised, many academic and practicing conservation biologists do not give them sufficient consideration when applying theory to the study and conservation of biota.

4.0 Summary

Whether or not we use a particular theoretical tool for conservation depends directly on how we define and assess theory. Theories are traditionally ranked according to their 'validity'. Nevertheless, because conservation theory has both heuristic and practical uses, using this approach means we can reject theories and concepts that are potentially useful. We suggest that 'usefulness' is a more appropriate measure of the worth of a theory than 'validity', because it covers a wider range of attributes other than just its ability to give precise predictions or explain. One implication of this is that it requires users of theory to be more

explicit about what the theory is supposed to be useful for, reducing confusion and ill-posed criticism when debating the appropriateness of theory. The approach also highlights the need to identify the limitations of theories and the methods used to assess them. Irrespective of how we assess theory, we suggest that: 1) conservation biologists need to recognise that theories can have many different uses and that all theories will have some limitations. 2) Identifying attributes of theories that make them useful to practitioners may aid the development of practical theory that is less misleading. 3) Qualitative methods will be needed, in addition to quantitative empirical methods, to assess some theories. 4) Continual re-evaluation and rigorous testing of conservation theory is necessary for theory to keep pace with increasing knowledge and changing conservation issues. 5) Because all theories have limitations, a risk-spreading approach using multiple theories will be required to guide many management decisions.

4.1 Introduction

Conservation biology aims to increase understanding of ecological systems and the influence humans have within and upon these systems (Soulé 1985). It also aims to provide knowledge and tools to help alleviate anthropogenic impacts and prevent the loss of biodiversity. Ecological systems are complex with processes rarely being driven by a single cause (Pickett *et al.* 1994). Adding the effect humans have within ecological systems increases this complexity, making the development of conservation theory difficult. It is therefore not surprising that the young discipline of conservation biology is dominated by descriptive research with few publications grounded in theory (With 1997).

Conservation biologists often find themselves in a dilemma. Faced with a need for immediate conservation action, and usually with limited resources, they can either accept and apply a possibly simplistic theory knowing it may not lead to effective long-term conservation of biota, or they can spend valuable time searching for more comprehensive and costly solutions.

Although there are examples where ecological theory has been successfully applied to conservation (e.g. Ripple *et al.* 2001), the scientific community has been criticized for not providing theory that is practical (e.g. Hobbs 1997, Whitten *et al.* 2001). Without practical theory, managers often resort to using simple concepts as tools to help them guide decisions. Such concepts include flagship (Bowen-Jones & Entwhistle 2002), keystone (Kotliar *et al.* 1999) and focal species approaches (Hess & King 2002). They also include rules of thumb, such as those derived from threshold theory (McIntyre *et al.* 2000) or the one migrant per generation rule in conservation genetics (Mills and Allendorf 1996).

There has been considerable debate about the validity and usefulness of these simple concepts. Many are used because of the necessity to act quickly with incomplete data and in the hope that decisions have at least some theoretical basis (Hess & King 2002). In some cases, their application has resulted in conservation benefit, such as helping to raise vital funds (see Bowen-Jones & Entwhistle 2002) or communicating complex ideas and integrating different approaches to solving environmental issues (McIntyre *et al.* 2000).

However, the concepts described above can be difficult to define and apply appropriately (e.g. Mills *et al.* 1993, Simberloff 1998). In addition they are often not supported by empirical evidence (Andelman & Fagan 2000), can have significant biological limitations, or may be theoretically flawed (Lindenmayer *et al.* 2002). There is also the danger that applying overly simplistic concepts may set a precedent where the true complexity and uncertainty of conservation issues is not fully acknowledged (Harrison 1991).

How we define and assess theory has important implications for deciding whether or not we use simple concepts. In this paper we suggest an approach to help conservation biologists advance the debate about the role of theory in management. To do this we provide a practical, rather than deeply philosophical, account of the nature of conservation theory. We begin by defining what we mean by 'conservation theory', then highlight some of the problems that can arise when attempting to assess a theory's 'validity'. We suggest that comparing the 'usefulness' of competing theories can be more effective than attempting to test their validity because it provides a practical way to assess a wider variety of valuable attributes. Finally, we propose several practical activities that can help conservation biologists improve their assessment and use of conservation theory.

4.2 Defining conservation theory

4.2.1 Theory

We define a theory to be a model or conceptual framework that is believed to capture the way that some part of the world works. We all routinely develop a range of private and public 'theories' to help us order daily events, to categorise, to explain and predict (see for example Kelly 1963, Lakoff 1987). While our theories can be explicit and formal, many of them are unconscious and used intuitively (Lakoff & Johnson 1980, 1999). Therefore the definition encompasses a wide range of abstract constructs, ranging from unconscious mental models, notions, assumptions, and generalisations, through descriptive theories and models, to formal mathematical models and physical laws. The higher-level frameworks that bring the different components of theory together are also included, and the terms 'model', 'mental model', 'conceptual framework' and 'worldview' are taken to be synonymous with 'theory'.

The nature of theory has been widely discussed in ecology. While the definition is broader than many others (e.g. Peters 1991, Pickett *et al.* 1994, Wiens 1995, Waltz 1997), it is not inconsistent with them.

4.2.2 Conservation theory

Theories generally help us summarise our understanding of the world and make better use of our knowledge. 'Conservation theory' is therefore defined to be theory that helps us summarize our knowledge of how to preserve, maintain, sustainably harvest, restore or enhance biodiversity and the natural environment.

Conservation theory is based on principles from a range of disciplines (Fig. 4.1). These foundations include: 1) Ecological theory that summarises our knowledge about how the biophysical and biological world works. 2) Conservation-specific ecological theory that summarises our knowledge about how the natural world works when influenced directly or indirectly by humans. 3) Theory from non-biological disciplines such as economics or business management. Table 4.1 lists some of the many applications of conservation theory. The list is not meant to be comprehensive, and a theory may have more than one use depending on the circumstance to which it is applied.

Theory is essential for conservation. Scientists need theory to generate questions and hypotheses, build frameworks of understanding, design studies, integrate different types of information, and help them understand the ecological processes that generate observed patterns. Theory is also essential for conservation practitioners because it allows them to build a picture of how the world operates to guide their actions to mitigate or alleviate human impacts on ecological systems. Theory helps practitioners anticipate the likely outcome of a management action, and reflect on how the results of their actions alter their own understanding.

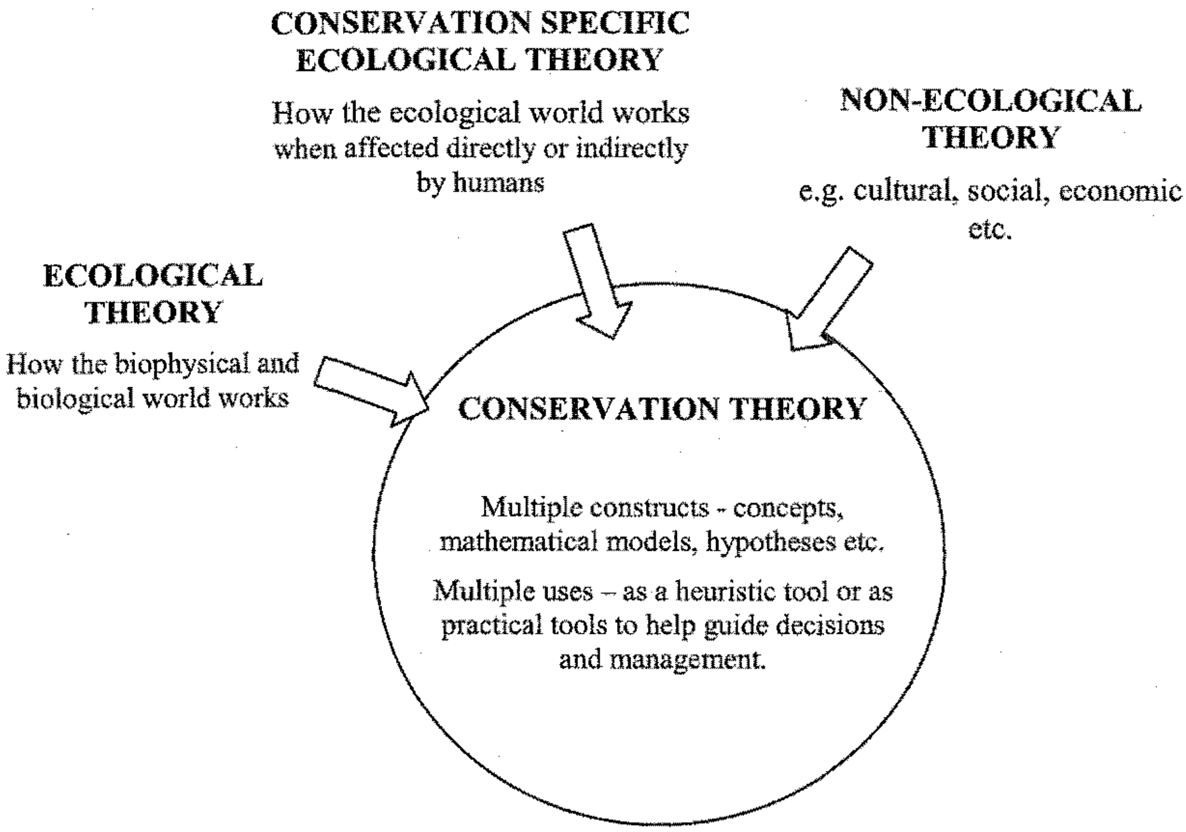

Fig. 4.1: Different components of conservation theory.

Table 4.1: Different uses of conservation theory

Use	Example
Anticipate/Predict	To help make decisions about the likely outcome of a course of action, e.g. by using a mathematical model to anticipate the future population of a species (Lindenmayer & Lacy 1995).
Explain	To suggest a cause of an observation, e.g. using process based metapopulation theory to explain patterns of species declines (Telfer *et al.* 2001).
Describe	To represent a process or collection of observations, e.g. habitat modelling tools (McIntyre 2003)
Facilitate design	To help form a plan or scheme such as a model or framework to assist reserve selection (Margules and Pressey 2000).
Identify key questions	e.g. developing a process based understanding of population changes in fire-prone landscapes (Whelan *et al.* 2002).
Communicate	To convey knowledge between researchers and practitioners, e.g. a framework to help practitioners decide when to transclocate freshwater mussels (Cosgrove and Hastie 2001).
	To communicate to non-ecologists about conservation issues (farmers, politicians, schoolkids etc.) using broad concepts like metapopulation or habitat threshold theory (McIntyre *et al.* 2000).
Motivate/Engage	To increase interest in conservation issues, e.g. focal species as a 'social hook' (see Lindenmayer and Fischer 2003).
	To attract funding, e.g. flagship species (see Bowen-Jones and Entwhistle 2002).
Facilitate change in the way we think	To change how we perceive the world e.g. the contour landscape model (Fischer *et al.* in press b. [Appendix 2])

Nevertheless, there is a distinct lack of conservation theory in the literature, particularly theory directly applicable to management (With 1997). Very little of the published theoretical work is explicitly commented on, reviewed or tested. From a total of 547 papers published in 2001 in three journals devoted to conservation biology (124, 210 and 213 papers from *Biodiversity & Conservation*, *Biological Conservation* and *Conservation Biology* respectively) that only 14.1% explicitly addressed some aspect of theory. 52% of these theoretical papers specifically tested or reviewed the empirical evidence for theory (Fig. 4.2). Of all the theoretical papers, the types of theories most often reviewed or tested with empirical data tended to be those most amenable to a hypothetico-deductive approach (e.g. asking whether indicator species co-occur with other species or whether edge effects occur at habitat boundaries – see Fig. 4.3). The theories least often reviewed or tested with empirical data tended to involve broader concepts or frameworks or more complex ideas. In many of these cases it is often not feasible to assess the theories directly using empirical data.

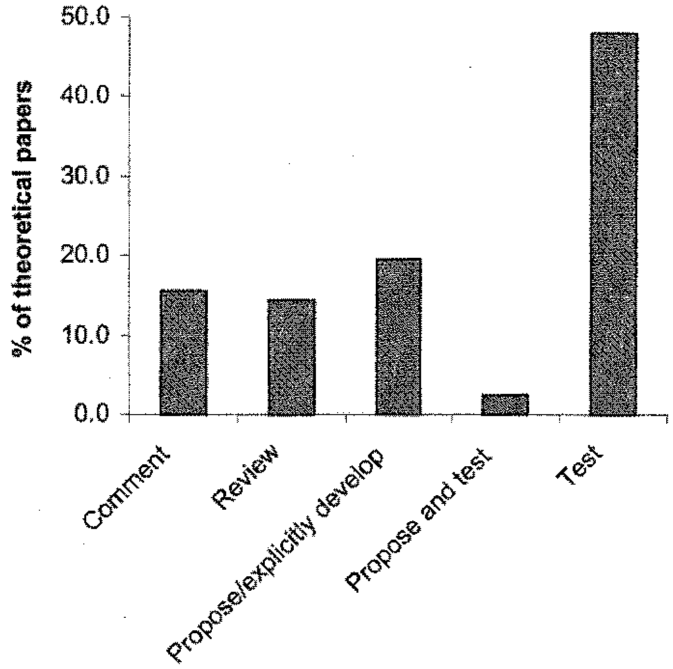

Fig. 4.2: The types of papers explicitly addressing theory (total n = 77) from a survey of 547 publications in 2001.

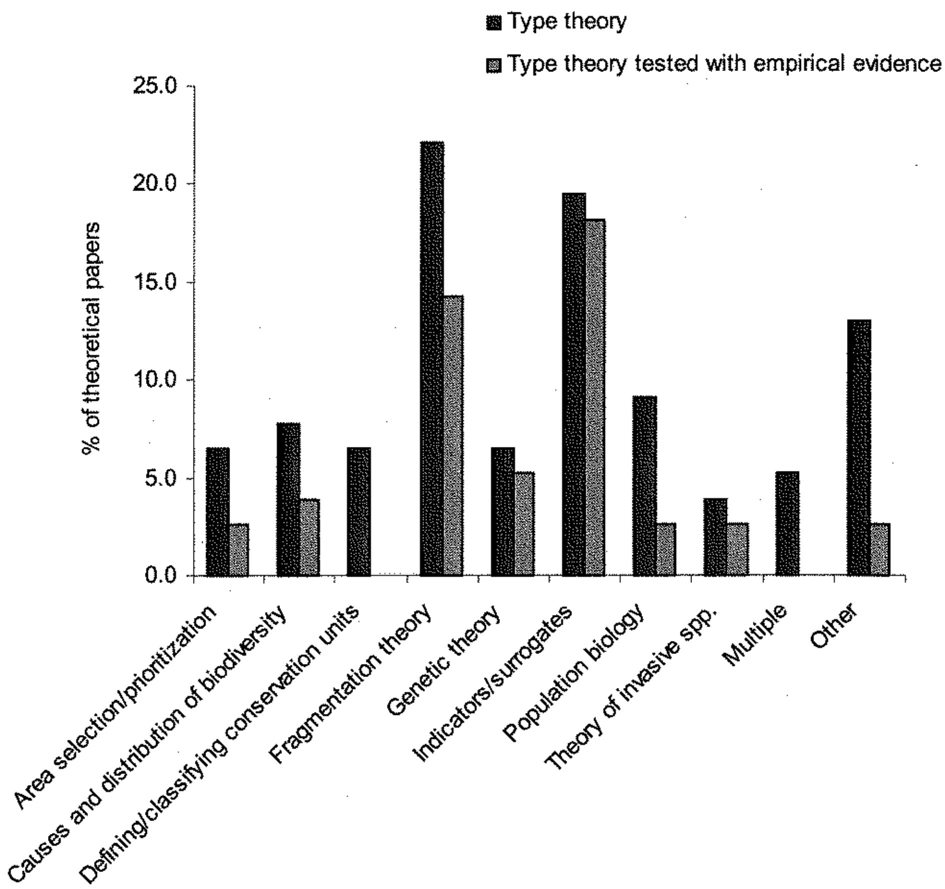

Fig. 4.3: The proportion of theoretical papers for different types of theory and the proportion of theoretical papers for different types of theory tested or reviewed using empirical data (total n = 77).

4.3 Assessing theory

4.3.1 Assessing the validity of conservation theories

In some of the literature of philosophy there is an assumption that theory will only be used as a heuristic tool. This assumption can sometimes lead philosophers to the conclusion there are set criteria for assessing all theory, with considerable emphasis being placed on their 'validity', which is usually taken to mean their predictive or explanatory power (e.g. Watanabe 1975). However, theory does not necessarily need to give precise predictions or full explanations to be useful (as discussed below).

Most people consider a valid theory to be one that gives a good explanation of how the world actually works or that provides reliable predictions. In conservation biology, attempts to determine the validity of a theory usually depend on an assessment of 1) the degree to which the theory is supported by empirical evidence, or 2) the theory's dependence on 'robust ecological principles' (e.g. Andelman & Fagan 2000, Lindenmayer *et al.* 2002).

This approach suffers from four main limitations. First, many important theoretical constructs are not easily 'tested' with empirical data *via* the hypothetico-deductive approach. Second, there will always be some mismatch between empirical data and the theory because theories only describe a segment of the entire system - if investigators try to falsify a theory they will always find something wrong with it (Weinberg 1992, p. 93). Third, asking if a theory is based on 'sound ecological principles' is circular, because the principles themselves have underlying assumptions and generalisations which are just as much affected by the problem of 'proof' as the theory that is based on them. Fourth, the degree to which a theory is 'valid' is not necessarily correlated with its usefulness (see below).

There are two traditional solutions to the first three problems. First, when a theoretically predicted result is not obtained in an experiment, a scientist will often choose to continue as if the theory is correct. They may continue to test the theory, collecting more data or revising procedures, with the intention of providing some confirmation of their ideas (Greenwald *et al.* 1986). This approach is particularly prevalent in the biological sciences (Murray 2001). Second, theories may be altered to take into account the results of experiments by adding auxiliary hypotheses (Lakatos 1978, p. 4). For example, Terborgh (1977) noted that the theory that habitat complexity causes bird species diversity did not hold for tropical forests. He found that other factors, including competitive interactions, changing composition of available resources and a decline in productivity at higher elevations, were involved. Terborgh concluded that avian diversity was a complex community property that could not be explained without adding other theoretical components. In either case, the decision to accept or reject a theory is subjective and involves weighing up the advantages and disadvantages of using a particular theory (Sterman 2000).

The fourth limitation is that validity and usefulness are not necessarily correlated (Fig. 4.4). For example, Copernicus's theory of the Solar System, where the Earth revolves around the Sun and not *vice versa*, has superseded Ptolemy's theory. However, for nearly three centuries, available astronomical instruments were not accurate enough to demonstrate that Copernicus's theory gave a better explanation of planetary motion. For much of this time, both theories seemed to provide equally accurate predictions of planetary motion (Lakatos

1978 p. 169-172). Ptolemy's theory may have been invalid, but it still gave useful predictions.

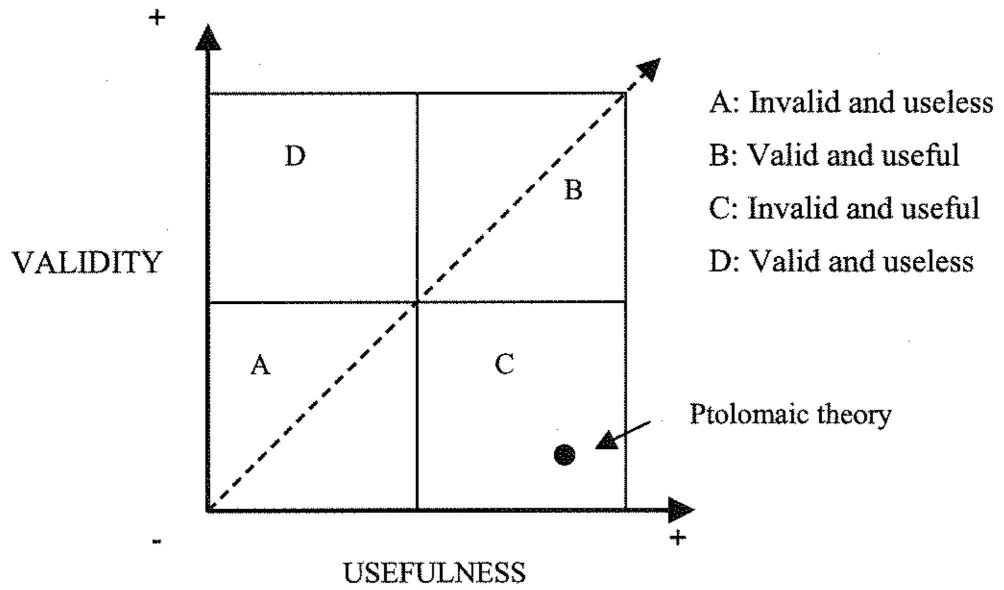

Fig. 4.4: The relationship between validity and usefulness of theory. There are four domains of: A: Invalid and useless; B: Valid and useful; C: Invalid and useful; D: Valid and useless. The dotted line represents a commonly held view that usefulness is positively correlated with validity. As an example, Ptolomaic theory proved to be an incorrect explanation of the workings of the solar system (i.e. invalid), but still provided equally accurate predictions of planetary motion to Copernican's theory for almost three centuries (i.e. it was useful).

The flagship species approach provides an example from conservation. A high profile, charismatic species is used to help raise funds or increase public awareness of the need for the conservation of a 'fleet' of other species that share the same habitat. In many cases it is assumed that the conservation of the flagship will result in the conservation of other species, but this assumption is not necessarily valid and is not easily tested (Simberloff 1998). Nevertheless, if the primary objective is to increase public awareness of the conservation needs of particular species, then the approach may be considered socially useful (see Lindenmayer and Fischer 2003), even if some of its ecological aspects turn out to be biologically invalid.

Because conservation theories can have many uses (Table 4.1), a validity-only approach can lead to the loss or suppression of useful ideas. It is therefore generally better to use an approach that encourages a weighted assessment of a broader range of attributes of a theory (usefulness), rather than just focussing on its ability to predict or explain (validity).

4.3.2 Comparative usefulness of conservation theory

A 'useful' theory is defined as one that helps its users achieve a desired end. Under this definition, a theory can only be judged by its success in achieving what it was supposed to be useful for, or for which it was designed. For example, the focal species approach was originally developed as a practical tool to guide the restoration of landscapes. The basic idea was to manage landscapes for those species affected most by key threatening processes, such as habitat isolation or resource depletion (Lambeck 1997). However, the focal species concept has also been used to guide the deconstruction of landscapes, i.e. to determine where areas of habitat can be removed from a landscape without major ecological impact (e.g. Rubino and Hess 2003). To claim the focal species approach is useful, independent assessments are required of each use.

Regardless of whether we are asking about validity or usefulness, the only practical way to assess a theory is to compare it with another. Such comparative, or differential, measures are more robust than methods that require absolute assessments and provide a more powerful process to drive scientific progress. It is recognised there will be many cases in conservation biology where there are no alternative theories to use as a comparison - in such cases a given theory can always be compared with a less advanced version of itself.

The most desirable attributes of theory and their relative importance are dictated by the problem to which the theory is to be applied. Table 4.2 gives some of the most important attributes. Fig. 4.5 explains the attribute 'range of convenience'. The list is not meant to be comprehensive and the attributes are not necessarily mutually exclusive, e.g. a more 'accessible' theory that does not rely on computer technology may be more 'practical' if it is to be used in developing countries. In many cases the most important attributes determining a theory's usefulness will be its ability to predict or explain.

Table 4.2: Attributes of usefulness of theory

Prediction	Range of convenience	Range of circumstances in which the insights and/or predictions from a theory can cover (Fig. 4.5). One theory may be considered more useful than another if it can provide insights to a greater number of situations, species landscapes etc.
	Accuracy	The correctness of a theory's insight or prediction – e.g. the degree to which it is certain a prediction of a result is larger or smaller than a value, or how likely a specific value will be the real value.
	Precision	The exactness of a theory's insight or prediction – i.e. is the result qualitative (e.g. concave or convex, more or less) or quantitative – e.g. the number of decimal places. The prediction can be a accurate but not precise and *vice versa*.
	Consistency of error	Is the value provided by the theory consistently erroneous? E.g. the error might always be two measurements greater than the real value.
Explanation		How well a theory tells us why something happened. Prediction without providing a reason is useful, but such a tool is a poor substitute for understanding. If we understand we will also be more able to predict.
Simplicity		Simplifying some aspect of the world is essential for a theory to be a useful summary of our understanding. The simpler a theory is, the more likely it will be useful. However, there is a clear distinction between simple and simplistic. Simple theory avoids unnecessary detail, whereas simplistic theory has the connotation of being misleadingly simple. Albert Einstein once commented that a theory should be as simple as possible but no simpler.
Accessibility		The range of people who can use a theory easily, e.g. a model or theory that requires arcane mathematics or complex computer packages would be less accessible than a framework written in relatively non-technical language. The clarity with which the theory is expressed, and the language used to express it are also important attributes that may affect the usefulness of a theory.
Prescriptiveness		How well a theory tells you how to think. Does the range and quality of the concept focus attention on what is meaningful or significant, on facts and solid ideas rather than just on opinion, the trivial or tautologous?
Productivity		How well does a theory generate new work, thoughts and hypotheses?
Practicality		Can include many attributes – can the theory be easily be applied, does it take into account the constraints practitioners are working under? E.g. - a framework that summarises ecological processes to help assessors decide whether a proposed development will trigger legislation aimed to protect listed species. The framework may need to help the decision process, help achieve consistency between assessors or document the thought process that takes them to the decision that has been made. It may also need to work under certain bureaucratic constraints. Realism of the model should be compromised as little as possible, but the framework might be useless if it weren't practical.

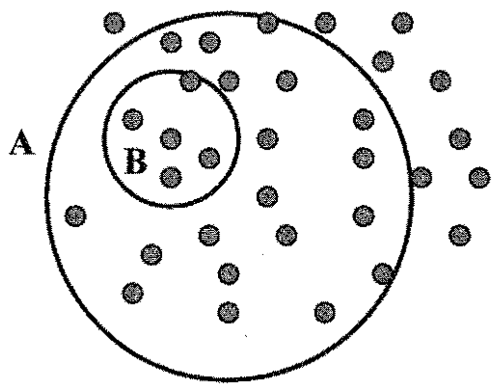

Fig. 4.5: The range of convenience of two different theories. The grey dots represent different cases in which a prediction or insight from a theory is required. The larger circles represent the range of circumstances of the theory A and B. A has a larger range of convenience than B.

The 19th century philosopher Charles Pierce believed science continues to advance because of the unattainability of the absolute truth. Although human knowledge is constantly progressing, perfect and absolute truth must be seen as an ideal limit which we cannot reach (see Chen 1994, p. 48-49). Similarly, usefulness is not absolute. There will always be scope for improvement such as developing a theory that is just as practical, but is more predictive. There will always be the potential for a more useful theory, and so the continuous re-evaluation and testing of theory is required.

There are four important reasons for focussing on the comparative usefulness of conservation theories:

1) It reduces the chance of abandoning potentially useful theories.

2) It ensures a healthy focus on the limitations of theory. Rather than seeking evidence that a given theory is valid, attention should be focused on the theory's limitations to ensure that it is not misused (Sterman 2000).

3) It allows scope for the development of conservation theory that is valued for its practicality in addition to the traditional attributes of prediction and explanation.

4) It requires the user to be more explicit about what they are trying to achieve when using a particular theory.

If such an approach is to work, then users must learn to state clearly the context within which a given theory is supposed to be useful. Unfortunately, the intended use of theories is often confused or ill defined (e.g. corridors; Hess & Fischer 2001, ecological boundaries; Strayer *et al.* 2003). A focus on clear definitions of usefulness would help to reduce confusion and ill-posed criticism when debating the appropriateness of a conservation theory.

4.3.3 The Usefulness of Simple Theory

Theory can help us achieve a desired end, but it can also be misleading. At best, a misleading theory can be unhelpful; at worst it can have negative consequences for biodiversity. For example, the keystone species concept suggests that a few species have strong community interactions and effects, and thus protecting them could be an effective way to conserve others. However, because strong ecological interactions do not necessarily occur and it can be difficult to identify keystone species, conservation activities based on the approach could be a waste of valuable time and resources (Mills *et al.* 1993). There is now considerable evidence that restoration and management based on simple concepts that do not consider the context specific relationships between an ecosystem's environment and its organisms are misguided (e.g. Platt & Peet 1998, Schmiegelow & Monkkonen 2002). Claims that some conservation theories are simplistic and misleading are therefore fully supported (e.g. Harrison 1991, Andelman & Fagan 2000, Lindenmayer *et al.* 2002).

Nevertheless, there is also the problem that we rarely acknowledge that the structure of our minds and our bodily experiences greatly influence the way we think and therefore whether we accept or reject a particular theory (Lakoff & Johnson 1999, Anderson 2001). Hoffman (2003) suggested that certain attributes of theory figure prominently in a person's decision to accept or reject it. He suggested those that get accepted tend to: 1) be simple; 2) tell a good story; 3) do not need consultation with their originator; 4) stimulate experiment; 5) provide a framework for understanding (even if they are not very predictive); or 6) bring clarity to a small corner of the world. Our decision to use a theory is also influenced by factors including our education, cultural values, previous experiences, or the status and strength of the personality of the person proposing a theory.

A good example of a widely acclaimed conservation theory is metapopulation theory (*sensu* Levins 1969). However, the generality of metapopulation dynamics has been questioned (Doak & Mills 1994) and there are few species whose populations behave in a classical metapopulation way (Harrison & Taylor 1997). Many of the assumptions of the theory are rarely met, e.g. species may not be confined to specific habitat types (e.g. Telfer *et al.* 2001), and many have dispersal rates that are either too high or too low for metapopulation theory to fully explain regional dynamics (Doak & Mills 1994). The concept also sets an expectation that habitats can be neatly delineated, thereby playing down the role of the matrix in conservation. This can set a dangerous precedent that current activities between habitat patches (e.g. agriculture) have no detrimental effect or that the matrix has little value for conservation (Fischer *et al.* in press a. [Appendix 2]).

Despite these limitations, the metapopulation concept has been widely accepted (e.g. Stinchcombe *et al.* 2002). Many consider the metapopulation concept has been successful because of its perceived heuristic value and mathematical tractability (e.g. Telfer *et al.* 2001). It has, however, been successful also because it is easy to understand at a generic level, helping practitioners explain the need for conserving more than one population of a species to non-ecologists, and emphasising the need for conservation at multiple scales (e.g. Lindenmayer 2000).

There will always be situations where simple theories are more useful than complex theories, particularly when field conditions make tests of predicted outcomes difficult or impossible to perform. The human mind did not evolve to fully understand complex dynamics and probabilites, and concepts like flagship, umbrella and focal species tend to be accepted primarily because they reflect the metaphorical way we think about and understand the world (Lakoff & Johnson 1980, 1999). We suspect that metapopulation theory is widely accepted not because it is computationally sophisticated in application (although there will be those who value this aspect of the approach), but because the basic concepts of the theory fit neatly with the way humans look at the world, i.e. there are discrete units of habitat that people can delineate, categorize, and think about in simple terms. For the human mind, "a model of reality that assumes less, and promises less may be more reliable than one that includes a lot more detail" (Anderson 2001).

4.4 Suggestions

We are a long way from achieving fully integrated ecological or conservation theory (Pickett *et al.* 1994, Holling 2000). We will therefore be using imperfect theoretical tools to guide management and restoration for the foreseeable future. Irrespective of how we assess theory, it is suggested that:

1) Academics, practitioners and non-biologists need greater awareness that theory can have many different uses and that all theories will have limitations. Academics can play an important role in ensuring that the limitations of theory are clearly understood by practicing conservation biologists and non-biologists. Practitioners need to explicitly state the

weaknesses of the theory they use when talking to non-biologists. Being open about a theory's limitations is not easy in a critical and competitive academic environment, nor in an environment where experts are expected to deliver a single 'correct answer'. However, being clear about what a theory is supposed to be useful for can reduce confusion and undue criticism.

2) Conservation biologists have often been drawn towards simplistic theory out of desperation for something practical. Identifying some of the attributes of theories that lead practitioners to consider them useful may aid the development of practical theory that is not misleading.

3) Not all of the theoretical constructs applied to conservation will be amenable to testing using statistical or quantitative methods. Qualitative methods will also be required to compare theories.

4) Applied conservation theory needs to change to keep pace with increasing knowledge of ecological systems and conservation issues. This requires continual re-evaluation and rigorous testing of the usefulness of conservation theories. For example, greater understanding of human-impacted environments has demonstrated that habitat fragments are not equivalent to islands in a sea of inhospitable habitat. This has ultimately resulted in the recent rejection of the theory of island biogeography as a useful tool for some conservation problems (Haila 2002). Specific assessment of its usefulness for conservation management may have resulted in its limitations being highlighted sooner.

5) No single theory will ever give us a definitive conservation approach. We therefore need to apply multiple approaches to guide conservation action. This risk-spreading strategy was strongly advocated in a critique of the focal species approach (Lindenmayer *et al.* 2002). Although the critics did not necessarily reject the focal species approach as a tool for restoration, they did express considerable concern that it would be widely adopted without acknowledgement of its limitations. Much of the criticisms were based on the premise that it would not work in all situations or for all species. Consequently, Lindenmayer *et al.* (2002) suggested using multiple restoration approaches to spread the risk of a single one proving deficient or unworkable. Such risk spreading strategies applied at multiple spatial scales will be a useful way forward for many conservation issues (Lindenmayer & Franklin 2002, p. 51).

In this paper it has been suggested that we need to broaden our focus from 'validity' to a more inclusive concept of 'usefulness' when assessing conservation theory. This broader approach does not reduce the need for rigorous assessment and scrutiny of the theoretical approaches currently being applied to conservation problems.

Conservation biologists rarely state the theoretical basis of their studies (With 1997) let alone what they are trying to achieve by using a particular theory. A call is therefore made on those who develop or use a theory to be more explicit about what the theory is supposed to be useful for, and think carefully about how they evaluate its effectiveness. Academics, conservation practitioners and non-biologists need to recognize that all theories have limitations, be open about the weaknesses of their theories and the methods used to assess them, and give greater consideration to the need for risk-spreading strategies that apply multiple approaches over multiple spatial scales.

4.5 Acknowledgements

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Chapter 5

APPLYING ECOLOGICAL THEORY FOR CONSERVATION MANAGEMENT

Citation: Ioan Fazey & Andy McQuie (In Press). Applying ecological theory for conservation management. Ecological Management and Restoration.

5.0 Outline

This study explores how conservation practitioners use ecological theory and the constraints to its application. The work is based on the results of observations, discussions and interviews with staff of the North Plains Region of the New South Wales National Parks and Wildlife Service (NPWS).

5.1 Introduction

Theory is essential for effective conservation because it helps people understand the complexity of the real world by providing a summary of the way that some part of it works. Scientists need ecological theory to generate questions and hypotheses, build frameworks of understanding, design studies, integrate different types of information, and help them understand ecological processes (Pickett *et al.* 1994). Practitioners need ecological theory to help them build a picture of how the world operates, guide their actions and help them understand how the results of those actions fit within the context of the problem they are addressing.

Conservation has been criticised for not basing its science on theory (With 1997) and for not providing useful theory for practitioners (e.g. Hobbs 1997). A starting point to addressing such issues is to ask how practitioners apply ecological or conservation theory and begin to identify some of the practical constraints to this process.

5.2 Methods

Research was conducted between March and June 2004 while principally based at the Coonabarabran area office of NPWS. During this period the senior author assisted with field operations and had numerous discussions with staff. Semi-structured interviews were conducted with 12 staff from the North Plains Region who were involved in the planning and management of conservation activities. Three subjects were women, a proportion roughly equivalent to that in the workplace of the North Plains Region of NPWS. Interviewees were selected to cover activities over a range of ecological systems (single species to broad habitat types), scales (local to regional), and issues (management of forests, grassland, fire, water and pests).

Subjects were asked about their education and experiential background, the nature of their job, and the role of ecological theory in their work. They were also asked to identify constraints to the application of ecological theory, and were then presented with a list of possible constraints for comment. Interviews lasted between 1 – 2 hours. Transcripts were coded and analysed using a grounded theory approach (Strauss and Corbin 1990).

5.3 Results and Discussion

5.3.1 Work activities, education and experiential background

Equal numbers of subjects fell into three broad categories: 1) Those who primarily planned activities, 2) those with roughly equal planning and implementation roles, and 3) those who primarily implemented conservation work. Planners tended to conduct desk-based work, including research, whereas implementers were largely concerned with ensuring management plans and policies were implemented. Planners spent more time on activities to which formal ecological theory had greater relevance, compared to implementers whose duties were often practical or administrative.

While all interviewees had graduate qualifications, the type of education differed between the three groups. Planners had a strong ecologically-oriented education, planners/implementers a mix of ecological and general science degrees, and implementers a more general or applied science education. Experiential background also differed with planners predominantly having research backgrounds, planners/implementers a mix of ranger and planning experience, and implementers having a strong background as rangers.

5.3.2 Explicit and implicit use of ecological theory

Almost all interviewees indicated that they frequently used ecological theory when dealing with conservation-related activities. However, theory was usually applied implicitly. Subjects found it difficult to articulate precisely which theory they applied to address a particular issue, and they used and integrated a range of principles by pulling out a mix of theory from a "mishmash somewhere in the back of (their) head". Articulating which ecological theory was being used at any one time was also difficult because it was only one aspect that influenced a decision. As one implementor put it:

"It's a bit like a cake recipe; the environmental theory gets thrown into the mixing bowl (with) environmental experience, life experience and personality. At the end you get the product that is the solution or the explanation of how something works."

While all subjects frequently applied ecological theory implicitly, they differed in how often they used it explicitly. Planners tended to do this more often, and felt they could be explicit about what they were using, if necessary. On the other hand, implementers rarely felt their work required them to be explicit about which ecological theory they were using, although they did acknowledge that the implicit use of theory influenced their decisions.

5.3.3 Top down flow of ecological theory through the institution

The flow of ecological theory through the agency was largely a top-down process. This is because many of the conservation-related decisions are made at policy and planning stages, and decisions have already been made for those implementing them. Ecological theory is often embedded in policy or planning documents without the knowledge of the implementers. One planner remarked that implementers "don't necessarily know they are using theory, as there are lots of things set up for them already".

Planners therefore have a much greater influence on how ecological theory enters the decision making process through both their position in the hierarchy of decision-making, and because they have a stronger education and background in ecology, and greater exposure to in-house or external ecological research. Compared to implementers, constraints affecting planners will therefore have the greatest impact on the effectiveness of NPWS to apply ecological theory (Fig. 5.1).

Flow of ecological theory through the institution

	Constraints to the application of ecological theory
PLANNERS Strong influence on application of ecological theory: • Strong ecological education • Strong research background • Greater exposure to ecological research	• Managerial staff who do not understand the nature of ecology • Insufficient time to search the literature for theory • Often insufficient information about species/ecosystem to apply theories • Insufficient resources
EQUAL PLAN/IMPLEMENT	• Lack of monitoring prevents effective validation of theories • Not enough time to apply theories appropriately • Sometimes insufficient information about species/ecosystem to apply theories
IMPLEMENTERS Weak influence on application of ecological theory: • More general education • Practical background • Less exposure to ecological research	• Do not know enough about what's in the literature to be able to apply theories • Insufficient time to search the literature for theories • Theories are not specific enough to deal with context specific issues

Fig. 5.1: Factors detected that influence the application of ecological theory. Planners have a much stronger effect on the application of ecological theory because they have a greater role in conservation related decisions, and have a stronger ecological education/background and greater exposure to ecological research. Practical constraints affecting planners will therefore have the greatest overall impact. Constraints are only listed if at least half of the subjects in each job type considered them to be important.

5.3.4 Constraints to the application of ecological theory

A variety of constraints to the effective application of ecological theory were suggested, with the most common shown in Fig. 5.1. There were differences between the three groups as to what constraints were considered to be important. Implementers felt they did not know enough about what was in the literature and did not have enough time to find out. They also felt that many ecological theories were not specific enough to the problems they were trying to address.

Interviewees with roughly equal planning and implementation roles generally felt there was insufficient information about a species or ecological system to apply a theory appropriately, or did not have enough time to do so. They were the only group that commented on the lack of monitoring and validation as a significant constraint to the effective application of ecological theory. This was perhaps not surprising given they were in a unique position where they both planned and executed decisions. When planning future actions they had a lot to gain from reflecting on the outcomes of previous ones, and were in a better position to do so.

All planners emphasised the problem that managerial staff who did not understand the nature of ecological systems often heavily influenced final decisions. They commented that many of the managers had little ecological background, and therefore did not appreciate that conservation decisions are rarely "black and white". The planners felt the situation was exacerbated by the recent merging of the Environmental Protection Agency (EPA) with NPWS to create the Department of Environment and Conservation, as many of the managers from EPA were now influencing NPWS-related decisions. The planners pointed out that many of the EPA managers were more at home with quantitative tests from which to draw conclusions, such as whether a pollutant in a river had reached a certain level. They were less familiar with incorporating ecological principles when making more complex and value-laden decisions such as whether sufficient water had been allocated to maintain the health of a river system.

In this study, we found that ecological theory was usually applied implicitly, irrespective of whether the individuals are planners or implementers. The background and experience of those making the decisions therefore had a major influence on how individuals perceived and/or dealt with an issue. With limited ecological background, the worldview of managerial staff is substantially different to that of planners and implementers. Because the managerial staff have such a strong influence on final decisions in an agency where ecological theory flows top-down, any lack of ecological understanding by the managers is likely to be a major constraint to the effective application of ecological theory. Solutions to this problem lie in ensuring that more managers have an ecological background, and that they are aware of the difficulties of dealing with conservation issues and take them into account when making their decisions.

5.4 Acknowledgments

This research could not have been conducted without the support of NPWS staff at the Coonabarabran Office. D. Lindenmayer, S. Dovers, B. Newell, and T. Soderquist provided constructive comments on the manuscript. IF was supported by a GSS scholarship from the ANU, and funds from D. Lindenmayer.

SECTION C:

ELICITING IMPLICIT KNOWLEDGE

Chapters 4 & 5 suggested that: (1) Theories are summaries of a complex and dynamic world and therefore all theories will have limitations; (2) multiple concepts are necessary to guide conservation actions; (3) the human mind significantly affects the theories we accept; (4) ecological theory is combined with a multitude of other experiences to generate "personal theories" to guide decisions.

Section C considers the issues addressed in Chapters 2-5. Chapter 6 is a case study of eliciting the implicit knowledge of on-ground conservation managers working in a complex and dynamic wetland system where data and appropriate research are lacking. The influence of previous chapters is highlighted in Fig. C.1.

There are three main initial influences on the study. First, in accordance with the need for greater links between research and practice (Chapters 2 & 3), the study was informed by working and consulting with the conservation practitioners, rather than making independent assumptions about the type of research that was required. In this case, the practitioners wanted to be able to articulate their understanding of the conservation of the wetland to ensure that adequate focus was given to the ultimate causes of the conservation problems, and not just to dealing with the symptoms of the problems.

Second, consideration was given to the need for the research to be accessible to a wide audience (Chapter 3). The study was therefore intended to be a publication, produced in a way that ensured the results could be understood by people from a broad range of backgrounds. The intention was to submit the paper to "Ecology & Society", which is a free journal accessed through the internet. Extensive use of appendices helped mould the chapter to the journal format.

Third, the dynamism and complexity of the wetland system meant that other approaches, in addition to experiments, were needed (Chapter 3). It was felt that an experimental approach would have been unable to capture the complexities of the conservation issues. Another problem was that previous research and data were limited, yet there was extensive on-ground experiential knowledge about the conservation of the wetland.

The study therefore aimed to elicit the implicit knowledge of on-ground managers about the conservation issues affecting the wetland that was disseminated through a publication that used a conceptual model to explain the complexities and dynamics of the conservation issues affecting the system.

To achieve the aims of the study, three main issues were considered. First, because experiential knowledge is a collection of implicit and explicit theory, research, educational, environmental and personal experience (Chapter 5), research methods were required that captured the "whole" of the practitioners' set of experiences. The study therefore employed qualitative methods including a combination of semi-structured interviews and a workshop.

Second, when developing formal theory with a practical focus (in this case a conceptual model) it is important to be clear about what the theory is supposed to be useful for, acknowledge its limitations and consider the influence of human cognition on the acceptance of the theory (Chapter 4). The model aimed to be a communication tool to be accessible to a wide audience (including politicians and landholders). Given that humans do not deal well with complex probabilities and feedback in dynamic systems, the model was designed to be largely visual and relatively simple. However, it was important to ensure that by being simple, it did not lose the essence of the dynamics of the system and become misleading (Chapter 4).

Third, the dynamism and complexity of environmental systems means that holistic and interdisciplinary approaches are often required (Chapters 2 and 3). Practitioners were asked to draw boundaries around the components of the system they felt were most important and relevant. The study was therefore not confined to bio-physical realms, but also integrates social, political and economic issues.

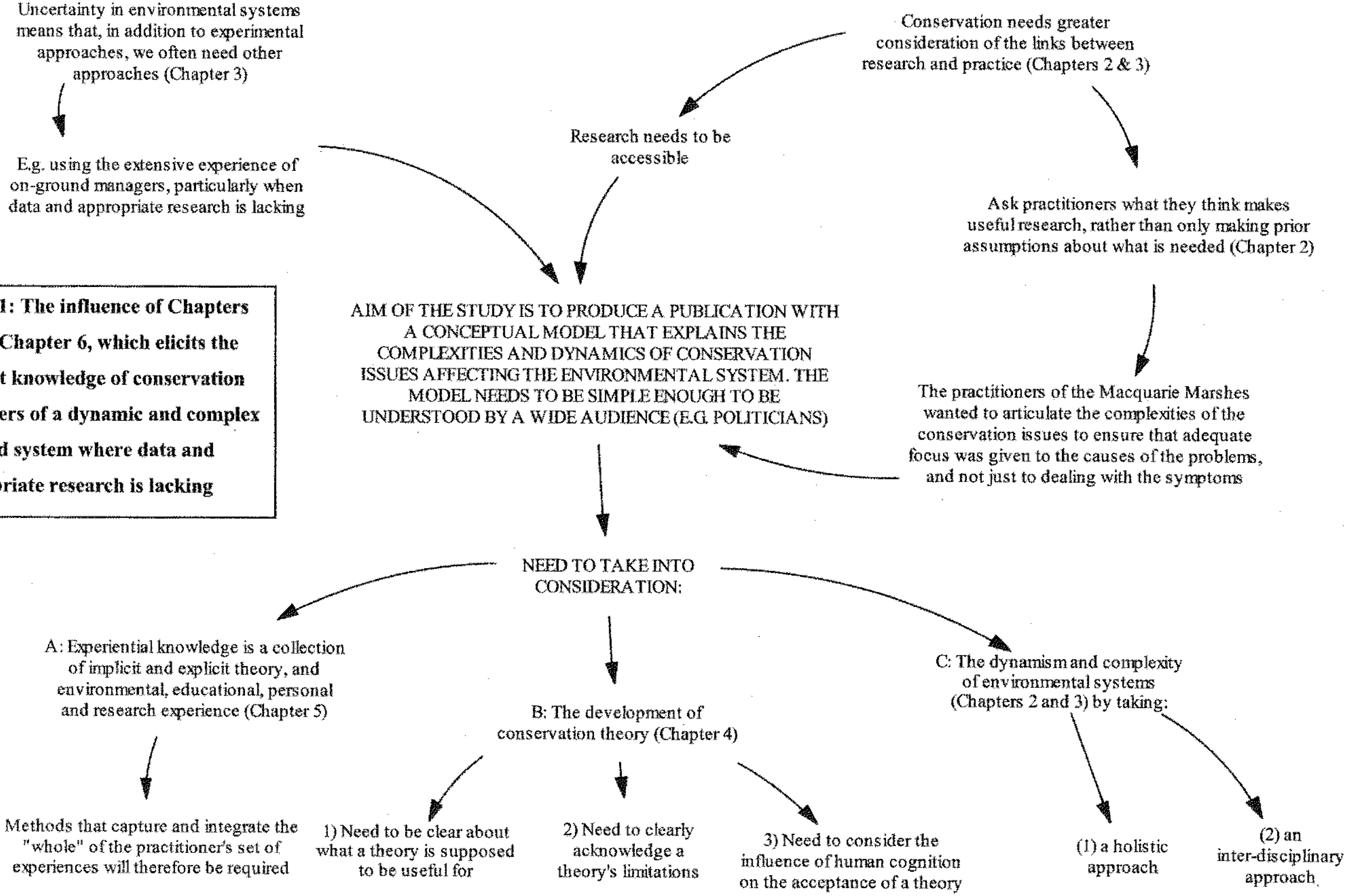


Fig. C.1: The influence of Chapters 2-5 on Chapter 6, which elicits the implicit knowledge of conservation managers of a dynamic and complex wetland system where data and appropriate research is lacking

Chapter 6

ELICITING THE IMPLICIT KNOWLEDGE OF ON-GROUND MANAGERS: A CASE STUDY OF THE MACQUARIE MARSHES

Citation: Ioan Fazey, Katrina Proust, Barry Newell and Bill Johnson (Submitted). Eliciting the implicit knowledge of on-ground managers: A case study of the Macquarie Marshes. Ecology and Society.

6.0 Summary

Experiential knowledge can be particularly valuable for guiding conservation action. We capture the extensive implicit understanding of seven on-ground conservation managers about the conservation issues affecting the Ramsar listed Macquarie Marshes in New South Wales, Australia. Multiple interviews, a workshop, and meetings were used to elicit the managers' knowledge about the main problems affecting the conservation of the wetland, the impediments to achieving effective conservation outcomes, and the feedback dynamics that reinforce the lack of conservation action. The results suggest that: (1) the Macquarie Marshes are seriously threatened by lack of water; (2) there are many complex interacting social, physical, political and institutional impediments to achieving effective water delivery; (3) immediate steps need to be taken to achieve more effective water delivery and (4) there are strong feedbacks in the system which continually reinforce the tendency for water agencies to favour the short-term interests of the irrigation industry. The feedback is primarily driven by three factors: (1) the community's belief in economic growth; (2) the water agencies' traditional engineering and resource-use worldviews; and (3) individual's drive to protect their own interests. Without major governmental intervention and a shift in the prevailing worldviews of the water agencies and the public, the health of the Macquarie Marshes is likely to continue to decline.

6.1 Introduction

Environmental practitioners rely heavily on experiential knowledge when planning and implementing conservation actions (Fazey and McQuie In Press, Boiral 2002). Without such knowledge, many day-to-day management activities would be ineffective. Thus, given the complexity of socio-biophysical systems and the inevitable lack of data and appropriate research, it is often the amount of experience a practitioner has about a particular system that counts most when making judgements about resource management (Woodwell 1989).

Quantitative methods to combine expert judgement with field data are being employed in conservation (Calheiros *et al.* 2000, Martin *et al.* in press). However, experiential knowledge is often difficult or impossible to articulate quantitatively (Polanyi 1997, Boiral 2002). Researchers have therefore turned to social science methods to elicit expert knowledge. Such approaches have been used to help understand patterns of vegetation change (Lykke 2000), determine natural flood regimes (Robertson and McGee 2003), and guide ecosystem management (Olsson and Folke 2001).

Qualitative experiential knowledge can generally be separated into two categories: (1) implicit knowledge, and (2) tacit knowledge (Nickols 2000). Implicit knowledge is that which can be, but has not been, articulated. It includes knowledge that can be teased out of an expert, such as how to set traps for feral animals, or how to operate GIS systems. Conversely, tacit knowledge cannot be articulated. That is the expert may "know more than they can tell" (Polanyi 1997). For example, expert trappers might not be able to explain precisely how they know where to set their traps, and instead rely on intuition to inform their activities. Such in-depth expertise, built through many years of experience, reflects a much deeper understanding than simply recalling isolated facts or using general strategies (see Fazey *et al.* Revision submitted [Chapter 7] for a discussion of expertise in an environmental context).

On-ground conservation managers are in a good position to develop implicit and tacit knowledge about environmental systems because they see first-hand the short- to medium-term results of management decisions (Whiteman and Cooper 2000). In this paper, we capture the extensive experience of seven on-ground conservation managers of the Macquarie Marshes (referred to herein as the "Marshes") in south-eastern Australia. We aimed to elicit their implicit understanding of: (1) the main problems affecting the conservation of the wetland, (2) the impediments to achieving effective conservation outcomes, (3) actions required to achieve more effective outcomes, and (4) the feedback dynamics within the system that may be contributing to the lack of conservation action. Our aim has been to capture and articulate the experience of those directly involved in the conservation of the Marshes. The results clearly show that in order to achieve effective conservation the involvement of many different stakeholders will be required.

6.2 Approach

6.2.1 Study area: The Macquarie Marshes

The Marshes are a large, complex and ephemeral wetland situated in the lower third of the Macquarie River catchment in the central-west of New South Wales, Australia (see figure 6.1). The Marshes cover around 220,000 ha, (Brereton *et al.* 2000). Within this area, 21,654 ha is managed as a Nature Reserve by the Department of Environment and Conservation (DEC) (formerly New South Wales National Parks and Wildlife Service). The reserve is in three main blocks: the Northern and Southern Marshes, and the Ninia property. The Marshes are important ecologically with both the Reserve and a private property being listed under the Ramsar Convention. The wetland is best known for its extensive reedbeds, river redgum forests and is arguably Australia's most important breeding site for colonial nesting waterbirds (Kingsford and Auld 2003). The Marshes are also important for the economy of the local community, which is reliant on flooding to provide vegetation growth for cattle grazing (Brock 1996).

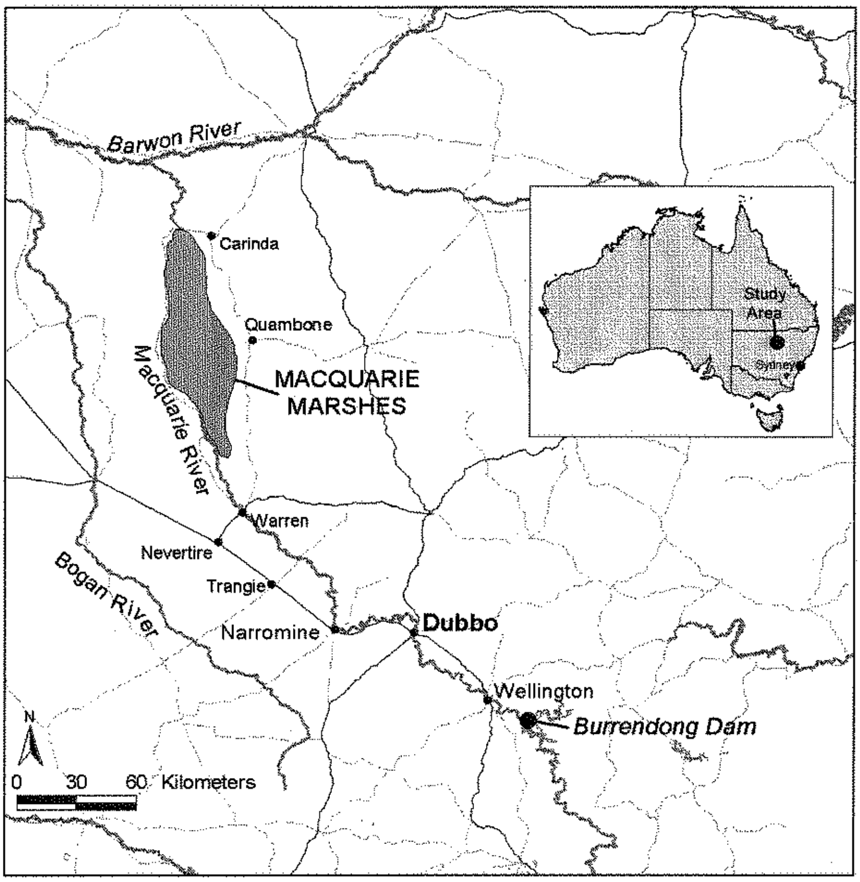


Figure 6.1: Location map of the Macquarie Marshes.

Water flows through the Marshes are highly variable, with the flora and fauna dependent on flooding events. However, the natural flow regime has been significantly altered since the completion of Burrendong Dam in 1966 (Kingsford and Thomas 1995, Kingsford and Johnson 1998). This dam is located 250 kilometres upstream of the Marshes. Currently there are seven significant dams in the Macquarie River catchment, which regulate flows to support urban towns and agricultural enterprises (Wolfgang 2000). There is also considerable conflict between stakeholder groups due to the over-allocation of water resources (see Smith 1998).

6.2.2 Participants

Seven on-ground conservation managers participated in this study. They included DEC staff and members of the Macquarie Marshes Management Committee, an organisation of landholders working towards the sustainable management of the Marshes (Jones 2003). By on-ground conservation managers, we mean those who are or have been based primarily at the Marshes, and who are actively involved in either managing some aspect of the ecological system or managing and dealing with issues of water delivery for the purposes of conservation. They are referred to herein as the 'mangers'.

Individual managers were chosen primarily because of their expert knowledge which has been directly built from observations of the ecology of the wetland, and through their experience of being involved in the conservation of the Marshes. They had a total of 140 years of being involved in the management of water on the Marshes, 234 years of experience of the Marshes generally, and 275 years of exposure to or working on Australian wetland and riparian systems. Some of the managers have spent most of their lives on the Marshes and have learnt from previous generations of landholders with similar amounts of expertise.

6.2.3 Method

The research was conducted between February and August 2004, when the first author was primarily based at the Coonabarabran Area Office of DEC. The implicit knowledge of the participants was captured using multiple interviews, a workshop, and a group meeting. To articulate the feedback processes inhibiting effective conservation action a conceptual model of the social, economic and biophysical system of the Marshes was developed using causal loop diagrams (CLDs) (see Appendix 6.7.1 for full details of the methods). Figure 6.2 illustrates the labelling conventions for CLDs and how to interpret them (see Sterman 2000 for detail).

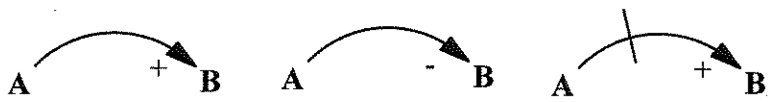


Figure 6.2: Labelling conventions for causal links. The arrows indicate that a change in variable A causes a change in variable B. Each link is assigned a polarity. The polarity of the causal link between A and B is said to be positive when an increase/decrease in A causes B to increase/decrease above/below what it otherwise would have been. A causal link is negative when an increase/decrease in A causes B to decrease/increase below/above what it otherwise would have been. A short line indicates that there is a delay between a change in A and the corresponding change in B.

The expressed implicit knowledge of the managers is presented under four headings in the results: (1) the underlying convictions about the wetland; (2) the impediments to achieving effective water delivery; (3) immediate action that is required to help reduce the rate of ecological change on the wetland; and (4) the feedback dynamics contributing to the difficulties of achieving effective conservation outcomes.

Sections (1)-(3) and the material presented in Appendix 6.7.2 are derived from data collected during the interviews and the workshop. In many cases, the managers referred to documents for detail and/or to back up their statements. These documents have been included as references in the results for completeness. Section (4) presents the conceptual model of the Marshes system, which the researchers developed on the basis of the managers' views and using additional supporting documents. Extensive feedback on all sections of the results and appendices has been sought from the participants to ensure that their knowledge has been presented accurately (see Appendix 6.7.1).

6.3 Results

6.3.1 Underlying convictions

The managers have four main convictions about the wetland. Some of the evidence for these convictions is provided in Appendix 6.7.2. The convictions are: (1) the Marshes are an extremely important part of Australia's natural and cultural heritage; (2) a functioning wetland ecosystem is vital to the local community; (3) the Marshes are undergoing major ecological change and are seriously threatened; and (4) the main cause of the threat to the wetland is lack of water (primarily caused by over-extraction upstream of the Marshes).

6.3.2 Impediments to effective water delivery

To the managers, "effective water delivery" means the establishment of an appropriate water flow regime that is able to maintain the ecological character of the Marshes. That is, a flow regime that does not impair or imbalance any of the processes or functions which maintain the products, attributes and functions of the wetland (as described in O'Connell 2003). Given the degree of variability of natural water flows before river regulation, the managers recognise that determining an appropriate regime is extremely difficult. However, they suggest there are five main requirements for a flow regime to be considered appropriate, none of which are currently being fully met (Table 6.1). These requirements are similar to the main parameters used for assessing hydrologic alteration (Richter *et al.* 1996).

The managers believe there are a number of interacting physical, social, political and institutional impediments to achieving effective water delivery (Table 6.2). They were particularly concerned about the lack of neutrality of the water agencies. The managers gave numerous examples of policies and management decisions that appeared to have been made in favour of irrigation over environmental or other concerns. The managers provide a number of examples that have occurred in the last four years, where the water agencies have: (1) ignored the requests of the River Management Committee (RMC); (2) manipulated the rules of the water share plans against the wishes of the RMC; (3) regularly made it difficult to use the water allocated to maintaining environmental flows; and (4) undermined the decision-making process and reneged on promises to support environmental interests. The managers also point to the NSW Government 2000 Water Management Act which clearly states that the extraction of water must not prejudice the protection of a water source and its dependent ecosystems and basic landholder rights (NSW Government, Chapter 2, Part 1, Division 1). They believe that the act is not being followed.

The managers have had considerable difficulty communicating with the water agencies. It often takes several months to obtain replies to letters and it is difficult to obtain updates of accounts of the water allocated to maintaining environmental flows. In some cases, water allocated to the environment has not been forthcoming and appears to have been used to service other interests. For example, in 2002, an informal committee set up to manage the environmental water decided to release the total amount of water that was supposed to be available in the account (76,000 ML). However, the committee was informed that only 45,000 ML were available as the other 31,000 ML "were accounted for in rainfall that hadn't fallen yet". The managers had to wait until the following year before they could access the remaining water that had been allocated to the environment. This resulted in two separate smaller floods over two years, contributing to considerable stress and death of wetland trees in areas that a single, larger flood would have covered.

Table 6.1: The main requirements for achieving an appropriate flow regime for the Marshes. Only some of many examples are presented (see Appendix 6.7.2 for more detail).

Main requirement	Examples of requirement	Why the requirement is not being met
Delivery of a sufficient overall volume of water	A minimum of 200, 000 ML of water are required to trigger a breeding event of colonial nesting waterbirds (Kingsford and Johnson 1998). Breeding events are occurring less frequently than before river regulation due to lack of sufficient volumes of water (Kingsford and Johnson 1998).	The volume of water allocated to maintaining an ecologically functioning environment is insufficient for bird breeding. Water allocated to the environment is 160, 000 ML in a year when there is sufficient water in the dam for a 100% allocation (DLWC 2002).
	To achieve floods that are large enough to cover vegetation that is dependent on inundation, but at less regular intervals than wetland vegetation at the wetland core, at least 400, 000 ML is required over a period of 0-300 days (Kidson and Raisin 2000).	Large floods have significantly decreased in the Marshes since construction of the dam. Estimates from theoretical modelling suggest that they have decreased by at least 25% (Brereton et al. 1996), while mangers suggest that the decrease is much greater. Large floods are currently only possible when the dam spills.
Delivery of water at appropriate rates of flow	Flows are required at sufficient rates to prevent erosion and to generate widespread flooding. In some areas erosion is occurring in some of the wetland channels and it now takes three times the amount of water in the channels to achieve overbank flow and flooding of the surrounding wetland (Brereton 1994).	Continuous low flows of water to service irrigation and stock contributes to the erosion (Brereton 1994), and limited size of the dam valves and restrictions on the floodplain upstream of the Marshes prevent high rates of flow.
To ensure floods persist for appropriate periods of time	Effective breeding of colonial nesting birds requires flooding of sufficient duration to ensure birds do not abandon their nests (Magrath 1991, Kingsford and Auld 2003).	Lack of sufficient overall volumes of water mean that it is difficult to achieve a tail on the flood that is long enough to ensure young birds can fledge and can build strength.
Delivery of water at appropriate times within years	The main breeding season for birds was thought to be between August and November before the construction of the dam (Masman and Johnstone 2000).	The breeding season for colonial birds in the Marshes is now two to three months later, due to the release of water from storage in spring and summer to satisfy irrigation and stock requirements (Kingsford and Auld 2003).
Delivery of water at appropriate times between years	The Marshes are adapted to natural variation in flooding between years, but this variation has been significantly altered. E.g. 2001-2004 were dry years with no bird breeding events, but rain that fell in August 2003 would have been sufficient to generate a breeding event if it had not been captured by the dam (Kingsford 2004).	River regulation aims to reduce variability.

Table 6.2: Impediments to achieving effective delivery of water to the Marshes (continued on next page).

	Impediment	Explanation
Bio-Physical	Insufficient water allocated to the environment in water sharing plans to sustain the wetland	The volumes of water allocated to environmental flows are insufficient to maintain the ecological character of the Marshes (see Table 6.1 and Appendix 6.7.2)
	Natural tributary flows, used as additional irrigation resources, no longer reach the Marshes	When rain enters the Macquarie River below the dam through tributaries, water release from the dam intended to service irrigation is reduced, and the tributary flows are used instead. However, tributary flows (which account for approx. 10% of the total amount of catchment water that would naturally have entered the Marshes), could significantly contribute to: (1) achieving larger floods and (2) achieving more natural variability.
	Flow of water for irrigation occurs at a different time of year to rainfall periods	Water is released from the dam for irrigation and stock watering during the summer months, and may therefore enter the Marshes during this period. Rainfall in the upper catchment usually occurs during winter.
	Physical impediments on the floodplain	Urban and agricultural development on the floodplain upstream of the Marshes creates a bottleneck, making it difficult for large volumes of water, which are necessary for widespread flooding, to reach the wetland.
	Size of release valves in the dam	The small valves prevent the release of large volumes of water, which reduces the capacity for flooding the wetland. Large floods on the wetland are only possible when the dam spills, which is a rare event.
	Translucent flows	Translucent flows aim to mimic a natural flow of water out of the dam by releasing water when it rains in the upper catchment. However, because of the size of release valves, only low volumes can be achieved . This process has failed to reproduce natural conditions and has contributed to channel erosion.
Political	Lack of will/ability to make significant changes	Many politicians at the state and federal level appear unwilling or unable to act to achieve changes that will help to achieve effective water delivery. This is partly due to (1) the lack of public awareness about the ecological state and importance of the Marshes and hence lack of public support for politicians to take difficult decisions, (2) pressure from an irrigation industry that has substantial economic leverage and has considerable lobbying power, and (3) the perception that the region has "safe" electoral seats which reduces politicians' willingness to make policy changes.

Table 6.2: Impediments to achieving effective water delivery to the Marshes (continued).

	Impediment	Explanation
Social	Threat of litigation	Previously, Macquarie River Food and Fibre (representing individuals who have developed agricultural enterprises on the floodplain) have threatened legal action against water agencies if access to their properties is restricted by large releases of water from the dam. This creates (1) pressure on the water agencies to conform to the requests of irrigators, and (2) decreases the possibility of achieving medium to large floods on the Marshes.
	Public perception that the Marshes are healthy	There is a general perception in the region that the Marshes are either healthy, or are within a natural drought period. This means that people are (1) less concerned about the Marshes, and (2) are less willing to support political actions.
	Public perception that the Marshes receives a lot of water	Water released from Burrendong dam to service irrigation, stock and domestic use upstream of the Marshes generates a perception in the region that the Marshes receives a lot of water. This is despite the problem that the volume of water is significantly less than that which the Marshes would have received historically, and that much of the continuous low volume flows that reach the Marshes goes round the wetland via the Northern Bypass Channel to service downstream users.
	Lack of general public interest in the conservation of the Marshes	There is a lack of public knowledge about the Marshes. Despite the size of the wetland, many people who live in the region have never visited them.
Institutional	Lack of will/ability to enforce floodplain restrictions	It appears that the water agencies are incapable of enforcing floodplain regulations. This can be due to (1) lack of resources, or (2) inability to deal with the pressure from different stakeholders. For example, in recent meetings of the local floodplain management committee (for managing areas upstream of the Marshes), representatives of the Macquarie Marshes Management Committee and NPWS have been barred by private landholders from conducting site visits to assess impacts of floodplain development. The water agencies, which have been allowed access, have resorted to a reassessment of the water flow models (at considerable cost), rather than enforcing previous decisions.
	Policies preventing dam spills	Water agencies appear to ensure that as much water as possible entering the dam can be retained for allocation to different stakeholders. This also includes maintaining "air space" to ensure that if it does rain, then no water is "wasted" through dam spills.
	Lack of neutrality of government water agencies	The managers provide numerous recent examples of policies and management by water agencies that favour the interests of the irrigation industry over environmental and other interests (see text).

The managers have an almost total lack of confidence in the willingness of the water agencies to service the broader environmental and community interests of the Macquarie Valley. They point out that this problem is not new, and refer to the Water Administration Audit in 1986, where the NSW Parliament approved the abolition of the Water Resources Commission (WRC):

"The Audit found the WRC was ineffective in management of the State's water resources, having difficulty in moving beyond its former role of rural supply authority. Broad water needs of the whole community, including the needs of the natural environment were residual considerations to irrigation development and operations.

It is likely that the extent of powers available to the WRC in development of the Water Management Plan for the Macquarie Marshes will radically change, as will the overall management philosophy. The new Department of Water will be required to address cultural, scientific and aesthetic values as legitimate community needs in terms of water management" (DEP 1987).

According to the managers, the culture of the water agencies is still focused on servicing the interests of the irrigation industry. While there have been some positive changes, as far as the managers are concerned, they have not yet resulted in any significant visible outcomes for the Marshes and only appear to be slowing the rate of ecological change rather than reversing the trend.

6.3.3 Suggestions for immediate action

To achieve more effective water delivery, the managers suggest three important actions that could immediately help slow the rate of ecological change of the Marshes. First, it is suggested there should be an embargo on extracting water that enters the river below the dam (through tributaries) or water that is released from the dam during controlled spills. This would enable more extensive and natural variability of floods on the Marshes when rainfall in the catchment was high. Second, greater enforcement is required to ensure that volumes of water extracted from the river is not greater than that stipulated in the licences . Third, water licences need to be purchased to increase the volume of the water that is used to maintain environmental flows.

6.3.4 Why is it so difficult to achieve effective conservation outcomes?

This section presents a conceptual model of the Marshes system as perceived by the managers that explains some of the feedback dynamics of the system that acts to reduce the likelihood of achieving effective conservation outcomes. The reinforcing feedback loops are first explained individually and are then presented in an overall, integrated CLD of the Marshes system.

6.3.4.1 Belief in economic growth

Figure 6.3 illustrates the continual reinforcement of the Macquarie Valley community's belief in economic growth. Historically, the search for a better life drove early settlement. The individual's desire for prosperity continues in the Macquarie Valley today, with a prevailing belief that economic growth will satisfy this desire. A belief in economic growth tends to focus attention on short-term economic returns, leading to support for high-profit agricultural enterprises. In Australia, between the late 1960s and late 1990s, cotton production has increased twenty-fold, with the result that cotton is now Australia's fifth largest agricultural export, making Australia the world's fourth largest cotton exporter (Eslake 2002). Similar levels of increase in cotton production have occurred in the Macquarie Valley since the construction of the dam. These developments have contributed to the community's perception that irrigation contributes to community prosperity. These perceptions then lead to increased levels of commitment to economic growth. The tendency to focus on short-term economic returns decreases the tendency to focus on long-term ecological sustainability.

6.3.4.2 Conflict among water users

Pressure on water resources (see Appendix 6.7.3 for details) inevitably leads to conflict between water user groups, as shown in Figure 6.4. As the tendency to protect individual water interests increases, so does the amalgamation of like-minded people. This acts to reinforce the opinions of individuals, exacerbating any existing conflict among groups, and further increasing the tendency to protect individual water rights. Conflict among water user groups increases the pressure on politicians to find solutions, and because of short terms of office, the politicians are likely to try to find quick answers or short-term solutions that delay the need to make major changes. This also increases pressure on the water agencies to find quick or short-term solutions.

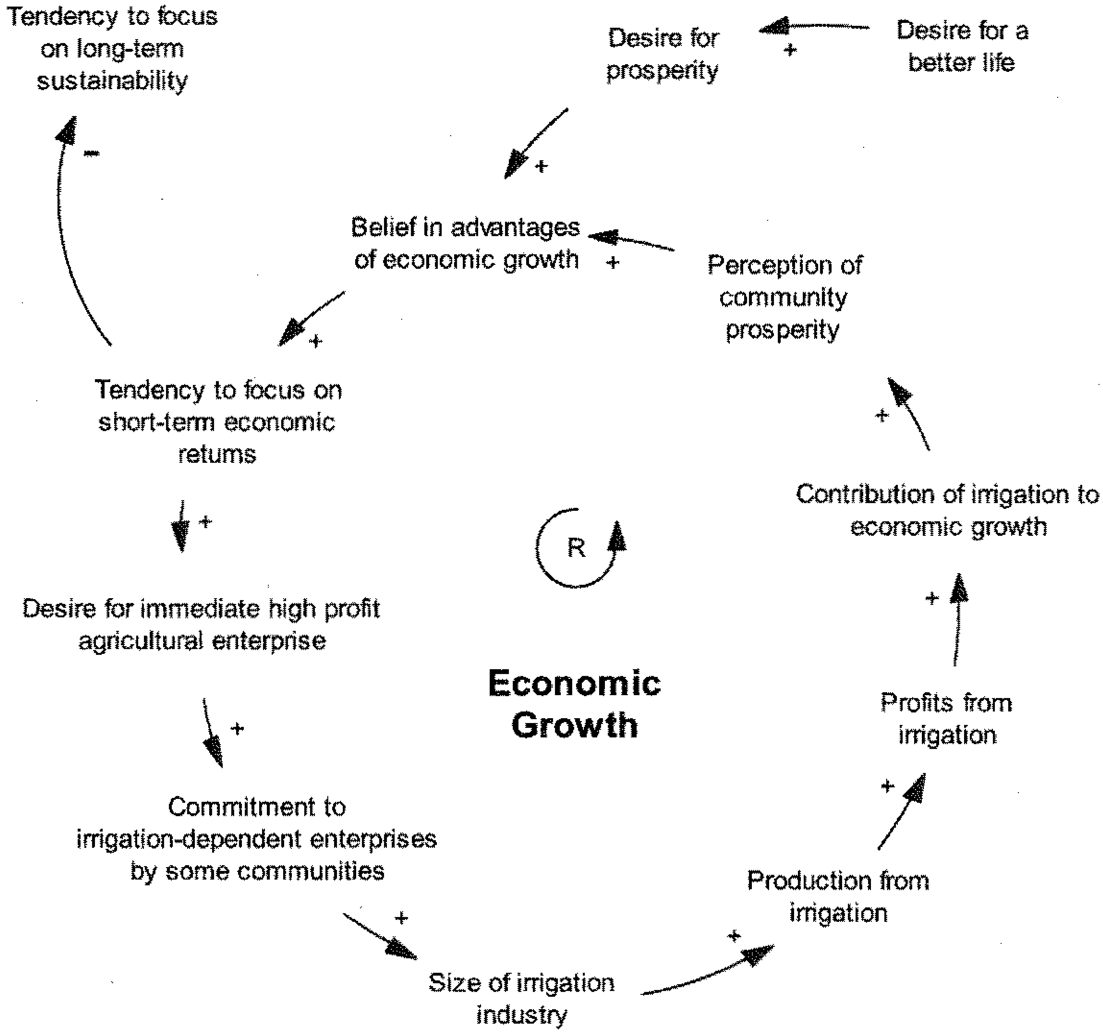


Figure 6.3. **Economic Growth. The reinforcing causal loop (R) illustrates some of the social factors contributing to, and arising from, a belief in the advantages of economic growth. As the tendency in the community to focus on the short-term economic returns from irrigation increases, it reduces the tendency to focus on long-term sustainability. See text for details.**

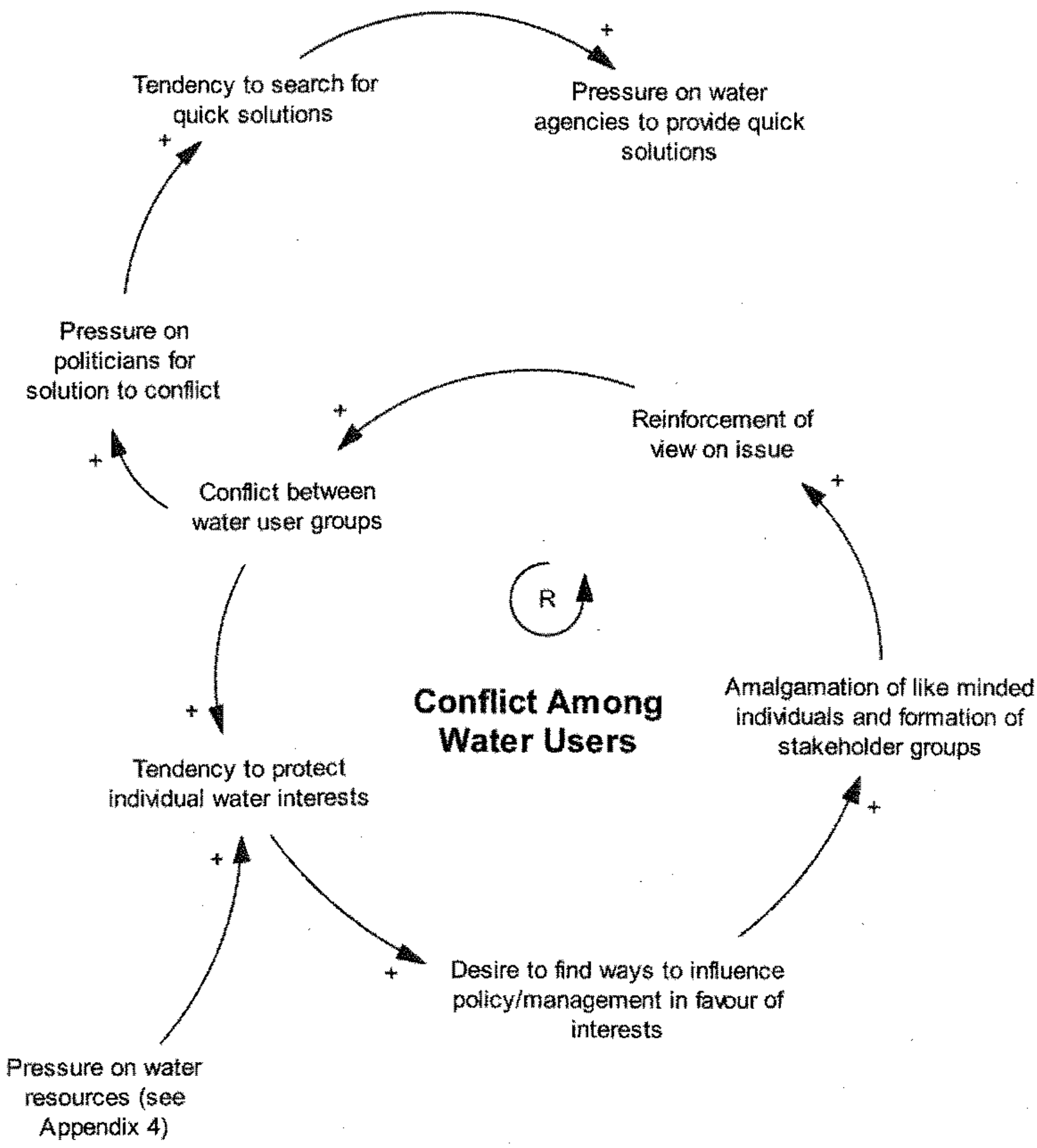


Figure 6.4. Conflict among Water Users. The reinforcing causal loop (R) illustrates some of the social factors that result from increased pressure on water resources. As conflict over water increases, the pressure on politicians to find solutions increases. This increases the tendency for politicians to search for quick solutions, resulting in increased pressure on water agencies to provide the same. See text for details.

6.3.4.3 Worldviews of water agencies

Figure 6.5 illustrates how the adoption of traditional engineering and resource-use worldviews influences the policy and management decisions of the water agencies. The water agencies were originally established to service the irrigation industry, and water-management decisions were primarily made by the same engineers who were charged with the construction of water-delivery schemes (Proust 2004). While there has been much restructuring and numerous name changes to the New South Wales water agencies (Proust 2004), many individuals with a strong traditional resource-use and engineering background remain in the organisation. According to the managers of the Marshes, the prevailing worldviews and culture of successive water agencies continue to focus on servicing irrigation. Worldviews affect the unconscious perceptions of a group of people (Kalu 2001), and have both implicit and explicit influences on policy and management.

In addition, compared to many other stakeholder groups, the irrigation industry has significant lobbying power and access to water agencies and politicians. The power is derived from (1) the ease with which an economic argument can be made for supporting the industry because of the immediate economic returns gained from irrigation and (2) the funds available for lobbying. Overall, the prevailing worldviews of the water agencies and the extensive lobbying power of the irrigation industry increases the likelihood that policy and management will favour irrigation.

6.3.4.4 Community, politics and environment

Figure 6.6 illustrates some of the relationships between political actions in favour of the environment, and community awareness. Increasing awareness increases the level of community interest in the environment, which also acts to increase the community's awareness of environmental problems (R1). Increasing community interest also increases the likelihood that politicians will act in favour of the environment (R2), which increases the capacity of the ecological system to withstand natural extreme events or threats from detrimental human activities.

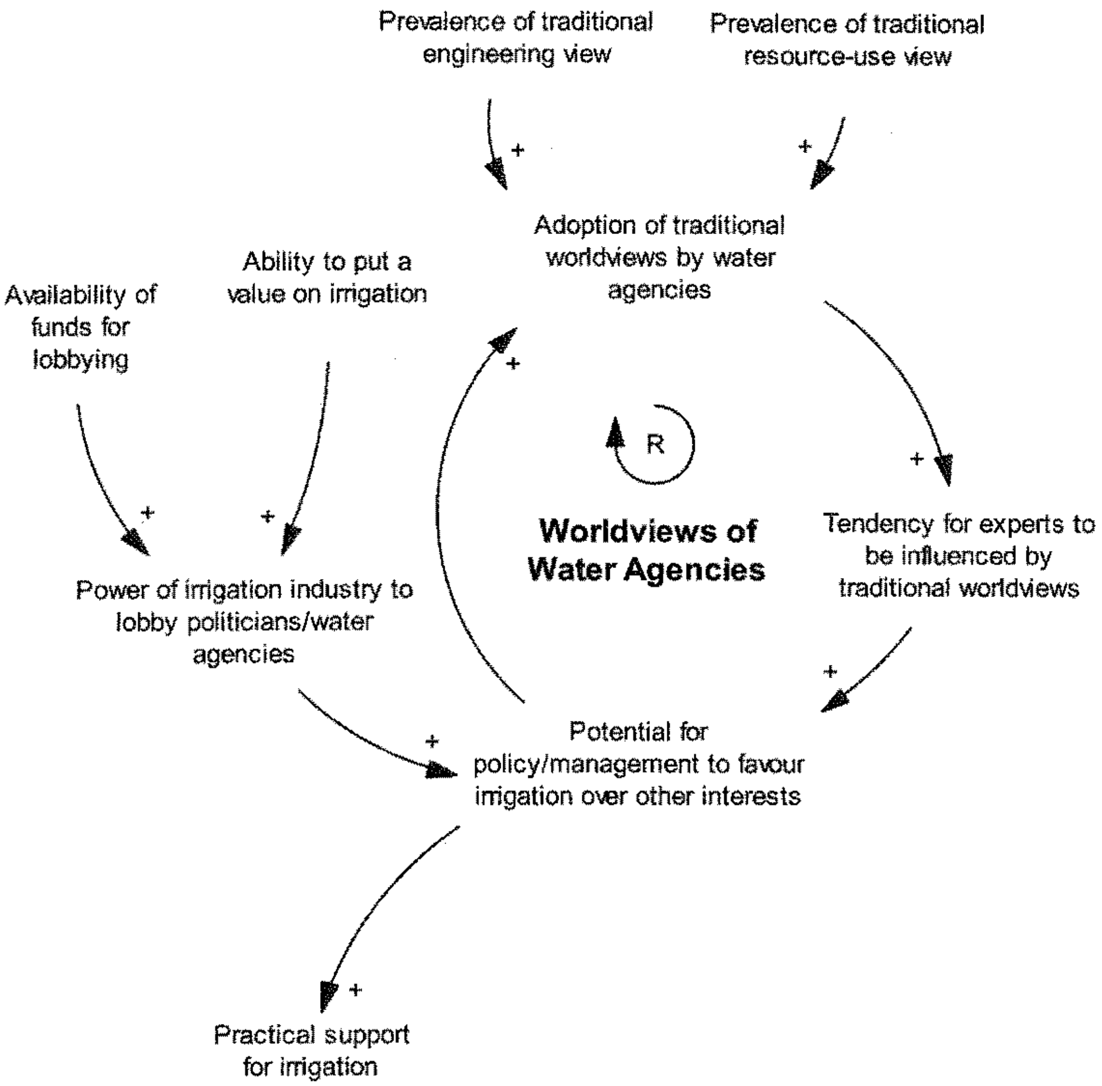


Figure 6.5. Worldviews of Water Agencies. The reinforcing causal loop (R) illustrates some of the effects of the traditional engineering view and the traditional resource-use view prevalent in water agencies. Combined with the lobbying power of the irrigation industry, the worldviews of the water agency increase the potential for policy and/or management to favour irrigation over other interests. See text for details.

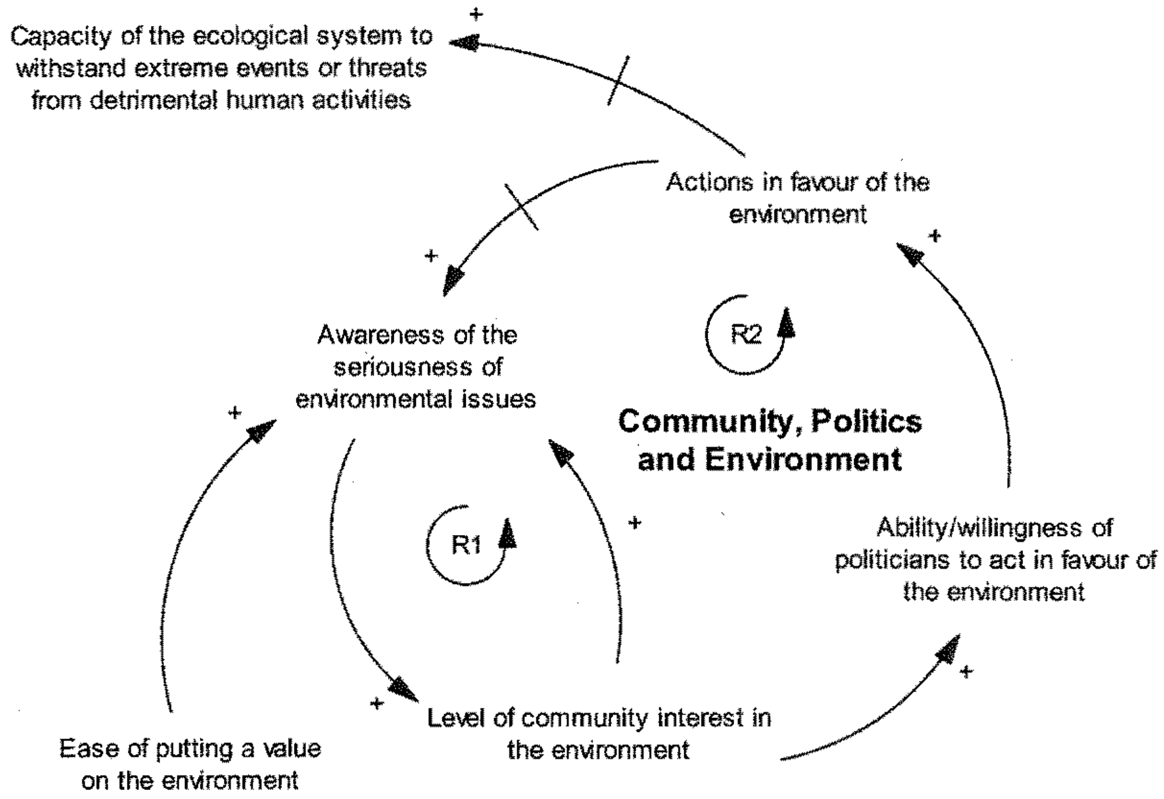
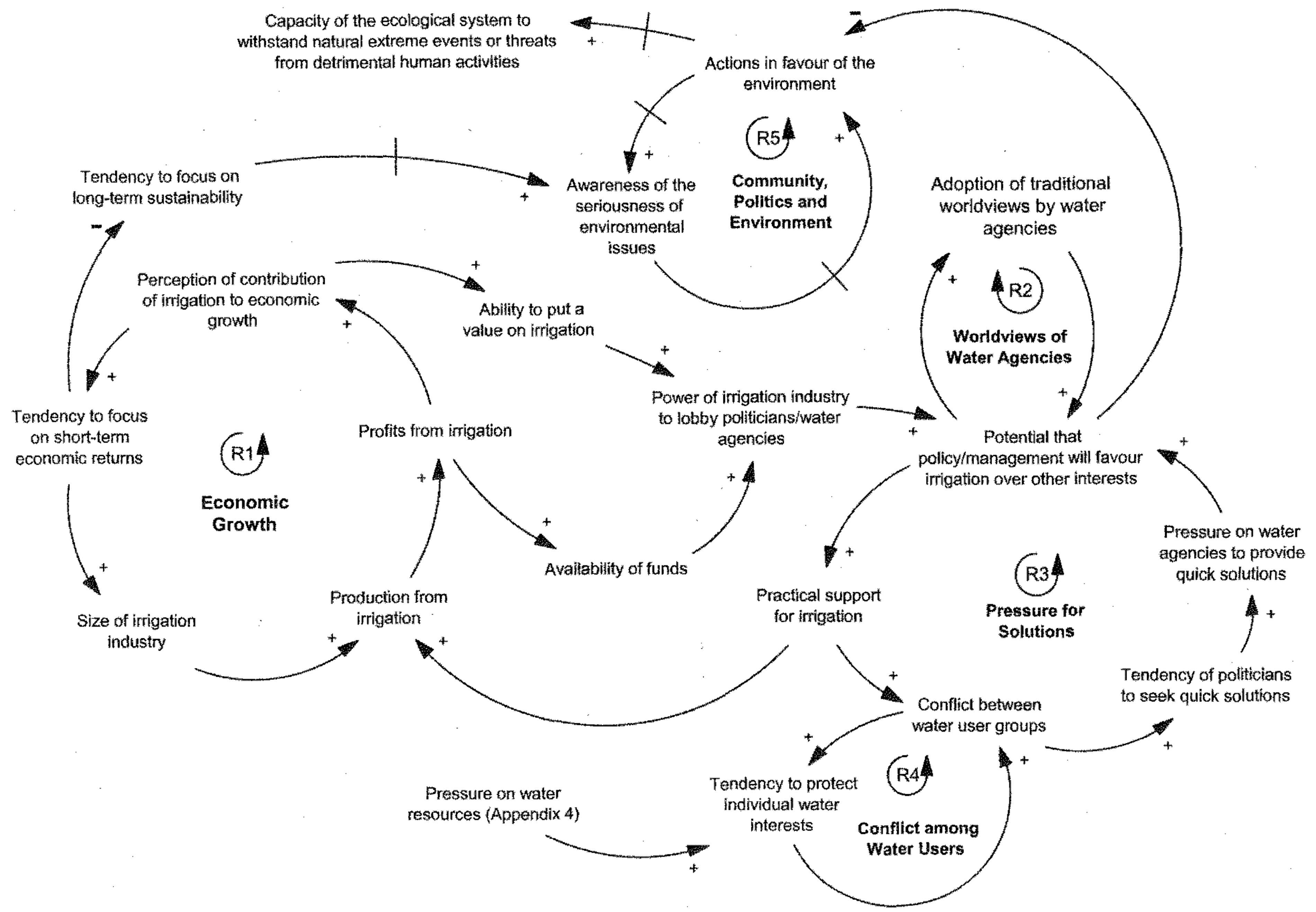


Figure 6.6. Community, Politics and Environment. The reinforcing causal loop (R1) illustrates the social effects that may result when the community takes an interest in the environment. The reinforcing causal loop (R2) illustrates the effects that this interest may produce in the political domain. As actions in favour of the environment increase, so does the capacity of the Macquarie River to withstand extreme events or threat from detrimental human activities. See text for details.

6.3.4.5 Linking current feedback loops

Figure 6.7 presents a wider view of the Marshes system showing the links between the variables in Figures 6.4-6.7. Strong feedback effects reinforce the potential that policy and/or management will favour irrigation, thereby reducing environmental awareness and action (R5). The likelihood that policy and management will favour irrigation is driven by: irrigation activities that provide lobbying power (R1); the traditional worldview of the water agencies (R2); and the tendency for politicians to seek advice from the water agencies to solve conflict (R3 and R4). Decreased actions in favour of the environment ultimately lead to a decrease in the capacity of the ecological system to withstand natural extreme events or threats from detrimental human activities. This was apparent in the Marshes in January 2005, when a fire lit by lightning burnt 90% of the main reed-bed. This would not normally be a problem as reeds usually re-grow very quickly, but it appears that because there was so little moisture in the soil, the root structure of the reed-bed had also been burnt over large areas.

Figure 6.7 (Next page).The Marshes system. Key variables in the individual CLDs described in Figures 6.3-6.6 collectively illustrate important connections between the sub-systems. With this wider view of the system, additional feedback dynamics become visible. The loop labelled Economic Growth (R1) is linked to Pressure for Solutions (R3) via the power of the irrigation industry to lobby politicians or water agencies. The loop labelled Worldviews of Water Agencies (R2) is linked to Pressure for Solutions (R3) via the potential for policy/ management to favour irrigation over other interests. The loop labelled Conflict among Water Users (R4) is linked to Pressure for Solutions (R3) via conflict between water user groups. These links form part of the positive feedback behaviour driving the system. Increasing potential for policy and management to favour irrigation decreases actions in favour of the environment (R5), while a decreasing tendency to focus on long-term sustainability decreases awareness of the seriousness of environmental issues (R5). This ultimately leads to a decrease in the capacity of the Macquarie River to withstand extreme natural events or threats from detrimental human activities.



Capacity of the ecological system to withstand natural extreme events or threats from detrimental human activities
Actions in favour of the environment
Awareness of the seriousness of environmental issues
R5
Community, Politics and Environment
Tendency to focus on long-term sustainability
Adoption of traditional worldviews by water agencies
R2
Worldviews of Water Agencies
Perception of contribution of irrigation to economic growth
Ability to put a value on irrigation
Power of irrigation industry to lobby politicians/water agencies
Potential that policy/management will favour irrigation over other interests
Tendency to focus on short-term economic returns
R1
Economic Growth
Profits from irrigation
Availability of funds
Production from irrigation
Size of irrigation industry
Practical support for irrigation
R3
Pressure for Solutions
Pressure on water agencies to provide quick solutions
Tendency of politicians to seek quick solutions
Conflict between water user groups
Tendency to protect individual water interests
R4
Conflict among Water Users
Pressure on water resources (Appendix 4)

6.4 Discussion

Overall, the managers suggest that: (1) the most immediate threat to the Marshes is lack of water; (2) there are many complex interacting social, physical, political and institutional impediments to achieving effective water delivery; (3) some immediate steps need to be taken to ensure more effective water delivery and (4) there is strong feedback in the system which is continually reinforcing the potential that policy and/or management will favour irrigation (Figure 6.7). This feedback is primarily driven by three prevailing beliefs and worldviews: (1) belief in economic growth; (2) the water agencies' traditional engineering and resource-use worldviews; and (3) individual's drive to protect their own interests.

Strong political leadership is required to achieve any significant positive environmental outcomes. There have been some important steps by policy-makers towards effective water reform, including the recent release of the National Water Initiative (NWI) in June 2004 by the Council of Australian Governments. The NWI represents a significant change in Australian water policy, and is partly a result of policies that are geared towards achieving greater environmental stability through market-based systems (Connell *et al.* 2004). However, care is needed when advocating market-based systems for reforming water resource allocation, as there can be significant counter-intuitive environmental effects (Crase *et al.* 2004). The initiative also places little emphasis on institutional development, new funding arrangements, environmental research, or dispute resolution (Connell *et al.* 2004). Without such emphasis, given the prevailing strength of the worldviews and the positive feedback driving the Marshes system, many significant on-ground impediments to effective water delivery will remain.

In the case of the Macquarie Valley, the strength of the prevailing worldview of the community continually acts to reinforce current activities, and deflects attention from any looming environmental crisis. There are two major effects: First, a perceived need to protect individual interests results in activities that increase pressure on water resources, such as intensifying the capture of surface run-off, preventing it from reaching the river. As pressure on water resources increases, uncertainty and risk can also increase. Second, belief in economic growth results in demand to reduce the risk associated with the delivery of water to irrigators. Water agencies with a traditional engineering and resource-use worldview respond with technological solutions that aim to control the natural environment. This can result in extensive attempts to find technological solutions, irrespective of the cost or likelihood of success.

For example, in March 2004, the New South Wales Parliament passed legislation to provide $A20 million to fund a cloud-seeding experiment to attempt to mitigate the effects of global warming in the Australian Alps. There is no scientific evidence that cloud seeding works (especially to mitigate climate change), and little consideration was given to the sensitivity of the alpine environment (NPANSW 2004). In the Macquarie Valley, continued pressure on water resources has also led to recent discussions about raising the height of Burrendong dam to increase its storage capacity. Such additional intervention would further reduce the natural variability in the river system, delaying and ultimately exacerbating the environmental degradation.

The robustness of the positive feedback loops in the system described by the managers suggests there are no easy solutions to the causes of the problems of water delivery. Strong political leadership is much easier with public support, which comes in part from greater awareness of the seriousness of environmental issues and the feedback from a demonstrated commitment by government agencies to service the broader community and environmental interests. Thus, in the case of the Macquarie Valley, long-lasting solutions will be achieved only with a shift in the current worldviews of the immediate community, and of society at large, to worldviews that favour more sustainable economic activity.

In general, the implicit knowledge of the managers suggests that feedback from Macquarie Valley ecosystems about sustainability of economic activity is lacking. This is common issue in resource management (Chapin *et al.* 1998, Whiteman *et al.* 2004). While major shifts in the worldviews of the community are unlikely to occur, the results do point to a possible social hook to instigate change in the way people think about the Marshes and the wider river ecosystem. Because the Marshes are located in the lower reaches of the Macquarie River, where the effects of environmentally detrimental activities are most apparent, the Marshes could be promoted as a useful indicator of the overall health of the river system. People directly or indirectly dependent on the Macquarie River (which includes the majority of people in the Macquarie Valley) may have greater incentive to document and look more objectively at the causes of the ecological changes if they can accept that the wetland provides a broad measure of the long-term ecological and economic sustainability of upstream human activity. Such ways of thinking are not only essential for conservation, but they are also essential for the long term resilience of businesses and their dependent human communites (Whiteman *et al.* 2004).

6.4.1 The implicit knowledge of the managers

The managers exhibited expert knowledge of different aspects of the Marshes system (see Fazey *et al.* Revision submitted [Chapter 7]). They were acutely aware of the ecological fragility and inherent variability of the Marshes and treated them with respect. One participant felt greater comfort when ecological outcomes were uncertain because assumptions were not being made about the system's dynamics. Another commented that it took at least 30 years of working within the system and observing the wetland's response to flooding before the extent of its complexity became apparent.

The results illustrate the extent of the manager's knowledge of the system, which was built from a mix of observation, experience, scientific reports, and discussions with researchers, landholders and with each other. However, by making parts of their knowledge explicit, those parts no longer remain linked to the rest of their implicit or tacit knowledge (Boiral 2002). The extent of the managers' expertise was more clearly highlighted in the workshop. In this case, unlike the researchers, the participants were able to tease out information from each other because they knew which questions to ask. This provided a more extensive expression of a depth of understanding about the conservation issues and their ultimate causes than those presented in this paper.

Scientific studies alone would not have captured the complexity of the Marshes system. Thus, while an adaptive scientific approach would greatly benefit the management of the Marshes, it would be much more powerful with guidance from the implicit knowledge of experts who have an in-depth understanding of the wetland (see Fazey *et al.* Revision submitted [Chapter 7]).

6.4.2 Limits to the conceptual model

Because all models are summaries of a complex and dynamic world, they inevitably have limitations (Fazey in prep. [Chapter 4]). The aim of the conceptual model in this paper was to communicate to a wide audience the strong feedback that is reinforcing impediments to the effective conservation of the Marshes. The model was designed to be a communication tool, and is therefore relatively simple. It was not designed to capture all the detail of the system, or give precise predictions. The model is partly limited in that it is built only from the experiential knowledge of the on-ground managers and from existing reports and publications. Ideally, additional experience and perspectives of the system would be included. However, as highlighted by this paper, the managers' knowledge of the Marshes and its conservation problems was extensive. While many people have experience of attempting to achieve effective conservation action on behalf of the Marshes, the participants were relatively unique in that their understanding was built from direct observation of the outcomes of the attempts. There are few other practitioners with a similar deep tacit and implicit understanding of the wetland.

6.5 Concluding remarks

This study represents a particular perspective on the prevailing worldviews of the wider Macquarie Valley community from a particular subset of people. There is likely to be a wide range of worldviews about the value of conservation in the community, and thus all stakeholders need to be involved in making final decisions about how the Valley's water resources are to be shared and used. However, it is important that such decision-making is not confused with the need for consulting people with the appropriate expertise to help determine the degree to which the levels of water extraction are impacting the Macquarie River and its dependent ecosystems.

The conservation of the Marshes is just one of many examples of the conflict between irrigated agriculture and wildlife conservation, which has reached a critical point on a global scale (Lemly *et al.* 2000). While there are many ways of perceiving the Marshes system, the perspective from the managers who have built their knowledge through first-hand experience, suggests there is strong feedback that increases the potential for decisions by water agencies to continue to favour the irrigation industry. From the perspective of the managers, without major governmental intervention and a shift in the prevailing worldviews of water agencies and the public, it is likely that the health of the Macquarie River will continue to decline and that the Marshes will be lost forever.

6.6 Acknowledgements

This work would not have been possible without the support and hospitality of the participants and the staff of the Coonabarabran Area office of DEC. D. Lindenmayer, S. Dovers, J. Fischer, and J. Clark read earlier versions of the manuscript. Research funds were provided by the Centre for Resource and Environmental Studies and from D. Lindenmayer. IF was supported by an Endowment for Excellence Scholarship from The Australian National University.

6.7 Appendices

6.7.1 Appendix 1: The Research Process – the 'Marshes Approach'

The Marshes Approach consisted of seven stages, many of which provided opportunities for the primary researcher to reflect on the results, and to seek clarification from the participants about the accuracy of the interpretation of their implicit understanding. Importantly, during the 6 month period of data collection, the primary researcher was predominantly based in the Coonabarabran Area Office of DEC.

In stage one (6 weeks) the first author participated in day-to-day management activities of the Marshes, working as a volunteer of DEC. This allowed familiarisation with the study area and its issues, and gave time to identify potential participants for the study and to gain their trust.

In stage two, each manager was interviewed twice. During the interviews, managers were asked to describe the "Marshes system". They were encouraged to draw a boundary around the parts of the system that they felt were most relevant to the conservation of the Marshes. In all cases, the managers took a broad system view. They did not consider the ecological components of the Marshes in isolation to the physical, social, political and economic components.

In both interviews, the interviewer (first author) used open-ended questions to begin construction of a conceptual model to describe the Marshes system. As the interviewee talked, the researcher built up a rough structural diagram of the topic that was being discussed, with preliminary causal links between different variables (i.e. a detailed spidergram). This enabled an initial exploration of some of the complex feedback effects that were occurring in the Marshes socio-biophysical system (similar to the approach used in Vennix 1996).

At the beginning of the first interview, the participants were invited to discuss what they considered to be the most important issues and aspects of the Marshes system. In the second round of interviews (1-3 weeks after the first round), the managers were shown data generated from the first interview, and a list of all topics discussed by the participants. They were then asked to elaborate on one of the topics, or discuss another topic, which had not yet been considered. By the end of the second interview, the raw data consisted of two sets of detailed spidergrams per individual (except in one case where two participants had been interviewed together at the same time as their second interview). As the overall intention was to capture the understanding of the managers, discussions up to this point had not been led in any particular direction, and no assumptions by the researcher had been made about what constituted the most important or relevant issues affecting the Marshes.

The third stage centred around a workshop (20th July 2004) with the aim of gaining deeper insights into the operation of the Marshes system. An attempt was made to identify changes which had affected the conservation or management of the Marshes in both positive and negative ways. At the beginning of the workshop, four underlying convictions from which the workshop could progress were presented (see Results and Appendix 6.7.2). These convictions were based on information already derived from interviews, and managers were asked if they agreed with them before the workshop commenced. The workshop was facilitated by B. Newell and separate notes were taken by both I. Fazey and K. Proust to ensure that the discussion was adequately captured, and to reduce any bias in its interpretation.

In stage four, a preliminary conceptual model was built which integrated components of the data from individual interviews and from the workshop. This provided the basis for stage five where, in a third round of individual interviews, the managers were asked to comment on the initial conceptual model and to clarify issues discussed in earlier stages.

In stage six, all information was distilled and integrated to produce a set of tentative hypotheses (CLDs) that explain why there appears to be so little positive conservation action in favour of the Marshes. This required the data that had already been collected and input from the researchers' understanding of the managers' perceptions. In stage seven, the sections of the results and the appendices (including the CLDs) were discussed at a final meeting with all participants to ensure that their implicit knowledge had been articulated accurately.

6.7.2 Appendix 2: Basis of the underlying convictions of the managers

The underlying convictions of the managers are based on their expert knowledge, and on their familiarity with various publications, reports and documents.

6.7.2.1 The Marshes are important ecologically

The Marshes are one of Australia's largest wetlands, and are arguably the most important site for the breeding of colonial waterbirds in Australia (Kingsford and Auld 2003). Some 220 species of bird, 15 fish, 14 snake and 15 mammal species have been recorded in the Nature Reserve, and it is a prime example of the red gum-reed-water couch vegetation association (NPWS 1993). It includes the largest and most northerly extensive area of reeds (*Phragmites australis*) in south-eastern Australia, has the largest area of River Red Gums

(*Eucalyptus camaldulensis*) in New South Wales, and has one of the most southerly occurrences of coolibah (*E. microtheca*) (NPWS 1993). Nine bird species are listed in the Japan-Australia and China-Australia migratory bird treaties, and 18 are listed as endangered (NPWS 1993).

The importance of the Marshes is formally recognised in a number of ways, including: The Ramsar Convention of 1971; the National Trust of Australia as a Landscape Conservation Area; the Australian Heritage Commission's Register of the National Estate; the directory of important wetlands of Australia; and the Japan-Australia and China-Australia Migratory Bird Agreements (from Brock 1998).

6.7.2.2 The Marshes are important to the local community

Before European settlement, the Marshes were used extensively by the Wailwan aboriginal tribe. The site held special cultural and spiritual significance, and provided a regular source of food and water (Masman and Johnstone 2000). By the 1850s most of the prime frontage of the Macquarie River was occupied by European settlers, and the pastoral industry had become well established.

The Marshes remain vitally important to the local community (Masman and Johnstone 2000, Jones 2003). Approximately one-third of the properties on the Marshes run only cattle, while two thirds run a mix of cattle and sheep, with cropping occurring on half of the properties (Cunningham 1996). The community is dependent on an ecologically functional wetland, as cattle production is only possible in areas that are flooded more regularly (see below). The Marshes are also a flow-through system, in which water passes through the wetland to service downstream users.

Recognition by the community of the importance of the wetland is exemplified by the good relationship between the Macquarie Marshes Management Committee and DEC. Given its relatively remote location, the co-operation of landholders for the management of the Nature Reserve is essential. Landholders report trespassers and are often the first people present in the event of bush-fire. They have also played a significant role in highlighting the plight of the wetland, and many individuals have contributed substantial amounts of their time in activities related to water resource management.

6.7.2.3 The Marshes are undergoing major ecological change and are seriously threatened

6.7.2.3.1 Experiential evidence from the managers

Because of the complexity of the wetland system, some of the strongest evidence for major change on the Marshes comes from the observations of the managers. Over the last 30 years the managers have observed a general drying out of the Marshes. They point to clear indicators of change. These include the loss of large areas of ephemeral wetland vegetation, dying of River Red Gums, and the regular appearance of deep cracks in the substrate. For example, in what used to be one of the wetter areas of the North Marsh (P Block), the 1982 drought was the first time in living memory that people could ride from the stock yards and not come across water. According to the managers, landholders are now generally surprised when the area is wet, as it seems to be dry most of the time. The fire trail that was constructed out to the Bora Well in 1994 provides another example. Construction of this trail was not previously possible, and it still remains clear even though similar trails usually grow over within 2-3 years.

The South Marsh has seen some of the greatest change. Here, large areas of wetland vegetation have disappeared to be replaced by weeds. For example, the reed-beds were burnt in 1992 as part of a fire-management program. The area did not recover, even though regrowth is usually expected one year after fire. It appears that the underlying root system had already died due to lack of water, and all that remained before the fire was surface vegetation. Overall, by the 1990's, only 50% of the reed-bed in the South Marsh remained compared to the situation before river regulation (Brander 1987). Now less than 10% remains.

There are suggestions that unusual events are occurring in response to changes in water flow. In many areas, River Red Gums are stressed or dying due to lack of water. In other areas, where ephemeral wetland vegetation is normally present, young trees are sprouting. This appears to be due to floods of smaller volume, which do not persist long enough to drown sprouting red gums. Assuming that the young trees obtain enough water to survive, they will shade out more ephemeral wetland vegetation resulting in the development of more homogeneous vegetation structures. In addition, in some areas, the watertable appears to have dropped, and because of the deepening of channels, it now takes an estimated three times the amount of water in the channel before overbank flow and flooding of the wetland can occur (Brereton 1994). Weeds, such as Noogoora burr (*Xanthium occidentale*) and Lippia (*Phyla nodiflora*) that are normally kept under control from flooding are also becoming a problem and are out-competing natural vegetation.

There are also social changes that have occurred in the local community that appears to be related to changes in the capacity of the ecological system to sustain agricultural practices. The number of families supported on the Marshes has fallen from about 50 to 30 over the last 30 years, and the size of properties has increased as landholders have bought land in attempt to maintain a viable income. While it is difficult to attribute such changes directly to a decline in the carrying capacity of the wetland, according to the managers, areas adjacent to the Marshes have not undergone such dramatic declines in population or seen similar amalgamation of property.

6.7.2.3.2 Waterbird breeding

There is limited peer-reviewed literature on the management of the Marshes. Most of the existing published research concentrates on the breeding of colonial nesting waterbirds. This research clearly demonstrates a significant decrease in the frequency of breeding events and the size of bird colonies since river regulation (Kingsford and Auld 2003). Bird breeding is usually triggered when annual flows exceed 200,000 ML. Flooding on the wetland also needs to be of a sufficient duration for breeding success (Kingsford and Johnson 1998, Kingsford and Auld 2003). When flows are between 200,000 and 500,000 ML, breeding colonies are usually less than 20,000 pairs (Kingsford and Johnson 1998). Estimates suggest that before river regulation, over 100,000 breeding pairs may have been involved in each breeding event. During the three large floods of the 1950s, colonies may have been much larger (Kingsford and Johnson 1998).

Between 1985 and 1995 there was a total of 124,000 nests of six heron and ibis species. This was estimated to be half of what would have occurred if no water had been diverted, and while it was estimated that a median of 4,000 nests would have been constructed each year, only 200 nests per year were observed (Kingsford and Johnson 1998). There have also been decreases in the number of bird breeding events. While the managers suggest that at least one breeding event every two years is expected, there have been none in the last four years. This was despite sufficient rainfall in the upper catchment in August 2003 to trigger a bird breeding event if the water had not been captured in the dam (Kingsford 2004).

6.7.2.3.3 River Red Gums

A recent study for DEC of the health of River Red Gum trees at 22 sites in the Macquarie Marshes clearly indicated that trees that had received water in the last two years had a similar health to these same trees that were assessed in 1994 (Woodlots and Wetlands 2004). Trees that had not received flooding since 2000 had a 61% decline in canopy density as well as significant increases in dead branch frequency and epicormic growth. In some plots, over 30% of trees had died over the past decade. There was no evidence that the decline in tree health was due to factors other than to a lack of water. In order to prevent further death of River Red Gums, it was recommended that the wetlands receive flooding as soon as possible, and preferably before the summer of 2004/05. This did not occur due to lack of available water in the dam. Extrapolating from the Woodlots and Wetlands (2004) study, the managers suggest that 75% of the estimated 20 000 ha of River Red Gum forest on the Marshes are showing signs of stress from lack of water. It is not known to what extent other tree species that grow in the peripheral areas of the Marshes are under stress. Because many of these species are less reliant on frequent flooding, the effects of lack of water take longer to become apparent.

6.7.2.3.4 The Marshes are seriously threatened

Overall, the managers believe that the Marshes are so seriously threatened that if no large floods occur within the next 5 years, the South Marsh area of the Nature Reserve will be lost altogether, and that the majority of the North Marsh will have been lost or its ecological character significantly and irreversibly altered.

6.7.2.4 The main cause of the threat to the Marshes is lack of water

Over the last 40 years, the managers have observed a significant decrease in the amount of water reaching the Marshes and point to a number of publications and reports that supports their observations. In general, water flows at the gauging station below the Marshes have decreased significantly for high and medium rainfall events, and the area flooded by large floods has contracted by at least 40-50% between 1944 and 1993 (Kingsford and Thomas 1995). Between 1944-1953, 51% of all water passing through the city of Dubbo reached the wetland, but by 1984-1993 this had decreased to 21% (Kingsford and Thomas 1995).

The volumes of water allocated to the environment have increased in subsequent water sharing plans, but the managers point out that it still falls very short of being able to maintain the ecological character of the Marshes. While more recent changes on the Marshes have been exacerbated by the 2001-current drought, the main cause of the lack of water is over-extraction upstream, which has reduced the capacity of the Marshes to be able to withstand extreme natural events (Kingsford 2004). In the Macquarie Valley, 89% of the water that is extracted is used for irrigation, with the dominant irrigation enterprise being cotton production (DLWC 2002, Wolfgang 2000).

There are many management issues for the Marshes, including the control of feral animals, weeds, erosion, fire and salinity (NPWS 1993). However, most of these are closely related to issues of water delivery. For example, flooding is one of the most efficient ways of controlling or inhibiting the growth of weeds, and erosion is also primarily caused by more continuous low flows of water through the channels. It has been suggested that agricultural land-use practices that are less reliant on irrigation both within and upstream of the Marshes (e.g. grazing) have considerable environmental impact (e.g. Kidson *et al.* 2000). However, the managers point out that areas of the Nature Reserve that have not been grazed since 1989 are exhibiting as much, and sometimes more change, than in areas outside the Reserve. Thus, while there may be a number of management issues for the Marshes, effective long-term conservation of the wetland can be achieved only by first solving the issues of effective water delivery.

6.7.3 Appendix 3: Historical basis of current pressures on water resources

In Australia, historically, irrigation has been strongly supported through subsidies, price-maintenance schemes, tariff barriers and cheap water. Governments have invested heavily in infrastructure, with a tenfold increase in the capacity of major dams between 1940 and 1990 (Smith 1998). In the Macquarie Valley, the first weirs and their off-takes were constructed in 1896 to improve water supply for pastoral purposes. As the extent of water control structures increased, so did the potential for irrigation. Plans for the construction of Burrendong Dam were made in 1907 and 1934, but were consistently and heavily opposed by settlers on the Lower Macquarie River, who argued that the extraction of so much water would prejudice their established interests (S. Knight and Partners, 1984). By the early 1940s, a large number of river regulation structures and water off-takes had been constructed, and there was greater pressure on water agencies and the government to service an irrigation industry. Burrendong dam was authorised in 1946, and completed in 1966. The increased stability of river flows enabled the growth of cotton which was first planted in the valley within one year of the completion of the dam (Cotton Australia, 2004). The irrigation industry expanded rapidly from 17,500 ha in 1965-1969 to 85,577 ha in 1990 (Kingsford and Thomas 1995).

The CLD in Figure 6.8 illustrates some aspects of irrigation development. An increasing number of people engaged in irrigation led to greater demand for the control of water resources so as to reduce the risk associated with variable river flows. This led to increased pressure on government to service the irrigation industry, raising the potential for irrigation and increasing the number of people involved in such activities.

Second, in the late 1980s and early 1990s, changes in licence regulations enabled licence holders to sell the water allocated to them, rather than have the water licence tied to a particular piece of land. This allowed licence holders to sell water if they were not intending to use it themselves, increasing the likelihood of over-use (Crase *et al.* 2004).

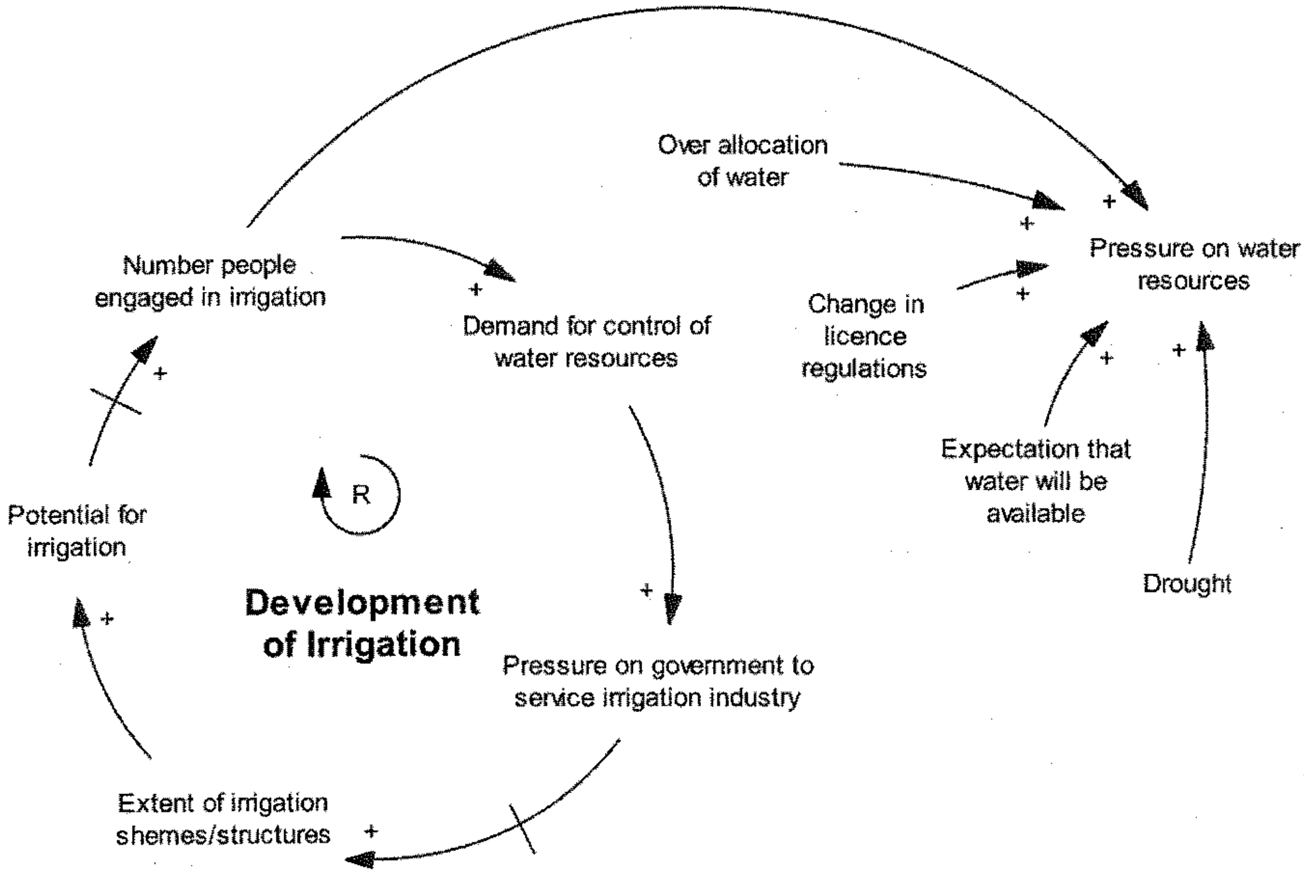


Figure 6.8. Irrigation Development in New South Wales. The reinforcing causal loop (R) illustrates some of the historical factors in irrigation development. When contemporary factors are taken into account, the combined effects increase the demand on water resources in the catchment. Note the delays. See text for details.

Four other significant factors contributed to current pressure on water resources. First, the amount of water in the river was significantly over-allocated. In the early 1970s water licences were issued to attempt to regulate water extraction. However, two unusually large floods in the 1950's influenced estimates of the amounts of water available in the catchment and the dam was re-designed to hold three times the amount originally intended (Knight and Partners, 1984). Licences were also granted even when it was apparent that demand would exceed supply, and many landholders in the Central Macquarie Valley began to subdivide their properties to obtain multiple licences (Masman and Johnstone 2000).

Third, greater predictability through regulation of the water supply has resulted in increased expectation that water will generally be attainable. For example, irrigators may plant cotton at the beginning of a season without knowing whether or not water will be available to finish the crop. Later in the season they have argued that they will suffer economic loss without additional allocation of water. In some cases, it is believed that water that was supposed to have been kept as part of the allocation to other stakeholders has been given to service the needs of irrigation, despite objections from those other stakeholders (e.g. use of town water in October 2003).

Fourth, pressure on water resources is greatest during periods of low water availability, such as the 2001- current (2005) drought, resulting in significant conflict between water user groups (see Figure 6.4).

SECTION D:

LEARNING MORE EFFECTIVELY FROM EXPERIENCES TO DEVELOP UNDERSTANDING ABOUT ENVIRONMENTAL SYSTEMS

Chapter 6 emphasised that extensive research and/or management experience of an environmental system has considerable value for informing conservation practice, and finding ways to articulate this knowledge is important. While scientific research is essential, in complex and dynamic systems like the Macquarie Marshes, detailed research is often not available. Even if it were, outcomes of many interventions are still likely to be uncertain. Thus, the extent of personal experience will often be an important factor influencing the effectiveness of decisions.

Given that the extent of personal experience is important, and that experience clearly has a role in environmental conservation (see also Sutherland et al. 2004), Chapter 7 takes the next step by asking how we can learn more effectively from our experiences to develop better understanding of environmental systems. It does not suggest that we should use experience instead of scientific knowledge, but it does recognise that considerable improvements can be made in how we learn from experiences and in how we apply experiential knowledge. Some of the research from phenomenography and cognitive psychology is reviewed to provide a way of thinking about learning to help researchers and practitioners develop their capacity to be more adaptable when faced with new situations. The chapter explains the nature of expertise and introduces the idea of variable reflective practice, suggesting how this can be applied in a conservation context. At the end of the chapter, differences between experimental evidence and experience are briefly discussed, highlighting that both are essential and complementary components of decision-making.

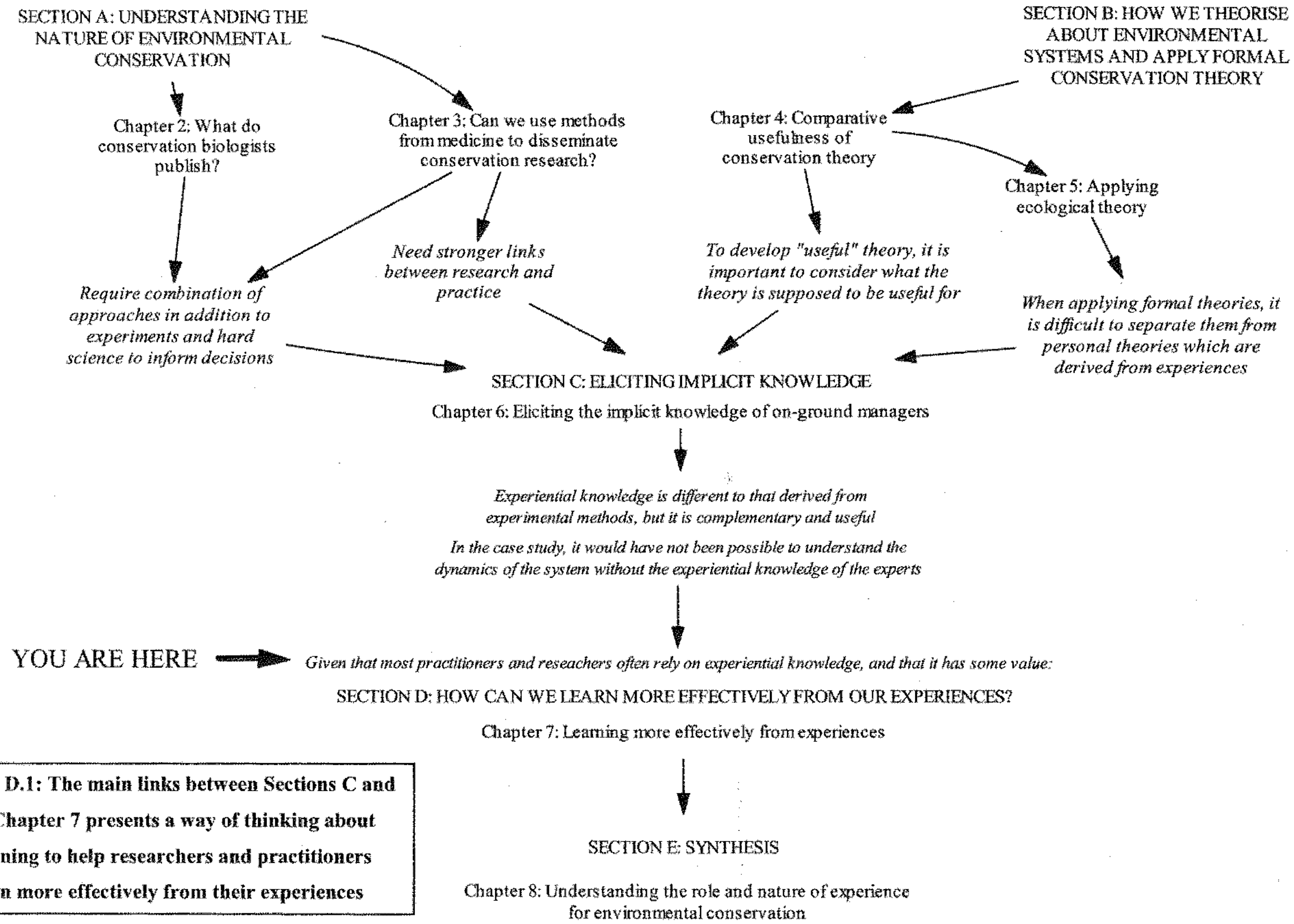


Fig. D.1: The main links between Sections C and D. Chapter 7 presents a way of thinking about learning to help researchers and practitioners learn more effectively from their experiences

Chapter 7

LEARNING MORE EFFECTIVELY FROM EXPERIENCES

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7.0 Summary

Developing the capacity for individuals to learn effectively from their experiences is an important part of building the knowledge and skills in organizations to do good adaptive management. This paper reviews some of the research from cognitive psychology and phenomenography to present a way of thinking about learning to assist individuals to make better use of their personal experiences to develop understanding of environmental systems. We suggest that adaptive expertise (an individual's ability to deal flexibly with new situations) is particularly relevant for environmental researchers and practitioners. To develop adaptive expertise, individuals need to: (1) vary and reflect on their experiences and become adept at seeking out and taking different perspectives; and (2) become proficient at making balanced judgements about how or if an experience will change their current perspective or working representation of a social, economic and bio-physical system by applying principles of 'good thinking'. Such principles include those that assist individuals to be open to the possibility of changing their current way of thinking (e.g. the disposition to be adventurous) and those that reduce the likelihood of making erroneous interpretations (e.g. the disposition to be intellectually careful). An example of applying some of the principles to assist individuals develop their understanding of a dynamically complex wetland system (the Macquarie Marshes in Australia) is provided. The broader implications of individual learning are also discussed in relation to organisational learning and the role of experiential knowledge for conservation.

7.1 Introduction

Active adaptive management is often suggested as a way of dealing with uncertainty in conservation and resource management (e.g. Walters and Holling 1990, Lee 1999). Using interventions as experiments, managers 'learn-by-doing', with the 'active' emphasizing an experimental approach (Walters and Holling 1990). Active adaptive management is based on the premise that knowledge of the system is always incomplete. The system is seen as a moving target, which is continuously evolving because of the human influences on it (Walters and Holling 1990). The results of experiments in these systems are often described as being surprising (e.g. North *et al.* 1994), thus a primary aim of active adaptive management is to learn something from the experiments, and for scientists to recognize the surprises and pursue their implications (Lee 1999).

An experimental approach prevents 'superstitious' learning, where erroneous connections between cause and effect can occur (Levitt and March 1988). This partly arises because environmental and resource problems are most apparent during extreme events, which are usually followed by less extreme events. A problem may therefore appear to have been solved, despite the possibility that it occurred because of a particular mix of fluctuating causal factors (Levitt and March 1988). Superstitious learning can also be induced by evaluations of success which are insensitive to the actions taken, particularly when there is a high degree of accountability, and where managers are held to standards that have little grounding in ecological science (Levitt and March 1988).

The concept of superstitious learning is partly based on the premise that humans have a limited capacity to understand the complexity of ecological systems. This is true to some extent because the human mind does not deal well with complex probabilities (Anderson 2001) and with the complex feedback between the different components of dynamic systems (Sterman 2000). However, when searching for objectivity, we often forget that, despite the complexity of our daily lives, we still manage to function effectively. The vast majority of our decisions are informed by our implicit understanding and experience of how the world works (Lakoff and Johnson 1999), not on evidence from controlled experiments. While experimental evidence is essential (Walters and Holling 1990), the extent of our personal experience is often one of the most important factors influencing the effectiveness of resource management decisions (Woodwell 1989).

Developing the capacity for individuals to be able to learn effectively from their experiences is an important part of building the knowledge and skills in individuals and organizations to do good adaptive management (Kleiman *et al.* 2000, Salafsky *et al.* 2001). This paper therefore aims to present a way of thinking about how individuals learn to help researchers and practitioners develop expertise in a way that enhances their ability to deal flexibly with new situations. The paper is based on the premise that, if individuals understand how to learn, they will be able to learn more effectively in complex, dynamic social, economic and bio-physical systems (referred to herein as 'environmental systems').

We first explain 'learning' from a phenomenographic perspective (i.e. from studies of what learners and teachers can say or demonstrate about their own experiences of learning), and highlight the importance of developing 'adaptive expertise'. We then review some of the key factors that influence learning and suggest how individuals can put the ideas into practice. This includes an example of applying the ideas to facilitate understanding about the conservation issues affecting a complex and dynamic wetland. Finally, we briefly consider the broader implications of developing the capacity for individuals to learn more effectively from their experiences.

7.2 Learning and expertise

7.2.1 What is learning?

We adopt the view about learning that comes from phenomenography. In this view, a person's understanding of the physical, social, emotional and conceptual/intellectual world is taken to be the dynamic relationship between that person and the world, and is therefore a product of the individual's experiences in and of the world (Marton and Saljo 1976 a, b). With new experiences, the way in which a person perceives and acts in the world changes. Learning can therefore be considered to be a change in a person's understanding of their place in the world and how they perceive it; i.e. a change in the person-world relationship (Fazey and Marton 2002).

This view of learning has several implications. First, a person's understanding and their learning cannot always be easily distinguished because understanding is directly related to what is learned. Second, because understanding is that which is arrived at by the learner, there may be individual differences in how people understand a system or situation. Third, understanding enables a person to do certain things, and, just as there are different ways of understanding the world, there are variations in what this understanding allows a person to do (Fazey and Marton 2002). This view of learning emphasises that each person may understand the environmental system they work in differently, because their understanding of the whole of the system is based on a unique set of experiences of how a subset of that system operates.

7.2.2 What is expertise?

Research indicates that experts acquire extensive knowledge that affects what they notice, and how they organize, represent and interpret information. This, in turn, affects their capacity to remember, reason and solve problems. Expertise is therefore not just memory and intelligence, or simply the use of general strategies (Bransford *et al.* 2000). In general, it takes around 10 years to develop expertise in something in the way that is typically discussed in the educational literature (e.g. Chase and Simon 1973).

There are six key outcomes from observations about how an expert's knowledge differs to that of a novice (from Bransford *et al.* 2000):

5) Experts recognize features and patterns that are not noticed by novices. For example, chess masters and less experienced, but still extremely good players, show no difference in thinking about the number of possibilities of making a move, or the number of possible counter moves that could be made by their opponents (deGroot 1965). Instead, experts appear to be able to "chunk" together related pieces of information, thereby enhancing short-term memory and decision-making (Chase and Simon 1973).

6) Experts organize content knowledge around central ideas, which guide their thinking about certain situations. In physics, for example, an expert's thinking is based around how general principles might be applied to a particular problem. Novices, on the other hand, tend to perceive problem solving as memorizing, recalling and manipulating equations to get answers (Larkin and Simon 1987). It is therefore probably more important to determine a basis for organizing facts, rather than concentrating on trying to retain large amounts of factual detail when beginning to develop understanding about an environmental system.

7) While experts have acquired vast knowledge, they do not need to search through everything in order to find what is relevant to a particular circumstance or task. Expert knowledge is attached to certain contexts (Simon 1980, Glaser 1992), and it cannot always be easily reduced to isolated facts or propositions.

8) Experts are able to retrieve knowledge effortlessly. This does not mean that experts always accomplish tasks in less time than novices, but fluent retrieval places less demands on conscious attention (Schneider and Shiffrin 1985). For example, novices cannot simultaneously drive a car and hold a conversation. With experience, the application of knowledge about how to drive becomes automated, and less cognitive capacity is required for driving.

9) An expert may not necessarily be good at helping others learn. Expertise can sometimes inhibit teaching, because many experts forget what is easy and what is difficult for the learner.

10) Experts display different degrees of flexibility in being able to adapt and deal with new situations. While a person may be technically proficient, they may not be able to adapt in a creative way. A hypothetical example is a trapper who demonstrates expertise in keeping a site free of rabbits. In this context, the specific trapping skill may be sufficient to achieve the desired outcome. However, if the desired outcome is to maintain the rabbit population for optimum grazing to conserve flora, more flexibility in their skill is required. Experts who are highly competent and have developed their understanding of something in a way that allows them to flexibly deal with new situations can be described as having developed 'adaptive expertise' (see Hatano and Inagaki 1986).

These observations highlight that expert knowledge and understanding can often be difficult to articulate, and that experts may not always be able to explain why they know or do something. Such personal knowledge is referred to as 'tacit knowledge' (*sensu* Polanyi 1958). It is built on our unique experiences of the world, and is often assimilated informally (Boiral 2002). While tacit knowledge cannot be articulated, it forms the basis of much of an expert's implicit understanding (which has not, but can be made explicit). Implicit and tacit knowledge have significantly contributed to environmental management. Examples include: helping focus conservation activities to the real causes of a problem (e.g. Fazey *et al.* Submitted [Chapter 6]), increasing the applicability of research results (Steiner 1998); asssiting industry to reduce discharge of pollutants (Boiral 2002), guiding ecosystem management (Olsson and Folke 2001); and determining natural flood regimes (Robertson and McGee 2003).

Experienced and highly skilled people demonstrate expertise by solving problems through using their tacit understanding of the systems they work in. Through such understanding, individuals may recognize emergent properties of a system and can often make good predictions. For example, subjective judgements about extinction risk made by experts were only slightly less accurate than models of population dynamics. Importantly, it only took experts 1-2 hours to make a prediction, compared to 1-2 days using the models (McCarthy *et al.* 2004). In recognition of the value of expert knowledge, many organisations are now trying to find ways of capturing the expertise of employees who are approaching retirement or are leaving to other jobs (Holloway 2000, McManus *et al.* 2003).

7.2.3 Expert understanding of environmental systems

Understanding how we learn is important for anyone who wants to develop expertise or learn how to do something better. In environmental conservation, the role of the practitioner is varied. Nevertheless, most environmental practitioners aim to achieve a better understanding of the environmental system they operate in or intervene with to ensure decisions are appropriate and outcomes are more effective. The particular physical, social or intellectual skills they learn or use, such as catching feral animals, developing communication skills, or acquiring greater understanding of statistical methods, all contribute to the development of the practitioner's personal understanding of some part of the system.

The concept of adaptive expertise has particular relevance for environmental practitioners who are making management and policy decisions within an endlessly varying, dynamic system. Adaptive experts have a depth of understanding that allows them to use their intellectual, physical, emotional and social capabilities to identify and interpret changes in systems. Individuals may initially be surprised by major unexpected events, which have the potential to result in abrupt changes in their understanding (e.g. Proust 2004). However, as they develop their ability to learn adaptively, they are no longer 'surprised' by unanticipated events. Adaptive experts are able to flexibly and more smoothly translate an experience into better understanding, even when those experiences have not been anticipated. They accept uncertainty, and have greater capacity to act appropriately when faced with unanticipated management outcomes.

We refer to individuals who are able to think and act flexibly as 'adaptable practitioners'. Experts may demonstrate a variable breadth of expertise, such as a rabbit trapper with a relatively narrow focus compared to an expert manager of a dune system, who might trap rabbits but also needs other skills and knowledge to be effective. In both cases, however, they can only be described as adaptable practitioners if they demonstrate adaptive expertise.

7.3 Factors affecting individual learning

In this section, we review some of the key factors that affect individual learning. While studies of learning provide several different perspectives on how to assist individuals to develop adaptive expertise, we restrict our focus to the importance of: (1) practice, (2) variation in practice and (3) reflection in learning and the importance of 'good thinking'.

7.3.1 Practice

Learning how to do something better requires regular practice. In the early stages of learning, a learner is conscious of almost everything, but is often unable to identify what is important. As learning progresses, thinking and behavior are gradually refined and it becomes increasingly automated until the learner can do what they want while paying little attention to doing it. After extended practice, improvement in even the most complicated routines may not be detected, but there is continued improvement in secondary tasks performed at the same time (Schneider 1985).

There are three striking ways of enhancing practice that supports effective learning. First, actual practice can be complemented and, in some cases, replaced by imagined practice in the form of detailed mental rehearsal or review (e.g. Feltz and Landers 1983, Malouin *et al.* 2004). Second, practicing making judgements about the performance of a task before and after receiving external feedback can improve any later performances, so long as the individual has an awareness of a set of understandable, objective criteria by which an attempt or performance can be judged (Wulf and Shea 2003). Third, random experience of variation of a task and/or frequent changes that introduce unrelated practice tasks leads to better retention and improved adaptability than when an individual constantly practices the same thing (Shea and Morgan 1979, Magill 1998) (see below).

7.3.2 Variation in practice

At the end of the initial period of practice, learners who have only practiced a task in the same way outperform those who have had higher levels of variation in the practice. In later tests, however, there is often no difference between the performance of high and low variation groups (Shea and Morgan 1979, Jarus 1994). Importantly, when trying a new variation that neither group has practiced, high variation practice groups always outperform low variation practice groups (Fazey and Fazey 1989). That is, those who have experienced variation during practice develop adaptive expertise.

To develop adaptability, there are five aspects of practice that can be varied (Fazey in prep-b): (1) the intended outcome; (2) the criteria by which the outcome is judged; (3) the way a task is done or experienced; (4) the reason for which the learning or creative task is undertaken; and (5) the perspective a person can take (e.g. van Merrienboer and de Croock 1997, Pramling 1990), such as a stakeholder who tries to look at a conservation issue from the perspective of other stakeholders (e.g. Lynam *et al.* 2002). These dimensions of variation are not mutually exclusive and interact in complex ways. Introducing variation in only one or two of these dimensions may therefore be sufficient to induce more effective learning (Marton and Booth 1997).

Introducing variation helps to break what phenomenologists call the 'natural attitude' - our habitual assumption that what we experience is reality - rather than the attitude that it is reality experienced in a particular way (Fazey and Marton 2002). That is, it helps to demonstrate that what we experience is not the same reality that others experience. Trying to look at a problem from different perspectives is therefore possibly one of the most crucial elements of variation that needs to be practiced (Marton and Wenestam 1988). People will not only be better learners if they are open to how an experience changes their current understanding, but also if they are open to how others have perceived the same experience.

7.3.3. Reflection and thinking

To be effective, practice must be purposeful and fit in an overarching framework that includes planning, monitoring and/or reviewing. The usually adopted model is a simplified version of Kolb and Fry's (1975) interpretation of K. Lewin's cyclical account of learning. In this model, the learner moves from active or concrete involvement in an experience, to observing and reflecting, through to forming abstract concepts and then to testing the implications of the concepts in new situations. This is popularized as the "plan, act, review and try again approach". The metaphor of a moving wheel or a spiral is often used to emphasize continuous change and the learning that occurs over multiple attempts to achieve a learning goal. With added emphasis on reflection, the model provides a useful template for designing experiences to facilitate learning (e.g. Boud and Miller 1997).

Such feedback-based models stress the need for monitoring the discrepancies between an intention and actual outcomes. In some professions, (e.g. branches of caring and medicine), reflection on critical experiences is taken to be an important aspect of both individual learning and the development of a professional knowledge base (e.g. Schön 1996). In such cases, asking personal questions about an incident like "what was my part in it" and "how did it affect me" can be considered equally important to asking "what happened and why". There is, however, evidence to suggest that it is more important to be aware of what was done, and what resulted from it than to be aware of the shortcomings of an attempt to do something (Wulf and Shea 2003).

For environmental practitioners, reflection on specific experiences aims to stimulate better understanding about an environmental system. Cognitive scientists take the view that people construct some form of dynamic working representation, or mental model, of how a system operates from their current understanding of that system (O'Connor and McDermott 1997). In developing major shifts in understanding, a person must also change their mental model. While mental models do not fully capture the dynamic learning process, they do provide a useful heuristic to communicate notions of how an individual changes their understanding.

The process of adapting mental models is captured in models of double-loop learning (e.g. Sterman 2000). In one loop, a decision is made, acted on, and the results used to inform better decision-making. Feedback from the actions in the first loop can also induce change in the mental model, which is represented in the second loop. As our mental models change, we change the structures, strategies and decision rules that control the decision-making processes in the first loop (Fig. 7.1).

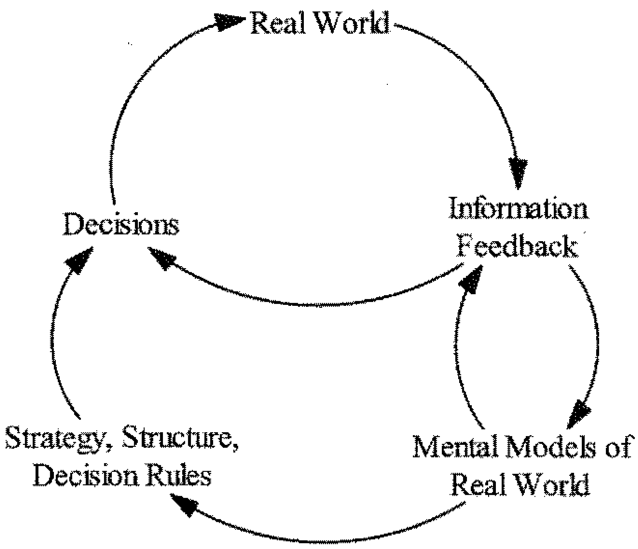

Fig. 7.1: Double-loop learning (from Sterman 2000). Feedback from the real world can induce change in mental models. Change in the mental model leads to new goals and decision rules, not just new decisions.

Our ability to evaluate our mental models is constrained because the tools we design to evaluate our working representations (GIS, scientific research, etc.) are influenced by those same mental models, which affect what we measure, define and give attention to (Sterman 2000). Humans are also notoriously poor at understanding the dynamic feedback of systems (Sterman 2000), which is made particularly difficult in environmental contexts because outcomes of management often take a long time to become apparent and are confounded by many other factors (Hinrichsen 2000). Further, humans are very defensive about altering their mental models (Argyris 1985) and change is often resisted until actions or decisions produce serious deleterious outcomes (Proust 2004).

To induce change in our mental models, we must become adept at taking different perspectives by applying ideas like variable and reflective practice (Table 7.1). Taking different perspectives allows us to vary our experience and question our current understanding. However, we also need to be open to changing our mental model as our understanding of the system develops. To do this, we need to become 'good thinkers' (Perkins *et al.* Unpublished). Good thinking can be characterized as seven broad thinking dispositions (Table 7.2). Each disposition has three elements: inclination (a person's felt tendency towards a particular behavior), sensitivity (a person's alertness towards a particular occasion), and capability (the ability of a person to follow through with a particular behavior). The 'ideal thinker' is disposed towards all of the thinking behaviors, and appropriately exhibits one or more of them depending on the occasion. The theory of good thinking is based on logical arguments and a scattering of empirical evidence for the importance of dispositions. Perkins *et al.* (Unpublished) argue that the theory raises provocative questions about existing models of thinking, casts new light on controversial issues in the field, connects in interesting ways to findings in other promising areas of cognitive research, and has important implications for the education of good thinking.

Table 7.1: Summary of some of the important factors influencing how individuals learn. Note that the points discussed apply equally to both learning a particular skill or ability and to learning how to learn.

Factor	Summary
Practice	With practice, the application of a learned skill or ability can eventually become automatic in a flexible and adaptive way
	Actual practice can be complemented and sometimes replaced by detailed mental rehearsal or review
	Practice making judgements improves performance, as long as there is a clear objective and set of criteria for judging performance
Variation	Variation breaks our tendency to assume that what we experience is reality, not reality experienced in a particular way
	Variable practice leads to better retention and develops adaptive expertise
	To develop adaptability, it is possible to vary: (1) the intended outcome, (2) the criteria or precision by which an outcome is judged, (3) the way a task is done or experienced, (4) the reason for doing a task, (5) the perspective a person can take
Reflection	For effective learning, continuous monitoring of discrepancies between intended and actual outcomes is required
	A number of explicit methods can be used to promote learning. However, having the right attitude by taking a mindfulness approach to learning is the most important factor influencing learning effectiveness
	Thinking about our thinking is essential for developing an effective learning attitude (Table 7.2)

Table 7.2: Developing an appropriate learning attitude is influenced by how we think. Good thinking has seven broad dispositions, each with three components (from Pekins *et al.* Unpublished).

Disposition	Component Inclination (examples)	Sensitivity (examples)	Ability (examples)
1) To be broad and adventurous	Tendency to be open-minded, impulse to probe assumptions, desire to tinker with boundaries	Alertness to binariness, dogmatism, sweeping generalities, narrow thinking	Identify assumptions, empathic and flexible thinking, to look at things from other points of view
2) Toward sustained intellectual curiosity	Zest for inquiry, urge to find and pose problems, tendency to wonder	Alertness to unasked questions, anomalies, hidden facets, detecting gaps in knowledge	To observe closely, focus and persist in a line of inquiry
3) To clarify and seek understanding	Desire to grasp the essence of things, impulse to anchor ideas to experience and seek connections to prior knowledge	Alertness to unclarity, discomfort with vagueness, a leaning towards hard questions	Ability to ask pointed questions and build complex conceptualisations, ability to make analogies and comparisons
4) To plan and be strategic	Urge to set goals, make and execute plans, a desire to think ahead	Alertness to lack of direction, lack of orientation, sprawling thinking	Ability to formulate goals, evaluate alternative modes of approach, make plans and forecast possible outcomes
5) To be intellectually careful	Urge for precision, a desire for mental orderliness, organisation, and thoroughness	Alertness to possibility of error, disorder and disorganisation, inaccuracy and inconsistency	Ability to process information precisely, to recognize and apply intellectual standards
6) To seek and evaluate reasons	A leaning towards healthy scepticism, the drive to pursue and demand justification, the urge to discover grounds and sources	Alertness to evidential foundations, responsiveness to superficiality and over generalisation	Ability to distinguish cause and effect, to identify logical structure, reason inductively
7) To be metacognitive	Urge to be cognitively self-aware and to monitor the flow of one's thinking, desire to be self challenging	Alertness to loss of control of one's thinking, detection of complex thinking situations requiring self monitoring	Ability to exercise control of mental processes, to conceive of the mind as active and interpretive, to be self evaluative, to reflect on prior thinking

As with learning anything, ideas like variable and reflective practice and good thinking can become automated in an adaptable way if practiced with intention (e.g. Palmer and Drake 1997). Practicing applying ideas about learning and good thinking to a wide variety of skills, abilities and circumstances develops flexibility in dealing with new learning situations. Initially, practicing learning or thinking requires careful analysis and reflection of events and experiences. Eventually, the process becomes more automatic. In the end, an expert learner is able to learn or think skillfully with little more than sporadic self-checking (Pramling 1990).

7.4 Applying the ideas of variable and reflective practice and good thinking

7.4.1 Developing understanding about complex systems

To develop individual understanding of environmental systems, the ideas of variable and reflective practice and good thinking should be applied to three main situations:

7.4.1.2 Whenever we use any technique, display skill or demonstrate ability:

For example, when building a fence for stock management, designing an experiment, evaluating the effectiveness of policy, or conducting an environmental impact assessment. Past performance should be reviewed, then the current performance planned, conducted and monitored to determine what was done and how it might have been done better. Variation can be introduced in many ways, such as by mentally considering how things could have been different, such as whether a fire would have responded differently if the wind had changed. A practitioner never experiences exactly the same situation twice, and variation is always present. However, without active reflection, we become comfortable with the way we do something, reducing our capacity to learn from new situations.

7.4.1.2 Reflecting on natural variation in the real ecological world:

A common cri de couer is that many environmental scientists and practitioners do not spend sufficient time directly in an environmental setting (e.g. Noss 1996, Campbell 2003). There are two reasons why this is important. First, we need to ensure that what is being learnt about an environmental system is relevant to what we are trying to achieve in the real ecological world. Scientific knowledge stresses objectiveness and distance. However, it is still important to observe events from within the system being studied or managed because spending time in an ecological setting helps to develop our tacit understanding, which guides our questions and how we go about answering them (see Polanyi 1958). As Noss (1996) points out: "abstractions and fancy technologies are no substitutes for the wisdom that springs from knowing the world and its creatures in intimate, loving detail".

Second, spending time in an environmental setting may also help to motivate environmental learning. Whiteman and Cooper (2000) suggest that managers who are physically located outside in their local ecosystems and who gather management knowledge through first-hand experience develop both a greater identification with their local ecosystem and have greater commitment to sustainable management practices. Strong personal identification with an environmental system will promote learning because the learning process is more likely to be perceived as being personally important. Such intrinsically motivated learning is more powerful and robust in the face of difficulties than learning that is driven by extrinsic factors, such as rewards or punishments, where a person does something because they have to, rather than because they want to (Deci and Ryan 1985).

While spending time in environmental settings can facilitate the development of understanding of an environmental system, individuals will also enhance learning by actively engaging in the learning process, such as by applying the ideas of variable and reflective practice and good thinking. To do this, it is necessary to actively reflect on observed events and become accustomed to spending field-time thinking about what is happening, and how it might be different even if nothing is actually occurring at the time. For example, spending field-time thinking about or discussing with others the different ways selective logging might impact a forest will help individuals improve their understanding of that particular forest and its biota.

7.4.1.2 Developing expertise in exploring the feedback in systems:

This requires practicing dealing with complexity by trying to understand the links between the different components of a system (e.g. specific taxonomic groups or ecological vs. social or economic) rather than always trying to reduce them to immediately manageable pieces. An example is the development of business practices that are resilient over the long-term. To be sustainable, corporations need feedback from ecosystems about the ecological impact of their activities (Whiteman *et al.* 2004). To be effective, however, a shift in culture in the corporate boardroom is required where individual decision-makers accept and understand the complex interactions and feedback between social and natural systems (Chapin *et al.* 1998).

Practicing building formal simulation models of environmental systems using tools such as causal loop diagrams or stock and flow models is particularly useful to induce learning about systems (Sterman 2000). Importantly, all simulation models provide individuals with opportunities to vary their perspective, by enabling them to explore how a system might operate with different initial conditions or contextual settings. They also help individuals to articulate their understanding, and allow them to compare their perspective with that of others.

In general, relatively simple ways of thinking about planning, acting and reflecting may be enough to induce some change in understanding, so long as people have developed the capacity to be open to changing their mental models. Discussing experiences with other people (e.g. Lybeck 1981) or roleplaying (e.g. Lynam *et al.* 2002) can be effective ways to provide alternative perspectives. Building relatively simple models such as spidergrams of links between components may also provide a basis upon which detail can be added and integrated. Thus, while considerable effort is required in the initial stages of developing expertise in learning, it is not meant to be an arduous life-long learning sentence.

7.4.2 An example of applying the learning ideas

Between February and August 2004, research was conducted which aimed to elicit the implicit knowledge of seven on-ground managers about the current conservation problems and issues facing the dynamic Macquarie Marshes (referred to from this point forward as the Marshes) in south-eastern Australia (see Fazey *et al.* Submitted [Chapter 6]). At the same time, the ideas about variable and reflective practice were also applied in an attempt to facilitate the development of the on-ground managers' personal understanding of the environmental system. The case study presented below therefore provides a useful illustration of applying the learning ideas presented in this paper. While detailed data was not collected that assessed the effectiveness of the approach to induce change in the understanding of the participants, a number of issues were raised that are worthy of reflection.

Research stages for eliciting the implicit knowledge of the on-ground managers to which ideas of variable and reflective practice have been applied

The Marshes are a 220 000 ha ephemeral wetland system located in the central west of New South Wales. The area is primarily managed privately by landholders, with around 21 000 ha managed as a Nature Reserve by the Department of Environment and Conservation (DEC) (see Fazey *et al.* Submitted [Chapter 6] for full details). The seven participating on-ground managers were all experts of at least some aspect of managing the complexities of wetland systems, with six having extensive experience of the Marshes. The on-ground managers had a total of 140 years of experience of being involved in the management of water on the

Marshes, and 234 years of general experience of working in the Marshes. Some of the managers exhibited a deep tacit ecological understanding of the wetland.

A number of research steps were used to elicit the implicit knowledge of the managers (Figure 2). During the research process, the ideas of variable and reflective practice (Table 1) were also applied to the different research stages by capitalising on the range of individual and group activities that provided variation in the perspectives taken, the process of data collection, and in the outcomes (Table 3). In the first stage (Figure 2), the researcher spent two months becoming familiar with the issues facing the managers by working as a volunteer with DEC. This provided a period for trust to develop between the participants and the researcher, and to ensure that the participants felt they had sufficient control in the process and that they were confident their knowledge would be communicated appropriately.

In other stages, repeated opportunities were provided for the participants to articulate their individual understanding. Each opportunity was deliberately structured to vary how their expertise was articulated. This not only ensured that the researcher was able to learn about and capture the complexities of the conservation issues, but also enabled variation in the way the participants explored their personal understanding. There were five stages that provided opportunity for variation: (1) Data consisting of simple conceptual links between statements made by a participant were generated in individual interviews. This enabled the initial examination of some of the feedback process occurring in the system; (2) The process was repeated in a second interview where a different aspect of the system was examined; (3) a workshop was held with all participants to identify and discuss the significant historical changes to the environmental system that had contributed to current conservation problems; and (4) a preliminary conceptual model describing the environmental system was discussed separately with each participant in a third interview (for a detailed account of the method, see Fazey *et al.* Submitted [Chapter 6]); (5) A final meeting was held with all the participants to enable them to collectively give feedback on the accuracy of the conceptual model and the presentation of their expert understanding.

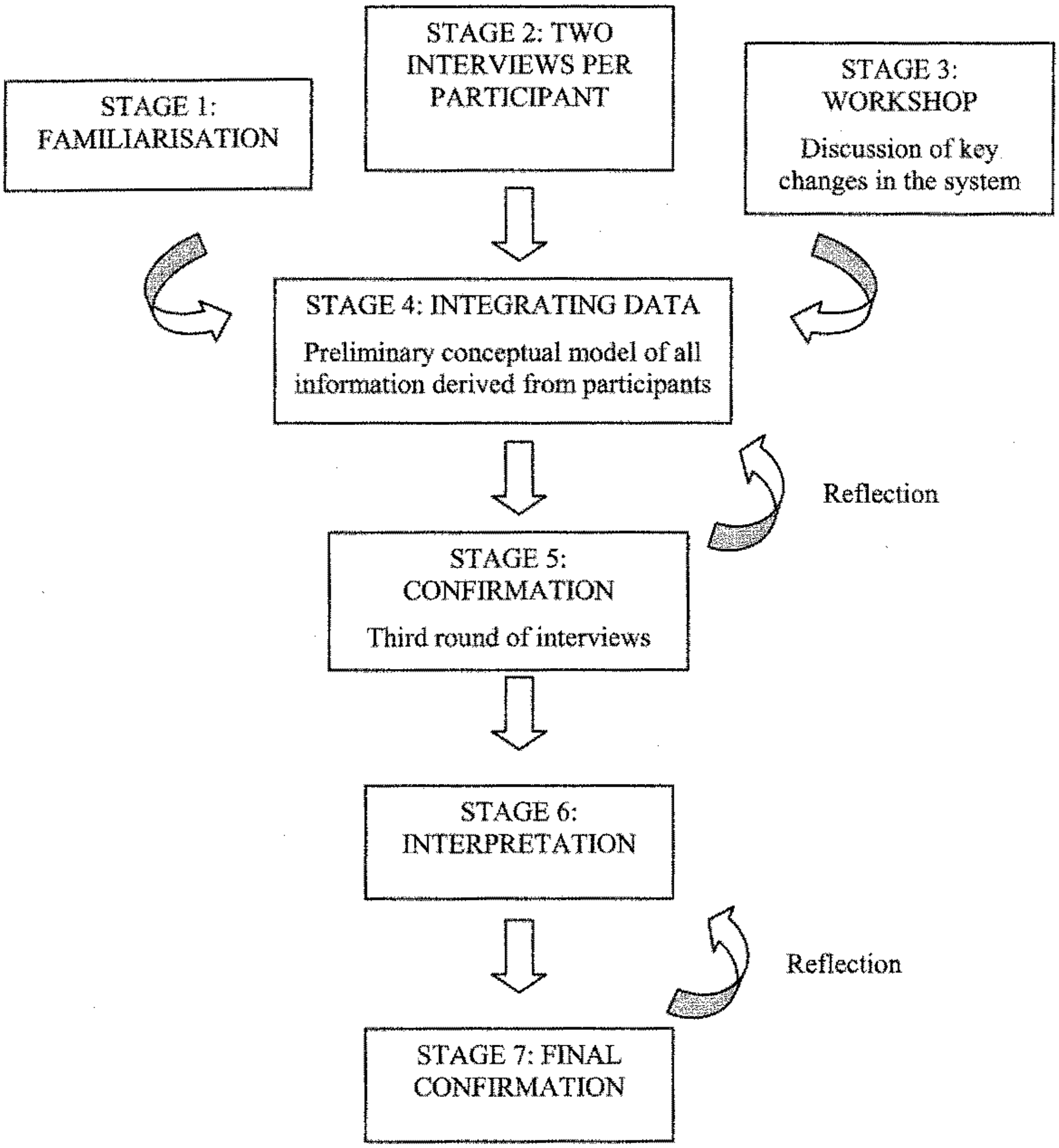

Fig. 7.2: Research method used to elicit the expertise of seven on-ground managers of the Marshes. Note that stages 5 and 7 allowed reflection of the process, including assessments that ensured the researcher was adequately reporting the expert understanding of the on-ground managers.

Table 7.3: Ways in which ideas of learning were applied to help research participants develop their personal understanding of the Marshes environmental system.

Factor influencing learning		Achieved by:
Providing an appropriate learning environment where participants felt motivated to participate		Participants were partly selected on the basis of their interest in participating, i.e. they participated because they wanted to/felt it would be useful to them and/or the Marshes
		Participants were only asked to provide information on aspects they felt they were competent to discuss
		Participants chose which components of the system they discussed
		No prior assumptions were made by the researcher about what issues/problems were most important
Practice	Of studying personal understanding of the Marshes system	Practicing articulating their understanding through describing the complexities in the first and second interviews, workshops and providing feedback to the researcher on a preliminary conceptual model in the third interview.
Variation	By looking at personal understanding of different components of the Marshes system, and sharing perspectives with others	Data produced in the first and second interviews were of different components of the Marshes system
		Different perspectives were shared at the workshop
		The preliminary conceptual model was discussed with individuals at the third interview
Reflection	On different stages during the data collection process	At the second interview, the data from the first interview was discussed
		At the workshop, data from first and second interviews were presented for reflection by all participants
		Reflection on the preliminary group conceptual model with each participant at the third interview
		Participants asked in third interview what they had learnt from the process and to reflect on whether their understanding had changed

7.4.2.2 Reflecting on applying the ideas about learning and on the expert knowledge of the participants

In the third interview, the managers were asked if they had personally gained from the process. The two participants with the least direct experience of the Marshes, who were from outside the core group of managers, felt they had learnt a great deal. One of these suggested that they had gained a better understanding of the perspective of the other participants and that it had been a good opportunity to show their willingness to learn from those with the most experience. Another three individuals suggested that, although they took in very little new information, the process confirmed what they thought they already knew. One manager commented that they sometimes wondered if their perception of the issue was valid, given the inaction by relevant government agencies to deal with the conservation problems. Being involved in a process where they shared and discussed their views reinforced their perceptions, and gave them greater confidence in their own expertise and in their understanding of the causes and severity of the conservation problems facing the Marshes.

The sixth participant would not commit to whether the process was personally useful, but acknowledged that the conversations with the primary researcher were influential in developing their thinking and understanding. Finally, only one participant felt they had personally gained very little. However, they acknowledged in the final meeting that the final document (Fazey *et al.* Submitted [Chapter 6]) was likely to be a useful tool to help articulate their collective expert understanding and add credibility to their expertise.

While a full evaluation of the application of specific ideas of learning is beyond the scope of this paper, the process appeared to have induced some degree of change in the way participants either understood the Marshes system, or in their perception of their competence in understanding. Importantly, however, the process confirmed the extent of the managers' experiential knowledge. This was most apparent in the workshop where they worked together in a dynamic and flexible way to provide answers to questions asked by the researchers. In the workshop, it was clear that certain individuals had a more complete understanding about a particular issue than others, but together they generated a collective understanding that was greater than the sum of the parts. As some of the managers put it, they "fed off each other" during the discussion. Their personal in-depth knowledge allowed them to ask pertinent questions when dealing with a topic that was outside their immediate area of expertise, enabling them to tease out the implicit knowledge of those with greater experience.

The expert knowledge of most of the managers was derived from their long-term experience of working and living in the Marshes. They also had a deep and longstanding respect for the natural environment they lived and worked in and had a strong personal motivation to learn about and conserve the Marshes and the human community that depended on it. This observation supports the proposed link between ecological respect and a sense of personal identification with a greater commitment to sustainable management practices (Livingston 1994, Whiteman and Cooper 2000).

Observations of the expert understanding of the managers also provides some support to the notion that personal identification with an ecosystem may promote an intrinsic motivation to learn about the ecology of that system. The personal interest of some of the participants to learn appears to have been derived from their economic dependence on an ecologically functional wetland. Without flooding on the Marshes to generate native vegetation growth to feed cattle, cattle graziers would not be able to sustain a living. Such dependence on natural flooding events means that cattle graziers (particularly those that are solely dependent on cattle production) are likely to be more aware of changes in wetland dynamics than individuals involved in other agricultural enterprises.

Compared to agricultural enterprises such as cropping (which are less dependent on flooding), cattle graziers on the Marshes continually receive and react to feedback from water flows entering the wetland. Cattle grazing on the Marshes is also different from other agricultural enterprises that are also heavily dependent on water resources, such as cotton production. Cattle grazing on the Marshes relies on working with, and responding to the variability in the timing, duration and extent of flooding events. Irrigation enterprises, however, generally depend on reducing risks associated with natural variability in water flows by attempting to control water delivery (e.g. through construction of weirs and dams). Because cattle graziers on the Marshes have such strong links to the variability in water flow, they are more likely to be intrinsically motivated to observe and reflect on the variability in flooding and the response of the wetland to those flooding events. The cattle graziers are therefore more likely to build a more in-depth ecological understanding of the Marshes.

Over the last 40 years, since river regulation on the Macquarie River, there have been major changes to the water regime with significant amounts of water being extracted to support upstream towns and irrigation industries (Kingsford and Thomas 1995). This has resulted in a major change in the ecological character of the Marshes, with direct consequences for the livelihood of many individuals on the wetland (Fazey *et al.* Submitted [Chapter 6]). In the case of the Marshes, the expert understanding of many of the cattle graziers therefore has particular relevance and value for providing insights into how much upstream water extraction is likely to be ecologically sustainable.

The economic dependence of some of the managers on the wetland clearly influenced their perspective and their own understanding of the Marshes, particularly when they were exposed to stakeholders with radically different views of how to best use river water. However, many other stakeholders in the Macquarie Valley lack the long-term embedded ecological knowledge of the Marshes. When it came to questions about its management, the on-ground managers were adamant that the wetland was under serious threat of ecological collapse, and that the answer predominantly lay in tackling the water delivery problems occurring beyond the geographical boundaries of the Marshes (Fazey *et al.* Submitted [Chapter 6]).

7.5 Implications of more effective individual learning

7.5.1 Individual to group and organisational learning

Many of the characteristics of a 'high quality' learning organization (Table 7.4) revolve around notions of openness and freedom of expression (Bapuji and Crossan 2004). To achieve such a learning culture, members of an organization must also aspire to such goals. In our view, personal characteristics such as integrity, humility and openness to criticism and change are necessary for an individual 'ideal learner' to be able to take and be open to different perspectives (see also Antonacopoulou 2004 for a discussion of the characteristics of good scholarship). Individuals with such characteristics will naturally engender an environment in which others can learn. Thus a high quality learning culture is only likely to be possible if individual members are also willing to engage in learning, and if they have developed the capacity to learn effectively.

Considerable emphasis is placed on the importance of leaders who can facilitate the learning of others (Richter 1998, Ramus and Steger 2000, Olsson *et al.* 2002, Naot *et al.* 2004, Rushmer *et al.* 2004). In formal organizations (e.g. corporations or recognized institutions), managers influence subordinates through role modelling, goal definition, reward allocation, resource distribution, communication of organizational norms and values, structuring work group interactions, conditioning subordinates' perceptions of the work environment, and through having influence over the processes and procedures used (Ramus and Steger 2000). Even though most leaders do not view themselves as facilitators of learning (Bapuji and Crossan 2004), these influences directly affect the learning opportunities of others (Ramus and Steger 2000).

Targeting leaders may therefore be a good place to begin to develop a culture of learning within an organization (Rushmer *et al.* 2004). For example, attempts are being made to change the culture within the UK National Health Service so that it can learn better from, and reduce the number of adverse incidents affecting patients and staff. Managers have first been assisted to gain a fuller understanding of learning as a process of change (Jones *et al.* 2005-a), and have then been supported by mechanisms that help them work and learn more effectively as individuals or in groups (Jones *et al.* 2005-b).

While it is generally accepted that it is the individuals who learn and not the organization (Miner and Mezias 1996), only focussing on individuals means that the social context of learning in which the individuals are embedded can be neglected (Richter 1998). Thus, in the interpretive perspective of organizational learning, learning is considered to be a social practice (Ortenblad 2002). To understand the way information travels through an organization, the relationships between individuals and the communities within the organization also need to be understood (Richter 1998). Individuals are considered to make sense of the world by communicating and using language and symbols that allows them to collectively invent and reinvent a meaningful order (i.e. 'sensemaking'; *sensu* Weick 1995). Actions are then made in accordance with that particular interpretation of reality (Westley *et al.* 2002). That is, the organizational learning is considered to be context dependent (Ortenblad 2002).

The interpretive perspective of organizational learning sees learning as a never-ending process (Blackler 1995), which is important when trying to manage environmental systems adaptively. The perspective also does not assume that organizational learning is confined to a formal organization, such as a corporation or recognized institution (Araujo 1998). This is particularly relevant for environmental practice where much of the learning occurs in loosely defined organizations, such as in the group of Marshes managers. Information flowed into the group through individuals with outside experience, and was then interpreted collectively through interactions between the members. This gave rise to a unique collective understanding of how and why the wetland was changing (Fazey *et al.* Submitted).

This suggests that while improving the capacity of individuals to learn is essential for building a learning culture, the resulting learning processes and knowledge will not only be confined to particular individuals within a group or organization. Collaboration between individuals is therefore necessary to gain a fuller understanding of dynamic environmental systems (Olsson *et al.* 2004), and social learning processes increase the capacity of organizations to respond to feedback from the environment so that actions can be more sustainable (Berkes *et al.* 2003).

Table 7.4 Hypothetical characteristics of a high quality learning organization (from Lipshitz *et al.* 2002, Naot *et al.* 2004)

Characteristic	Requirement	
LO achieves outcomes	The organization produces desired outcomes or averts undesired outcomes by learning	
LO employs processes that are likely to produce effective learning	Captures notions of single and double-loop learning	Where examination of sensitive issues and reframing of assumptions, values and goals can occur
	Transparency	Willingness to expose one's thoughts and actions to others in order to receive feedback
	Integrity	Willingness to seek and provide information regardless of its implications
	Issue-orientation	Focussing on the relevance of information to the issue under consideration regardless of the social standing, rank, source or recipient
	Inquiry	Persisting in investigation until full understanding is achieved
	Accountability	Willingness to assume responsibility for learning and for the implementation of lessons learned
LO sets (or is set in) a context where learning is most likely to occur	Reciprocal commitment between the organization and its members	
	Commitment of the organization's leadership to learning and its tolerance for error	
	An appropriate task structure and proximity to the core tasks of the organization	
	High cost of potential error (i.e. learning is more likely to occur if cost of error is high)	
	Environmental uncertainty (i.e. learning is more likely to occur where there is a high degree of uncertainty)	

7.5.2 The complementary role of experiential and experimental knowledge

Relying on experience to inform decisions has both advantages and disadvantages when compared to using experiments, and both experience and experiments are essential for effective environmental practice and can play a complementary role (Table 7.5). However, it is often difficult to separate their relative influence in making decisions. The majority of our decisions are predominantly governed by our implicit and tacit understanding of how the world operates (Lakoff and Johnson 1999). This influences the experimental questions we pursue, how we conduct the experiment, and how we analyse the results. The results may alter our understanding and allow us to adapt our mental model (Fig. 7.3). Other experiences may also influence our understanding, but our understanding also influences what we learn from, and how we perceive, those experiences (Fig. 7.3). When we make a decision, the results of research are therefore combined with the experience of doing the research, the way we interpret the results, and our personal, environmental, and educational experience (e.g. Fazey and McQuie In press [Chapter 5]).

The key to improving personal understanding of a system from both experience and the results of experiments is to develop the ability to take different perspectives and learn to become open to how they might affect our mental models. To do this, applying ideas like variable and reflective practice (Table 7.1) and good thinking (Perkins *et al.* Unpublished, Table 7.2) will be necessary.

Table 7.5: Some of the differences between expert and experimental knowledge highlighted by the characteristics of expertise and individual learning.

	Expert knowledge	Experimental knowledge
Perspective	Greater capacity for a holistic perspective	Greater capacity for a reductionist perspective
Historical perspective	Has some capacity to take into account the historical trajectory of something in order to make better predictions about the future by interpreting the present with respect to past experiences (Polanyi 1958). For environmental systems, this requires extensive experience of the same phenomenon or system (e.g. some of the managers of the Marshes).	Has less capacity to take into account the influence of a historical trajectory because predictions are based only on what is occurring in the present.
Learning from long-term outcomes	Less capacity to learn from interventions whose outcomes take a long time to become apparent because an individual's experience is finite and relies more on immediate feedback	Has greater capacity to learn from interventions that have long-term outcomes because experiments can run over long periods of time
Dealing with confounding factors	Has less capacity to deal with confounding factors when trying to distinguish between cause and effect	Has greater capacity to deal with confounding factors when trying to distinguish between cause and effect
Accessibility	Difficult for others to access and pick up because it is either inarticulate (tacit), or very difficult to articulate (implicit)	Easier for others to access and pick up because it is formalized and made explicit
Requirement	Requires experimental knowledge as a check and balance to ensure accurate connections between cause and effect	Requires expert knowledge to identify appropriate questions, interpret results and maintain a more holistic perspective

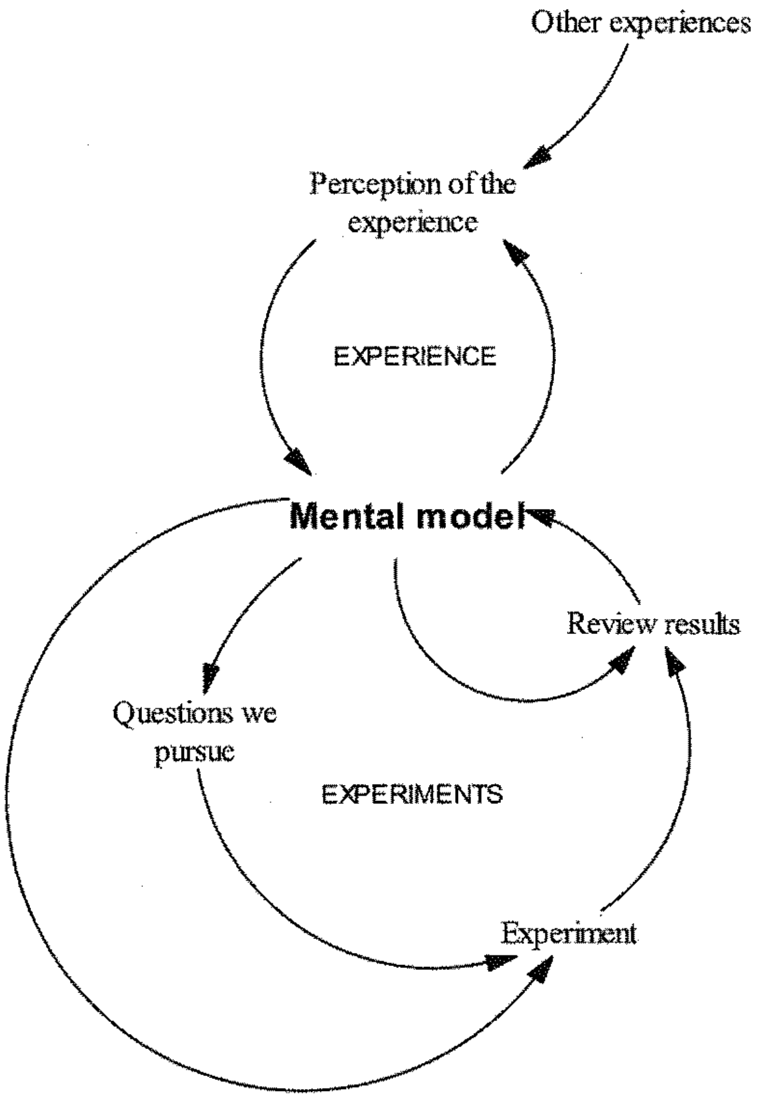

Fig. 7.3: Experiments and other experiences may stimulate change in our mental model as we develop understanding, but our understanding and mental models also influence the questions we ask, how we conduct the experiment, and how we analyse and perceive the results.

7.6 Concluding remarks

This paper acknowledges the importance of experiential knowledge for effective conservation research and practice. It is not, however, intended to be an argument for using experience as a replacement for appropriate research to inform decisions or for developing individual understandings of environmental systems. Instead, it is a plea for increased rigour in using what we know about turning experience into more effective learning.

This paper has highlighted that it is possible to greatly improve how we learn as individuals. In current educational settings, students are rarely taught how to learn, and learning is often just expected to 'happen' during the educational process. Thus the ideas presented may seem simple, but they have profound implications for educational and professional development. Giving greater consideration to applying ideas about learning from experiences to environmental practice would not only result in more adaptable practitioners with an inquisitiveness and ability to learn, but would also result in more people who were mindful that their view of the world is only one perspective of many.

7.7 Acknowledgements

We thank the Coonabarabran and Dubbo offices of DEC and the research participants for their support and hospitality. B. Newell, K. Sherrin, J. Fischer, D. Lindenmayer and S. Dovers provided valuable comments on earlier versions of the manuscript. D. Lindenmayer and the Centre for Resource and Environmental Studies provided research funds and DEC provided in kind support. I. Fazey was supported by an EE Scholarship from the Australian National University.

SECTION E:

SYNTHESIS

The aim of this thesis was to develop understanding about the role and value of experience for environmental conservation. This is addressed in detail in the next chapter. However, previous chapters have made independent contributions to the discipline of environmental conservation:

- *Chapter 2 reviewed current conservation literature and discussed its relevance to policy and management;*
- *Chapter 3 suggested ways in which conservation can do more to bridge gaps between research and practice;*
- *Chapter 4 discussed the problems of developing practical theory that is not misleading;*
- *Chapter 5 explored how practitioners apply formal theory;*
- *Chapter 6 developed and applied a method for eliciting the expertise of on-ground conservation managers, which included the development of a conceptual model specifically designed to be a communication tool;*
- *Chapter 7 suggested how researchers and practitioners could more effectively build expert understanding of environmental systems.*

Chapter 8 is a synthesis that considers the research from previous sections. That is, it considers: (A) the nature of environmental conservation; (B) the development and application of conservation theory; (C) the elicitation of implicit (experiential) knowledge; and (D) suggestions of how we can learn more effectively from our experiences (see Fig. E.1). The synthesis presents a conceptual model that explains how our level of expertise in learning influences the ability to change the way we think. The intention is that the model will facilitate change in the way researchers and practitioners perceive experiential knowledge. The implications of the model are discussed in relation to understanding the role and value of experience within an evidence-based approach. The chapter is meant to be a stand-alone piece of work accessible to a wide audience (see "approach" in Chapter 1), therefore some repetition with earlier chapters was unavoidable.

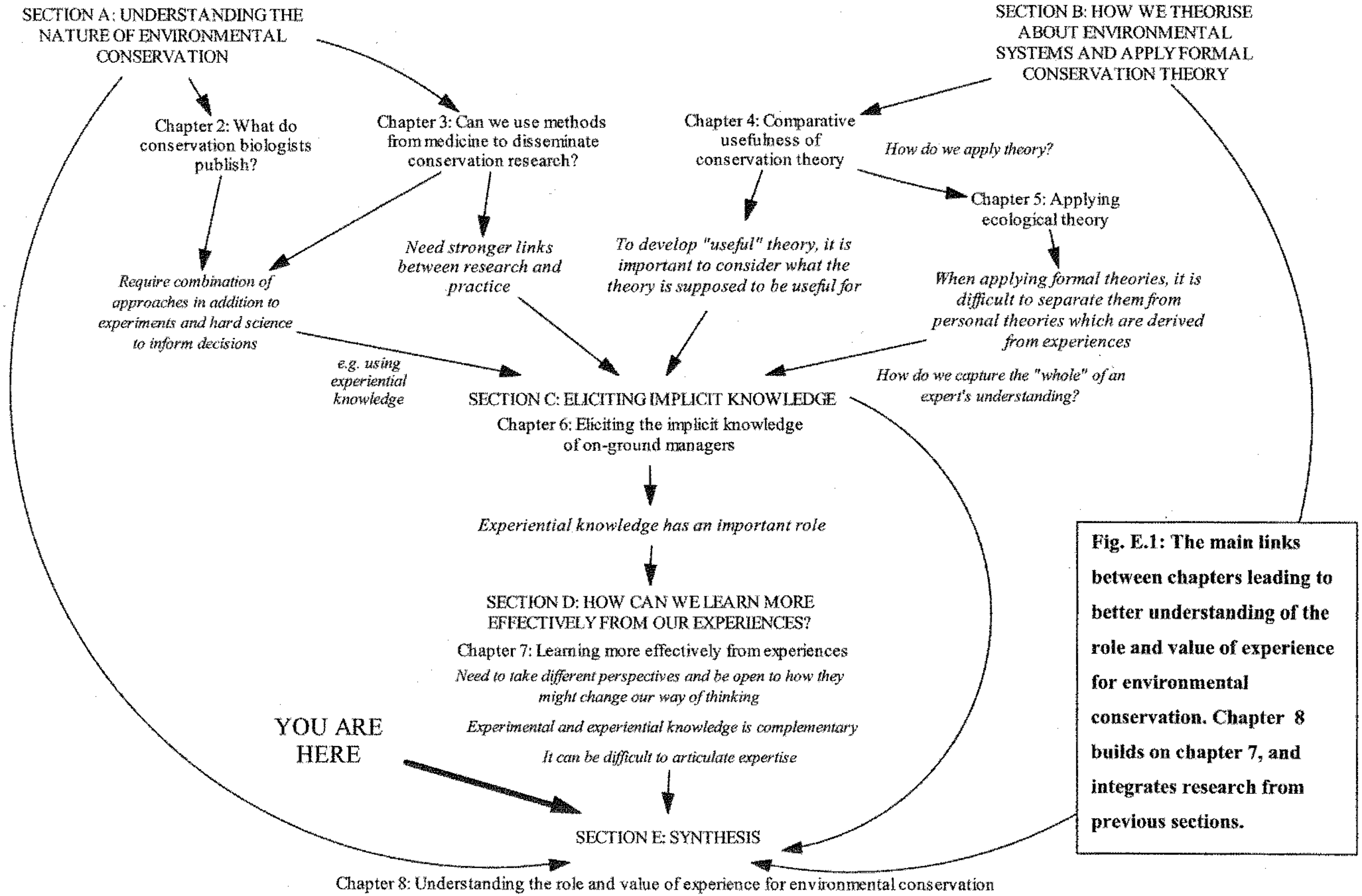

Fig. E.1: The main links between chapters leading to better understanding of the role and value of experience for environmental conservation. Chapter 8 builds on chapter 7, and integrates research from previous sections.

Chapter 8

THE ROLE AND VALUE OF EXPERIENCE FOR ENVIRONMENTAL CONSERVATION

Citation: Ioan Fazey, John Fazey, Janet Salisbury, David Lindenmayer and Steve Dovers (Submitted). The role and value of experience for environmental conservation. Environmental Conservation.

8.0 Summary

The importance of experiential knowledge has been acknowledged in discussions about evidence-based conservation. However, to integrate such knowledge with other types of evidence, it is necessary to understand the role and value of experiential knowledge. This paper describes experiential and expert knowledge, then presents a conceptual model to demonstrate how our ability to learn from our experiences influences the development of understanding about environmental systems. The aim of the model is to communicate a particular way of thinking about experiential knowledge and its implications for evidence-based practice. There are five main conclusions about the role and value of experiential knowledge for environmental conservation: (1) because experiential knowledge will always play a role in decision-making, developing a capacity to learn from our experiences (including research) will have a significant influence on the effectiveness of conservation outcomes; (2) while an expert's implicit and tacit knowledge is qualitatively very different from quantitative data, both are important and complementary; (3) some experiential knowledge can be expressed quantitatively, but making implicit knowledge explicit changes its nature because it is no longer linked to the rest of a person's experiential knowledge; (4) synthesizing and communicating research is essential to help prevent people from pursuing potentially erroneous ways of thinking; and (5) expertise is difficult to define, thus the extent of a person's experience and its relevance to a particular problem should be made clear. In general, this paper also suggests that an evidence-based approach can increase the emphasis

on reviewing, planning and reflecting on conservation actions, with potential for facilitating the development of an individual's expert understanding of environmental systems.

8.1 Introduction

"Scientific discovery reveals new knowledge, but the new vision which accompanies it is not knowledge. It is less than knowledge, for it is a guess; but it is more than knowledge, for it is a foreknowledge of things yet unknown and at present perhaps inconceivable. Our vision of the general nature of things is our guide for the interpretation of all future experience. Such guidance is indispensable. Theories of the scientific method, which try to explain the establishment of scientific truth by any purely objective formal procedure, are doomed to failure. Any process of enquiry unguided by intellectual passions would inevitably spread out into a desert of trivialities."

Michael Polanyi (1958). Personal Knowledge: Towards a Post-Critical Philosophy, p. 135

Conservation practitioners rarely apply primary research and rely heavily on experience to make decisions (Pullin *et al.* 2004). This has led to calls for the application of more science, the adoption of an evidence-based approach, and the provision of mechanisms to review and disseminate research to ensure that it is accessible (Pullin *et al.* 2001, Sutherland *et al.* 2004). Such mechanisms are essential to help bridge gaps between conservation research and practice, to facilitate the use of the best available evidence when making decisions (Fazey *et al.* 2004) and to ensure that untested practices are not widely adopted simply because they have been used previously (Sutherland *et al.* 2004).

While environmental conservation must be informed by appropriate research, in the end, it is the practitioner who must decide how to integrate the results of research with a wide range of context-specific issues and priorities (see Sakett *et al.* 2000). In addition, in conservation, the outcomes of decisions are often uncertain or difficult to measure (Dovers 2001). Thus, the amount of experience a practitioner has about a particular environmental system (which, for the purposes of this paper is a collection of interacting social, economic and bio-physical components; e.g. Fazey *et al.* Submitted), can have significant implications for conservation (Woodwell 1989). However, the experience of applying conservation actions also helps to build understanding of an environmental system. This understanding may, or may not, have been modified by the results of research (Fazey *et al.* Revision submitted [Chapter 7]).

The value of experience is acknowledged in discussions about evidence-based conservation (Pullin *et al.* 2001, Sutherland *et al.* 2004). However, these discussions clearly distinguish between using personal experience to apply the results of rigorous research, with the dissemination of possibly erroneous personal experience about the effectiveness of conservation actions that have not been evaluated. Nevertheless, in conservation, research and data are usually lacking, and given the complexity of environmental systems and the need for immediate action, experiential knowledge is often the best evidence that is available (e.g. Huntington *et al.* 2004, Fazey *et al.* Revision submitted [Chapter 7]). There is also, however, considerable difference between disseminating the opinions of an individual and using rigorous methods to elicit the experiential knowledge of a group of people with extensive experience of an environmental system. Thus, finding ways to both capture experiential knowledge and integrate it with scientific approaches is important (Fazey *et al.* submitted [Chapter 6]; Martin *et al* in press).

A first step to achieving such integration is to gain a better understanding of the role and value of experience for environmental conservation. In this paper, we briefly describe the overall nature of expertise, then present a conceptual model that incorporates research from cognitive psychology and phenomenography to explain how our capacity to learn from our experiences influences our ability to develop understanding about environmental systems. The primary aim of the model is to communicate a particular way of thinking about experiential knowledge. The implications of this view are discussed in relation to an evidence-based approach.

8.2 Experiential and expert knowledge

Knowledge derived from experience can broadly be separated into 'explicit', 'implicit', and 'tacit' knowledge (Nickols 2000) (Figure 8.1). Explicit knowledge is that which has been articulated; implicit knowledge can be, but has not been articulated; and tacit knowledge (*sensu* Polanyi 1958) cannot be articulated. To describe tacit knowledge, Polanyi (1997) gives the example of being able to recognise a person's face, but without being able to explain why or how it is done.

Experiential knowledge can also be broadly separated into 'expert' and 'non-expert' knowledge (Figure 8.1). Compared to less experienced individuals, experts have acquired extensive knowledge through their experiences which affects what they notice and how they organise, represent and interpret information. For example, there was no difference between chess masters and extremely good chess players in the number of possible moves they thought they could make, or the number of possible counter moves they anticipated from their opponents. The expert chess masters, however, appeared to be able to "chunk" pieces of information together allowing them to recognise features and patterns not noticed by the other players (deGroot 1965). Thus, expert knowledge can be difficult to articulate and cannot always be reduced to isolated facts or propositions, and is considered to be much more than just memory and intelligence, or the use of general strategies (Bransford *et al.* 2000; and see Fazey *et al.* Revision submitted [Chapter 7] for a more detailed description of expertise in a conservation context).

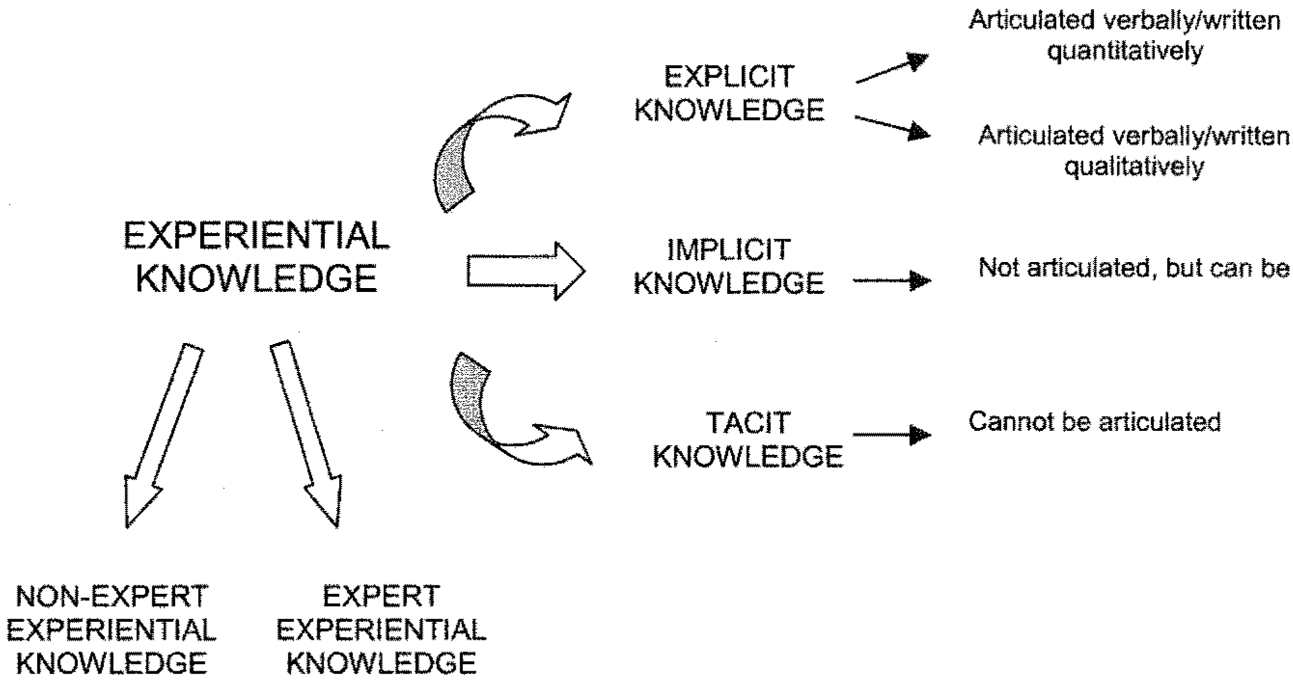

Figure 8.1: Different forms of experiential knowledge. Experiential knowledge can be explicit, implicit and/or tacit. Such knowledge can also be considered to be 'non-expert' or 'expert'. Expert experiential knowledge represents a deep level of understanding of an environmental system that has either been made explicit (qualitatively or quantitatively), or is implicit and/or tacit.

People who have developed a deep tacit understanding of an environmental system through extensive experience exhibit the hallmarks of an expert. Such individuals may be able to recognise emergent properties and make good predictions, even though they might not be able to explain why or how they make them (Fazey *et al.* Revision submitted [Chapter 7]). For example, expert judgement was compared with computer models when predicting population trends of several hypothetical species. The opinion of experts was only slightly less accurate than the simulation models, but it took the experts only 1-2 hours to make the predictions compared to the 1-2 days to run the models (McCarthy *et al.* 2004). In general, research suggests that it takes around ten years to develop 'expertise' of the form that is typically described in the educational literature (e.g. Simon and Chase 1973). There is, therefore, considerable difference between expert knowledge, which exhibits a considerable depth of understanding about an environmental system, and experiential knowledge, which may not yet have developed into expert understanding.

Expert knowledge has made a significant contribution to conservation. For example, when expert knowledge has been articulated quantitatively, it has greatly improved ecological models, providing a cost-effective way of making more confident predictions in the absence of published data (Martin *et al.* in press). In other cases, the implicit knowledge of experts has been captured qualitatively and has been used to assist management and research. It has been used to enhance the applicability of research results (Steiner 1998), guide ecosystem management (Olsson and Folke 2001), determine natural flood regimes (Robertson and McGee 2003), develop better understanding about the patterns of vegetation change (Lykke 2000), and help focus policy and management on the most important impediments to effective conservation action (Fazey *et al.* Submitted [Chapter 6]).

The value of indigenous (expert) knowledge in the conservation literature is particularly well recognised (e.g. Whiteman and Cooper 2000, Horstman and Wightman 2001, Olsson and Folke 2001, Aswani and Hamilton 2004). Olsson *et al.* (2004) highlight the difference between traditional ecological knowledge, which is an attribute of societies with a historical continuity in resource use practice (e.g. Whiteman and Cooper 2000, Horstman and Wightman 2001), and local ecological knowledge, which is an attribute of more recently evolved resource management systems (Roberston and McGee 2003, Fazey *et al.* Submitted [Chapter 6]). In both cases, however, expert understanding of an environmental system is generally built through many years of observation and reflection. Such knowledge can provide a valuable complement to knowledge derived from scientific methods (Horstman and Whightman 2001, Huntington *et al.* 2004, Olsson *et al.* 2004).

8.3 How do we learn from experiences to develop expertise about environmental systems?

To learn and develop expertise, we need to change our understanding of our place in the world and how we perceive it. This implies that, because we are always having new experiences, our relationship with the world and our understanding of it is always changing

(Fazey and Marton 2002). To better understand the dynamic learning process, cognitive psychologists often take the view that people understand the world by constructing working representations. That is, people construct 'mental models' from their observations and experiences, which then shape thoughts and actions (O'Connor and McDermott 1997). While the concept of having a working representation does not fully capture the dynamic learning process, it does allow an arbitrary boundary to be drawn around a person's understanding about a particular environmental system or conservation issue that occurs at a particular point in time.

Although our understanding about an environmental system may be continuously changing, it may take some time, or particularly significant events, before a major change in our mental model occurs (Proust 2004). Humans can be very defensive about changing their mental models (Argyris 1985) and are notoriously poor at learning in dynamic complex systems (see Sterman 2000 for an account of the problems and biases of human cognition). Over 95% of our thought is unconscious, affecting how we conceptualize all aspects of our experience (Lakoff and Johnson 1999), including the decisions we make and the research we conduct (Polanyi 1958). Because the vast majority of our decisions are driven by implicit understanding, learning how to learn better from the experiences that build this understanding, and how to more appropriately apply our expertise, would contribute to more effective decision-making in natural resource management and conservation (Fazey *et al.* Revision submitted [Chapter 7]).

Being a good learner depends on our capacity to do two things. First, if we can take different perspectives on an event or situation, then we will have a greater opportunity to understand an environmental system. For example, students developed a deeper understanding of Newton's physical laws when a computer simulation of a ball dropping from a moving plane allowed them to observe and analyse what was happening from different angles, such as from the ground or from above (Ueno 1990). To learn how to take different perspectives, we need to apply ideas like variable and reflective practice (Fazey *et al.* Revision submitted [Chapter 7]). This requires the learner to become accustomed to reviewing, planning, acting, and then reflecting on how they could have done something differently, or how outcomes might have varied if the contextual setting was different. By adding variation to our experiences, we develop adaptive expertise, enabling us to be flexible when facing new situations (Fazey *et al.* Revision submitted [Chapter 7]).

Second, we need to be open to the potential for an experience to change our mental model, and develop expertise in determining when it is appropriate to do so (Fazey *et al.* Revision submitted [Chapter 7]). This requires discipline in our thinking, and mindfulness of how we react to different experiences and perspectives. We need to become skilled in applying principles of 'good thinking', such as being empathic, flexible, inquisitive, asking pointed questions, evaluating different modes of approach, and being self-reflective. That is, we need to become more aware of the ways in which we think (see Perkins *et al.* 2004).

By applying ideas like variable and reflective practice and good thinking, we become better learners (Fazey *et al.* Revision submitted [Chapter 7]). Figure 8.2 explains how our level of expertise in learning from experiences influences our potential to change our mental models and our understanding of an environmental system. To understand Figure 8.2, it is easiest to begin with the variable "potential to change mental model". As the potential for change increases, we are less likely to be dogmatically committed to our existing model. Our potential to change our understanding of an environmental system increases, allowing identification of questions of which we may previously have been unaware. This, in turn increases our potential to re-evaluate our current mental model, closing the feedback loop (R1, in Figure 8.2).

As we change our understanding of an environmental system, we also have greater capacity to build a new, or modify an existing formal theory. The act of making our implicit theories explicit by building a formal theory helps us to: (1) identify and ask new questions (R2, in Figure 8.2), and (2) articulate our formal theory to other people to gain different perspectives on how the system might operate (R3, in Figure 8.2). Theories only describe a part of the real world, and irrespective of whether they are personal or formal, they all have limitations. Making our theories explicit so that we can share them with others helps us to identify those limitations, which also heightens the potential to re-evaluate the accessible parts of our existing mental model.

The conceptual model in Figure 8.2 demonstrates the potential for an individual to develop understanding about an environmental system. However, the positive feedback in the loops (R1-R3) can also act to constrain our thinking, particularly if we have a closed mind, lack an intention to change, or have a commitment to something that might be affected by such a change. This is because our mental models also affect how we perceive an experience, and how we try to gain a better understanding of the world. For example, when conducting research, our mental models influence the questions we identify and pursue, the methods we use to answer those questions, how we interpret the results, and our evaluation of the impact of the research experience on our mental model (Figure 8.3). The tools we use to interpret the world (e.g. science, GIS, computers) are also designed by our mental models, influencing what we measure, define and give attention to (Sterman 2000).

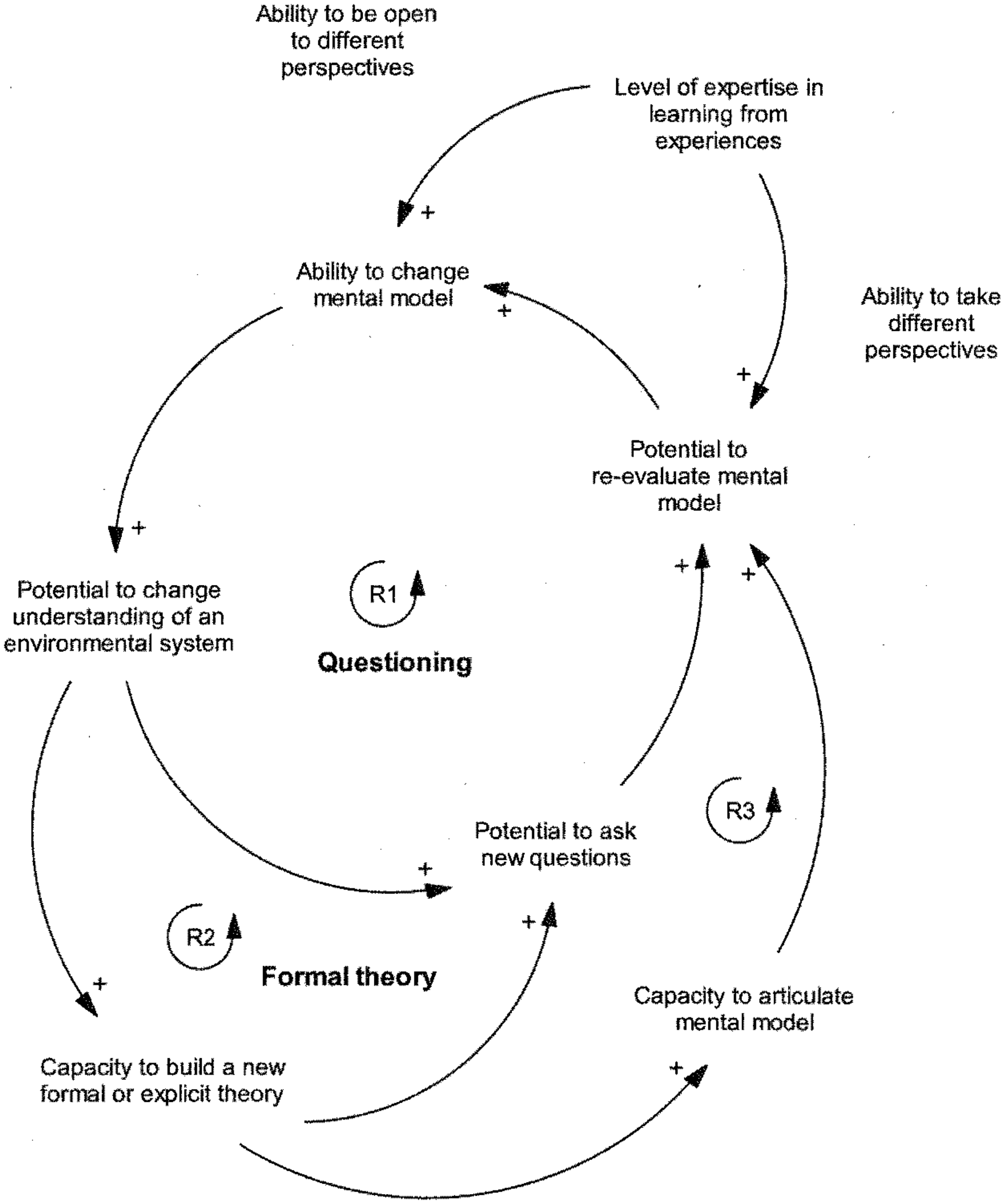

Figure 8.2: A conceptual model of how the level of expertise in learning from an experience influences a person's capacity to learn about environmental systems. The model is a causal loop diagram. The polarity of each arrow indicates whether a variable increases or decreases when the previous variable increases. For example, if the ability to change a mental model increases, then the potential to change understanding about an environmental system also increases (see Sterman 2000 for a full account of causal loops). In this diagram, all the arrows are positive creating a reinforcing loop (see text).

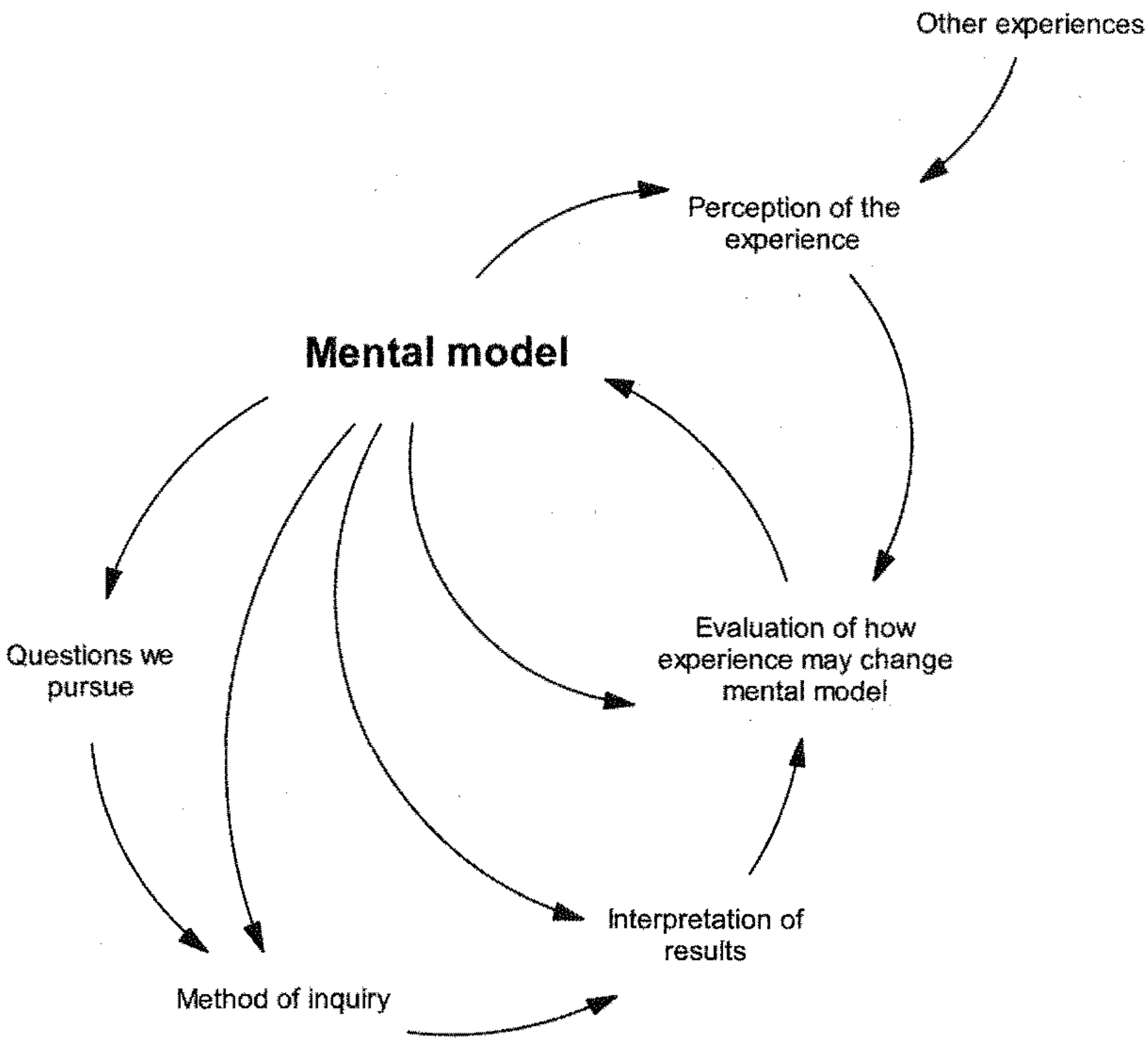

Figure 8.3: Mental models, which are built from observation and experiences, influence the way we perceive new experiences. This includes influences on how we perceive the experience of conducting research, such as by affecting the questions we pursue, the methods we use to design studies, the way we collect data, and how we perceive the results of research.

This means that while our understanding of the system may be changing with new experiences, we may also be reinforcing particular ways of thinking about that system, or possibly the ways of thinking about the approaches we are using to try to develop better understanding. This partly explains why certain formal theories with significant limitations can remain unquestioned for a long time. Initially, a theory may open up new insights into the way we think, but then our eyes begin to see the world through the lens of that theory. The acceptance of the theory can also be reinforced because of our tendency to read or publish in certain journals, present at particular types of conferences, and work with people who generally think and feel the same way. The application of Island Biogeography Theory to terrestrial systems for conservation is a good example. Despite its many limitations, it was widely accepted for many years. Recently, it has been suggested that we need to return to what researchers were thinking about before the theory's inception (Haila 2002).

The strongest defence against our current mental models driving us down particular thinking paths is our expertise in learning, which is defined by (1) our ability to take different perspectives and seek clarification by testing alternatives, and (2) by our capacity to be open to how an experience or perspective might change our mental model (Figure 8.2) (Fazey *et al.* Revision submitted [Chapter 7]). Taking a step back and finding new ways of looking at an issue reduces the tendency to assume that the way we perceive something is the only way, or that it is the same way that others perceive it. Taking different perspectives gives us greater potential for re-evaluating our mental model, and if we are open to how those perspectives might influence our understanding, our potential to be willing to expand and change our mental model and develop our understanding also increases (Figure 8.2).

8.4 Why do we not value experience?

Although experiential knowledge is qualitatively very different, it is complementary (with both advantages and disadvantages) to information derived from experiments (Fazey *et al.* Revision submitted [Chapter 7]). However, implicit and tacit experiential knowledge tends to be given less value than information that has been quantified or made explicit (Boiral 2002). There are five main reasons for this. First, by articulating experiential knowledge, the nature and value of the knowledge changes because it then no longer remains linked to the rest of a person's rich implicit and tacit understanding. Second, because of the way information is stored and processed in the brain, it can be difficult for someone to qualify why or how they know something (Bransford *et al.* 2000). Third, experiential knowledge is difficult to recalibrate (synthesise) against quantitative measures. Fourth, because experiential knowledge is based on a person's unique set of experiences (e.g. ecosystem or conservation issue), the degree to which the knowledge is relevant to other circumstances is difficult to determine. Fifth, our culture and society greatly affect the way we think and how we construct our mental models, reinforcing the view that experience may be less important than quantifiable or explicit information.

To understand this last point, it is necessary to consider the concept of "worldview". While there are many different definitions of worldview, it generally refers to the way the world is understood by a particular society (e.g. Kalu 2001, Hallowell 2002). It is literally the way a group of people perceive, understand and explore how the world and the universe works (e.g. spiritual outlook, scientific approach, belief in a free market economy etc.) (Hallowell 2002). Worldviews are resistant to change because of consistent and continued reinforcement by the behaviour of like-minded individuals (e.g. Fazey *et al.* Revision submitted [Chapter 7]). Thus, even though individuals may change their outlook through experiences, their particular society's worldview continues to reinforce an individual's thinking behaviour and mental models. This reinforcement also occurs within academic disciplines where the articles that are read and conferences attended influence the research produced, which is then reviewed and assessed by a similar-minded group of researchers.

For example, research output from the discipline of Conservation Biology suggests that it is dominated by a quantitative and reductionist worldview. The literature published in 2001 in three prominent conservation journals was predominantly comprised of quantitative research (89%), inferential statistics (63%) and studies that focused only on biological disciplines (87%). There were also relatively few studies at broad organisational scales, such as of communities and ecosystems (25%) (Fazey *et al.* 2005-b [Chapter 6]). However, while quantitative and reductionist approaches are essential, no single reductionist (or synoptic) view is sufficient to understand the world (Kline 1995).

The need for multiple approaches was recognised in the seminal paper "What is conservation biology?" (Soulé 1985), in which the discipline was described as needing to be "holistic", "synthetic, eclectic and multi-disciplinary", dependent on "biological and social disciplines", and a "mix of science and art requiring intuition as well as information". Soulé's (1985) vision captured a general trend by western society that has been steadily moving away from the Newtonion model of knowledge production set in a context predominantly governed by the interests of a particular academic community (Gibbons *et al.* 1994). Instead, in response to increased complexity, unpredictability and irregularity of society, knowledge production is increasingly being conducted in a context of application (Nowotny *et al.* 2001). This new mode of knowledge production has less disciplinary boundaries, is heterarchical, and is more accountable and reflexive to society (Gibbons *et al.* 1994). Such changes in knowledge production are already occurring in many applied conservation and ecological domains. However, irrespective of whether this change is perceived to be a positive or negative development, further shifts may be required before the value of experiential knowledge is more widely recognised and accepted.

8.5 Why evidence-based conservation and expert knowledge are both important

We agree with the proponents of evidence-based conservation (Pullin *et al.* 2001, Sutherland *et al.* 2004) that a revolution is required in the way we conduct conservation, and that an evidence-based approach is a good way to begin facilitating better environmental learning. The evidence-based approach is particularly important for three reasons: (1) it encourages the review of what is often disparate and inaccessible research; (2) it provides a forum for the dissemination of synthesized research; and (3) it sets a precedent for reviewing current information, formulating plans, and then evaluating and disseminating the outcomes (Fazey *et al.* 2004). Given the high degree of dynamic complexity in environmental systems, we therefore suggest that the strength of the approach is likely to be its capacity to facilitate greater reflection and learning from conservation interventions, rather than simply its provision of detailed *a priori* evidence for those actions.

Through greater accessibility to the results of research, individuals are more likely to be exposed to different perspectives providing them with greater opportunity to re-evaluate their mental models (Figure 8.2). As Sutherland *et al.* (2004) point out, this helps break particular (possibly erroneous) ways of thinking. In addition, an evidence-based approach encourages individual practitioners to apply some of the principles of reflective practice by setting precedents for greater evaluation of conservation actions. Such reflection is vital for the development of individual expert knowledge (Fazey *et al.* Revision submitted [Chapter 7]). However, disseminating information is only one step towards implementation (Lomas 1993), and in environmental conservation, the effectiveness of conservation decisions will be heavily influenced by our expertise because practitioners will always need to determine how to apply research results in context-specific and dynamic settings.

Compared to one person's experience of an intervention, the accumulation and dissemination of the experience of many individuals could be particularly powerful (Sutherland *et al.* 2004). However, accumulating information often loses the detail of what, how and why an intervention was applied. In particular, a practitioner may have a certain degree of understanding about the historical trajectory of a problem, whereas predictions from experiments are mostly based on a snapshot of what is currently occurring (Fazey *et al.* Revision submitted [Chapter 7]). Because environmental systems are complex, "learning-by-doing" approaches, like adaptive management (Walters and Holling 1990) or the application of expert knowledge will also often be required (Fazey *et al.* Revision submitted [Chapter 7]). Nevertheless, such approaches would benefit from, and are complementary to evidence-based practice (Fazey *et al.* 2004).

Because studies with rigorous experimental designs are easier to systematically synthesize than studies that lack strict control (Fazey *et al.* 2004), the amount of available evidence that is reviewed can become skewed towards interventions that make better experiments. For example, in medicine there is often considerable evidence that has been reviewed for the use of pharmaceuticals, compared to more individually tailored and holistic approaches such as counselling or cognitive therapy to treat mental illness (R. Woodward, pers. comm.). Environmental conservation will therefore need ways to integrate different types of knowledge to ensure that it does not become preoccupied with management solutions that make good experimental studies when more novel or holistic ways are required to treat the real causes of the problem (Fazey *et al.* 2004; Fazey *et al.* 2005).

To make sure we do not head down particular thinking paths that reduce our acceptance of other approaches, we will regularly need to take a step back, take different perspectives and be open to how something might change our way of thinking. That is, we will need to rely on our individual expert understanding of environmental systems to maintain focus on what is important (e.g. Fazey *et al.* Submitted [Chapter 6]). Without such understanding, much of conservation research would "spread into a desert of trivialities" (Polanyi 1958).

'Knowledge management' has become a major industry (McManus *et al.* 2003), and many organisations are trying to find ways to capture the implicit and tacit knowledge of employees before they move elsewhere (Holloway 2000). For example, in medicine, intranet systems are increasingly being used to capture, share and reflect on implicit and organisational information (e.g. Mimnagh 2002). Finding better ways to disseminate implicit knowledge could also benefit many conservation organisations. Mechanisms for the management of explicit knowledge may need to be in place for implicit knowledge management to work (Mimnagh 2002). Thus, provided that the value of implicit knowledge is recognised, an evidence-based approach could be a useful springboard for a much wider revolution that includes the development and sharing of experiential knowledge.

8.6 Concluding Remarks

There are five main conclusions arising from this paper about the complementarity of experience and science in conservation:

1) Experiential knowledge derived from a mixture of research, work, educational, and personal experience will always play an important role in decision-making (e.g. Fazey and McQuie in press), and will have a major influence on the way we study environmental systems. Developing our capacity to learn from our experiences

(including learning from the results of research) and our ability to re-evaluate our way of thinking will have a significant influence on the effectiveness of conservation outcomes.

2) Expert knowledge is often considered to be less important than quantitative or explicit information. However, while an expert's knowledge is qualitatively very different from explicit knowledge, both are important and complementary.

3) Some experiential knowledge can be articulated quantitatively and integrated with other quantitative information. However, experiential knowledge can often be difficult to isolate as single facts or propositions, and it loses much of its value because it is then no longer linked to the rest of the person's implicit or tacit understanding. Thus, if it is to be communicated, qualitative methods of inquiry will often be required.

4) Humans often learn very slowly and there is much potential for generating erroneous thinking. Synthesizing and communicating research is therefore essential to increasing the potential for individuals to re-evaluate their current ways of thinking.

5) There is no single definition of an 'expert'. It is difficult to compare one expert with another for dealing with a particular conservation issue as their knowledge is built from a unique set of experiences. However, it takes considerable time to develop the form of expertise that is typically discussed in the educational literature. When referring to expert knowledge, it is therefore important to be (1) clear about the basis and extent of this knowledge, and (2) the degree to which the knowledge is relevant to a particular circumstance.

An evidence-based approach provides an important springboard for increasing emphasis on reviewing, planning and reflecting on conservation actions. In addition to making research more accessible to the wider conservation community, the process could also facilitate personal development and understanding of environmental systems. To facilitate greater reflection to give rise to better understanding, academics and practitioners will need to be open to the perspective that it is a worthwhile endeavour to elicit, communicate, and share experiential knowledge.

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EPILOGUE

The conceptual model of how expertise in learning from experiences influences the capacity to understand environmental systems (Chapter 8) is an example of personal understanding that has been articulated and formalised. It is relatively simple, but has considerable potential for changing the way we think about the nature of expertise, and its role and value for environmental conservation. However, the importance of expertise in learning, defined by a person's desire to seek out and take different perspectives and their capacity to be open to changing their understanding, also has much wider implications.

Beliefs, worldviews, and dogma continually reinforce actions that are detrimental to the environment (e.g. Barlow and Clarke 2002, Fazey *et al.* Submitted [Chapter 6]), and people are becoming increasingly dissociated from nature (Glendinning 1995, Metzner 1995). Both of these issues are potentially contributing to reinforcing a lack of concern for the environment (Kempton and Holland 2003, Fazey *et al.* Submitted [Chapter 6]). To break reinforcing cycles of perception, individuals need exposure to experiences that will help them challenge their current ways of thinking. This emphasises the importance of environmental education programs and, given that most people are often forced to find their own ways to learn during the mainstream educational process, it also highlights the need for greater consideration to be given to teaching people how to learn (Fazey et al. Revision submitted [Chapter 7]). Increasing the capacity of people to be open to other perspectives could facilitate an increase in awareness of the link between an individual's behaviour and the global environmental and social problems. One of the keys is therefore to find ways of providing people with experiences that help them develop a deeper, and longer lasting connection with nature (e.g. Cohen 1997), and then helping them to translate such a connection into more ecologically sustainable activities (Cohen 2000).

REFERENCES

Allan, C. and Curtis, A. 2003. Learning to implement adaptive management. Natural Resource Management 6: 25-30.

Andelman, S.J. and Fagan, W.F. 2000. Umbrellas and flagships: Efficient conservation surrogates or expensive mistakes? Proceedings of the National Academy of Sciences of the United States of America 97: 5954-5959.

Anderson, J.L. 2001. Stone age minds at work on 20th century science: how can cognitive psychology inform conservation biology. Conservation biology in Practice 2: 20-27.

Antonacopoulou, E. 2004. On the virtues of practising scholarship - A tribute to Chris Argyris, a 'timeless learner'. Management Learning 35: 381-395.

Araujo, L. 1998. Knowing and learning as networking. Management Learning 29: 317-336.

Argyris, C. 1985. Strategy, change, and defensive routines. Pitman, Boston.

Aswani, S. and Hamilton, R.J. 2004. Integrating indigenous ecological knowledge and customary sea tenure with marine and social science for conservation of bumphead parrotfish (*Bolbometopon muricatum*) in the Roviana Lagoon, Solomon Islands. Environmental Conservation 31: 69-83.

Baldi, A. and McCollin, D. 2003. Island ecology and contingent theory: the role of spatial scale and taxonomic bias. Global Ecology and Biogeography 12: 1-3.

Bapuji, H. and Crossan, M. 2004. From questions to answers: Reviewing organizational learning research. Management Learning 35: 397-417.

Barlow, M. and Clarke, T. 2002. Blue gold: the battle against corporate theft of the world's water. Earthscan Publications Ltd., London.

Bensen, K. and Hartz, M.D. 2000. A comparsion of observational studies and randomized, controlled trials. New England Journal of Medicine 342: 1878-1886.

Berkes, F., Colding, J. and Folke, C. 2003. Navigating social-ecological systems: building resilience for complexity and change. Cambridge University Press, Cambridge.

Blackler, F. 1995. Knowledge, knowledge work and organizations: An overview and interpretation. Organization Studies 16: 1021-1046.

Block, W.M., Franklin, A.B., Ward, J.P., Ganey, J.L. and White, G.C. 2001. Design and implementation of monitoring studies to evaluate the success of ecological restoration on wildlife. Restoration Ecology 9: 293-303.

Boiral, O. 2002. Tacit knowledge and environmental management. Long Range Planning 35: 291-317.

Boud, D. and Miller, N. 1997. Working with experience: Animating learning. Routledge, London.

Bowen-Jones, E. and Entwistle, A. 2002. Identifying appropriate flagship species: the importance of culture and local contexts. Oryx 36: 189-195.

Brander, D. (1987). Environmental changes in the Southern Macquarie Marshes 1934 to 1987. Honours thesis thesis, University of New South Wales.

Bransford, J.D., Brown, A.L. and Cocking, R.R. 2000. How people learn: Brain, mind, experience, and school. National Academy Press, Washington, D.C.

Bray, N. (1994). 'Vegetation changes at selected sites in the Macquarie Marshes: 1983-1994.' NSW Department of Water Resources.

Brereton, G.J. (1992). 'An Investigation into the impact of erosion in the southern Macquarie Marshes. Summary Report.' NSW Department of Water Resources.

Brereton, G.J. (1994). 'An Investigation into the impact of erosion in the southern Macquarie Marshes.' NSW Department of Water Resources.

Brereton, G.J., Steenbecke, G. and Witts, T. (2000). 'A review of recent studies investigating biological and physical processes in the Macquarie Marshes.' NSW Department of Land and Water Conservation, NSW Government.

Brereton, G.J., Steenbeeke, G. and Witts, T. (1996). 'A review of recent studies investigating the biological and physical processes in the Macquarie Marshes: Proceedings of the Macquarie Marshes Scientific Workshop 27-28 February 1996.' NSW Department of Land and Water Conservation, Dubbo.

Brock, P.M. 1996. Landholder views on the boundaries of the Macquarie Marshes. Wetlands (Australia) 15: 62-81.

Brock, P.M. 1998. The significance of the physical environment of the Macquarie Marshes. Australian Geographer 29: 71-90.

Bullock, J.M. and Pakeman, R.J. 1997. Grazing of lowland heath in England: Management methods and their effects on heathland vegetation. Biological Conservation 79: 1-13.

CA 2004. Australian Cotton History. Cotton Australia. www.cottonaustralia.com.au.

Calheiros, D.F., Seidl, A.F. and Ferreira, C.J.A. 2000. Participatory research methods in environmental science: local and scientific knowledge of a limnological phenomenon in the Pantanal wetland of Brazil. Journal of Applied Ecology 37: 684-696.

Callicott, J.B. 1990. Whither Conservation Ethics. Conservation Biology 4: 15-20.

Campbell, A. 2003. Learning to live with fire. In: Cary, G., Lindenmayer, D., Dovers, S. (eds), Australia burning: Fire ecology, policy and management issues. CSIRO Publishing, Collingwood, Vic., pp. 243-247.

Chalmers, I. 1993. The Cochrane collaboration: preparing, maintaining, and disseminating systematic reviews of the effects of health care. Annals of the New York Academy of Sciences 703: 156-163; discussion 163-155.

Chapin, F.S. and Whiteman, G. 1998. Sustainable development of the boreal forest: Interaction of ecological, social and business feedbacks. Ecology and Society 2: Article 12.

Chase, W.G. and Simon, H.A. 1973. Perception in Chess. Cognitive Psychology 4: 55-81.

Chen, Q. 1994. Some aspects of Peirce's theory of knowledge. In: Debrock, G. and Hulswit, M. (eds), Living doubt: essays concerning the epistemology of Charles Sanders Peirce. Kluwer Academic Publishers, Dordrecht,

Clark, J.A. and May, R.M. 2002. Taxonomic bias in conservation research. Science 297: 191-192.

Clarke, M. and Oxman, A.D. 1999. Cochrane Reviewers' Handbook 4.0. The Cochrane Collaboration, Oxford.

Clevenger, A.P. and Waltho, N. 2000. Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. Conservation Biology 14: 47-56.

Cogger, H., Ford, H., Johnson, C., Holman, J. and Butler, D. (2003). 'Impacts of land clearing on Australian Wildlife.' WWF Australia.

Cohen, M.J. 1997. Reconnecting with nature. Ecopress, Corvallis, OR.

Cohen, M.J. 2000. Einstein's world: Educating and counseling with nature. The natural systems thinking process. Project Nature Connect, Friday Harbour, Washington.

Connell, D., Dovers, S. and Grafton, R.Q. (2004). Property rights and water management: a critical analysis of the National Water Initiative. In 'Proceedings of the 7th International Rivers Symposium 31 August - 3 September'. Brisbane, Australia.

Cooke, B. and Saunders, G. 2002. Rabbit haemorrhagic disease in Australia and New Zealand. Wildlife Research 29: U3-U3.

Cosgrove, P.J. and Hastie, L.C. 2001. Conservation of threatened freshwater pearl mussel populations: river management, mussel translocation and conflict resolution. Biological Conservation 99: 183-190.

Cox, A. 2004. Proposed cloud seeding in Kosciuszko National Park, briefing paper. National Parks Association of New South Wales, Australia.
http://www.npansw.org.au/web/conservation/kosciuszko/Cloud_seeding_briefing_note.htm.

Craik, J.C.A. 1998. Recent mink-related declines of gulls and terns in west Scotland and the beneficial effects of mink control. Argyll Bird Report 14: 98-110.

Crase, L., Pagan, P. and Dollery, B. 2004. Water markets as a vehicle for reforming water resource allocation in the Murray-Darling Basin of Australia. Water Resources Research 40.

Cunningham, G. (1996). 'Macquarie Marshes grazing study.' Macquarie Marshes Management Committee.

Czech, B., Krausman, P.R. and Borkhataria, R. 1998. Social construction, political power, and the allocation of benefits to endangered species. Conaservation Biology 12: 1103-1112.

Daily, G.C. 2001. Ecological forecasts. Nature 411: 245-245.

Davis, G., Wanna, J., Warhurst, J. and Weller, P. 1993. Public Policy in Australia. Allen & Unwin, Sydney.

de Leo, G.A. and Levin, S. 1997. The multifaceted aspects of ecosystem integrity. Conservation Ecology 1: 3.

de Maynadier, P.G. and Hunter, M.L. 2000. Road effects on amphibian movements in a forested landscape. Natural Areas Journal 20: 56-65.

Deci, E.L. and Ryan, R.M. 1985. Intrinsic motivation and self-determination in human behaviour. Plenum Press, New York.

deGroot, A.D. 1965. Thought and choice in chess. Mouton, The Hague, Netherlands.

DEP (1987). 'Regional Environmental Plan for the Macquarie Marshes, Department's Minute.' Department of Environment and Planning.

Diamond, J. 1986. Overview: Laboratory experiments, field experiments, and natural experiments. In: Diamond, J. and Case, T.J. (eds), Community ecology. Harper & Row, New York, pp. 3-22.

DLWC (2002). 'Draft water sharing plan for the Macquarie and Cudgegong regulated rivers water source.' Prepared by the Macquarie and Cudgegong River Management Committee for NSW Land and Water Conservation.

Doak, D.F. and Mills, L.S. 1994. A useful role for theory in conservation. Ecology 75: 615-626.

Dorner, D. 1996. The logic of failure. Metropolitan Books, New York.

Dovers, S., Norton, T.W. and Handmer, J.W. 2001. Ignorance, uncertainty and ecology: key themes. In: Handmer, J.W., Norton, T.W. and Dovers, S.R. (eds), Ecology, Uncertainty and Policy: Managing Ecosystems for Sustainability. Pearson Education Limited, Harlow, pp. 1-25.

Eberhardt, L.L. and Thomas, J.M. 1991. Designing environmental field studies. Ecological Monographs 61: 53-73.

Elliot, M. (1995). 'Irrigation farming in the Macquarie Valley.' National Landcare Program and NSW Agriculture, Trangie.

Ely, J.W., Osheroff, J.A., Ebell, M.H., Bergus, G.R., Levy, B.T., Chambliss, M.L. and Evans, E.R. 1999. Analysis of questions asked by family doctors regarding patient care. British Medical Journal 319: 358-361.

Eslake, S. (2002). 'An introduction to the Australian Economy.' ANZ Bank.

Fahrig, L. 2003. Effects of habitat fragmentation on biodiversity. Annual Review of Ecology Evolution and Systematics 34: 487-515.

Fazey, D.M.A. and Fazey, J.A. 1989. Modification of transfer effects in different practice schedules - an extension of the variability hpothesis. Journal of Human Movement Studies 17: 239-258.

Fazey, I. (2005). The role and value of experience for environmental conservation. PhD under examination thesis, Australian National University.

Fazey, I. In Prep-a. Comparative usefulness of conservation theory (Chapter 4). To be resubmitted to Conservation Biology.

Fazey, I., Fazey, J.A. and Fazey, D.M.A. Revision submitted. Learning more effectively from experience (Chapter 7). Ecology and Society.

Fazey, I., Fischer, J. and Lindenmayer, D.B. 2005-a. Who does all the research in conservation biology? (Appendix 1). Biodiversity & Conservation 14: 917-934.

Fazey, I., Fischer, J. and Lindenmayer, D.B. 2005-b. What do conservation biologists publish? (Chapter 2). Biological Conservation 124: 63-73.

Fazey, I. and McQuie, A. In Press. Applying ecological theory for conservation management (Chapter 5). Ecological Management and Restoration.

Fazey, I., Proust, K., Newell, B. and Johnson, B. Submitted. Eliciting the implicit knowledge of on-ground conservation managers: the Macquarie Marshes as a case study (Chapter 6). Ecology and Society.

Fazey, I., Salisbury, J.G., Lindenmayer, D.B., Maindonald, D. and Douglas, R. 2004. Can methods applied in medicine be used to summarise and disseminate conservation research? Environmental Conservation 31: 190-198.

Fazey, J.A. In Prep-b. Planned variation for unplanned learning outcomes: The use of variability and contextual interference in the practice of an academic discipline.

Fazey, J.A. and Marton, F. 2002. Understanding the space of experiential variation. Active Learning in Higher Education 3: 234-250.

Feltz, D.L. and Landers, D.M. 1983. The Effects of Mental Practice on Motor Skill Learning and Performance - a Meta-Analysis. Journal of Sport Psychology 5: 25-57.

Fischer, J., Fazey, I., Briese, R. and Lindenmayer, D.B. In Press a. Making the matrix matter: Challenges in Australian grazing landscapes (Appendix 3). Biodiversity & Conservation.

Fischer, J., Lindenmayer, D.B. and Fazey, I. In Press b. Appreciating ecological complexity: habitat contours as a conceptual landscape model (Appendix 2). Conservation Biology.

Flaspohler, D.J., Bub, B.R. and Kaplin, B.A. 2000. Application of conservation biology research to management. Conservation Biology 14: 1898-1902.

Fox, G.A. 1991. Practical Causal Inference for Epidemiologists. Journal of Toxicology and Environmental Health 33: 359-373.

Freyfogle, E.T. and Newton, J.L. 2002. Putting science in its place. Conservation Biology 16: 863-873.

Gates, S. 2002. Review of methodology of quantitative reviews using meta- analysis in ecology. Journal of Animal Ecology 71: 547-557.

Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P. and Trow, M. 1994. The new production of knowledge: The dynamics of science and research in contemporary societies. SAGE Publications, London.

Gilman, E. 2001. Integrated management to address the incidental mortality of seabirds in longline fisheries. Aquatic Conservation-Marine and Freshwater Ecosystems 11: 391-414.

Glaser, R. 1992. Expert knowledge and processes of thinking. In: Halpern, D.F. (eds), Enhancing thinking skills in the sciences and mathematics. Erlbaum, Hillsdale, N.J., pp. 63-75.

Glasziou, P., Irwig, L., Bain, C. and Colditz, G. 2001. Systematic Reviews in Healthcare: A Practical Guide. Cambridge University Press, Cambridge.

Glendinning, C. 1995. Technology, trauma, and the wild. In: Roszak, T., Gomes, M.E. and Kanner, A.D. (eds), Ecopsychology. Sierra Club Books, San Francisco, pp. 41-54.

Government, N. 2000. NSW Government 2000 Water Management Act No. 92: An Act to provide for the protection, conservation and ecologically sustainable development of the water sources of the State, and for other purposes.

Greenwald, A.G., Leippe, M.R., Pratkanis, A.R. and Baumgardner, M.H. 1986. Under wat conditions does theory obstruct research progress. Psychological Review 93: 216-229.

Haila, Y. 2002. A conceptual genealogy of fragmentation research: From island biogeography to landscape ecology. Ecological Applications 12: 321-334.

Hallowell, A.I. 2002. Obijwa ontology, behaviour, and worldview. In: Harvey, G. (eds), Readings in indigenous religion. Continuum, London and New York, pp. 17-49.

Harcourt, S. 2000. Conservation in practice. Evolutionary anthropology 9: 258-265.

Harrison, S. 1991. Metapopulations and conservation. In: Edwards, P.J., May, R.M. and Webb, N.R. (eds), Large scale ecology and conservation. Blackwell Scientific Publications, Oxford, pp. 111-128.

Harrison, S. and Taylor, A.D. 1997. Empirical evidence for metapopulation dynamics. In: Hanski, I. and Gilpin, M.E. (eds), Metapopulation biology: ecology, genetics and evolution. Academic Press, San Diego, pp. 27-42.

Hatano, G. and Inagaki, K. 1986. Two courses of expertise. In: Stevenson, H., Azuma, H. and Hakuta, K. (eds), Child Development and Education in Japan. W.H. Freeman, New York,

Hels, T. and Nachman, G. 2002. Simulating viability of a spadefoot toad *Pelobates fuscus* metapopulation in a landscape fragmented by a road. Ecography 25: 730-744.

Hess, G.R. and Fischer, R.A. 2001. Communicating clearly about conservation corridors. Landscape and Urban Planning 55: 195-208.

Hess, G.R. and King, T.J. 2002. Planning open spaces for wildlife I. Selecting focal species using a Delphi survey approach. Landscape and Urban Planning 58: 25-40.

Hill, A.B. 1965. The environment and disease: association and causation. Proceedings of the Royal Society of Medicine 58: 295-300.

Hinrichsen, R.A. 2000. Are there scientific criteria for putting short-term conservation ahead of learning? No. Conservation Ecology 4.

Hobbs, R. 1997. Future landscapes and the future of landscape ecology. Landscape and Urban Planning 37: 1-9.

Hoffmann, R. 2003. Why buy that theory? American Scientist 91: 9-11.

Holling, C.S. 2000. Theories for sustainable futures. Conservation Ecology 4.

Holloway, P. 2000. How to protect knowledge from walking out the door. Workforce Magazine Access through http://www.learnerfirst.com.

Horstman, M. and Wightman, G. 2001. Karpati ecology: Recognition of Aboriginal ecological knowledge and its application to management in north-western Australia. Ecological Management and Restoration 2: 99-109.

Hunter, M.L. 2002. Conservation and conservation biology. In: Hunter, M.L. (eds), Fundamentals of Conservation Biology. Blackwell Science, pp. 5-18.

Huntington, H.P., Suydam, R.S. and Rosenberg, D.H. 2004. Traditional knowledge and satellite tracking as complementary approaches to ecological understanding. Environmental Conservation 31: 177-180.

Hutchinson, M.F., Nix, H.A. and McMahon, J.P. 1992. Climate constraints on cropping systems. In: Pearson, C.J. (eds), Field cropping systems of the world. Elsevier, pp. 37-58.

IUCN (2001). 'Stepping into the new millenium - International Union for the Conservation of Nature's Intersessional Programme. Unpublished report.' IUCN.

Jacobson, S.K. 1990. Graduate-Education in Conservation Biology. Conservation Biology 4: 431-440.

Jarus, T. 1994. Motor Learning and occupational-therapy - the organization of practice. American Journal of Occupational Therapy 48: 810-816.

Jennions, M.D. and Moller, A.P. 2002. Publication bias in ecology and evolution: an empirical assessment using the 'trim and fill' method. Biological Reviews 77: 211-222.

Jones, D., Bartholomew, E. and Fazey, J. 2005-a. The changing culture in risk management: risk-e learning. Research Institute for Enhancing Learning. School of education. University of Wales, Bangor. www.risk-e.com/courses.

Jones, D., Bartholomew, E. and Minas, C. 2005-b. Developing the learning organization through learning communities: the risk-e project. Research Institute for Enhancing Learning. School of education. University of Wales, Bangor. www.risk-e.com/courses.

Jones, S. 2003. The Macquarie Marshes: A case study of conservation of wetlands by private landholders/managers. Wetlands Australia 11: 20.

Kalu, O.U. 2001. The sacred egg: Worldview, ecology and development in West Africa. In: Grim, J.A. (eds), Indigenous traditions and ecology: the inter being of cosmology and community. Harvard University Press, Cambridge, pp. 225-248.

Kareiva, P., Marvier, M., West, S. and Hornisher, J. 2002. Slow-moving journals hinder conservation efforts. Nature 420: 15-15.

Kelly, G.A. 1963. The psychology of personal constructs. Norton, New York.

Kempton, W. and Holland, D.C. 2003. Identity and sustained environmental practice. In: Clayton, S. and Opotow, S. (eds), Identity and the natural environment. Massachusetts Institute of Technology, Cambridge, Mass, pp. 317-341.

Kidson, R. and Raisin, G. (2000). 'A review of recent studies investigating biological and physical processes in the MM: Proceedings of the Scientific Workshop 27-28th Feb. 1996.' NSW Department of Land and Water Conservation.

Kidson, R., Witts, T. and Martin, W. (2000). 'Final project report: Macquarie Marshes management strategy stage 3: Implementation and audit.' Department of Land and Water Conservation, NSW Government.

Kingsford, R.T. 2004. Macquarie Marshes. In: Olsen, P. and Weston, M. (eds), The State of Australia's Birds 2004. Report by Birds Australia. Courtney Colour Graphics, p. 15.

Kingsford, R.T. and Auld, K. (2003). 'Waterbird breeding in the Macquarie Marshes.' National Parks and Wildlife Service (NSW), Hurstville.

Kingsford, R.T. and Johnson, W. 1998. Impact of water diversions on colonially-nesting waterbirds in the Macquarie Marshes of arid Australia. Colonial Waterbirds 21: 159-170.

Kingsford, R.T. and Thomas, R.F. 1995. The Macquarie Marshes in arid Australia and their waterbirds: a 50 year history of their decline. Environmental Management 19: 867-878.

Kline, S.J. 1995. Conceptual foundations for multidisciplinary thinking. Stanford University Press, Stanford.

Knight, R.L. 1998. Ecosystem management and conservation biology. Landscape and Urban Planning 40: 41-45.

Knight, S. and Partners (1984). 'NSW Inland Rivers Flood Plain Management Studies.'.

Kolb, D.A. and Fry, R. 1975. Toward an applied theory of experiential learning. In: Cooper, C. (eds), Theory of group processes. Doubleday and Company, New York,

Kotliar, N.B., Baker, B.W., Whicker, A.D. and Plumb, G. 1999. A critical review of assumptions about the prairie dog as a keystone species. Environmental Management 24: 177-192.

Kunz, R. and Oxman, A.D. 1998. The unpredictability paradox: review of empirical comparisons of randomised and non-randomised clinical trials. BMJ 317: 1185-1190.

La Peyre, M.K., Reams, M.A. and Mendelssohn, I.A. 2001. Linking actions to outcomes in wetland management: An overview of US state wetland management. Wetlands 21: 66-74.

Lakatos, I. 1978. The methodology of scientific research programmes. Cambridge University Press, Cambridge.

Lakoff, G. 1987. Women, fire and dangerous things: What categories reveal about the mind. University of Chicago Press, Chicago.

Lakoff, G. and Johnson, M. 1980. Metaphors we live by. University of Chicago Press, Chicago.

Lakoff, G. and Johnson, M. 1999. Philosophy in the Flesh: The Embodied Mind and its Challenge to Western Thought. Basic Books, New York.

Lambeck, R.J. 1997. Focal species: A multi-species umbrella for nature conservation. Conservation Biology 11: 849-856.

Larkin, J.H. and Simon, H.A. 1987. Why a diagram is (sometimes) worth 10000 Words. Cognitive Science 11: 65-99.

Lee, K.N. 1999. Appraising adaptive management. Conservation Ecology 3: 3.

Lemly, A.D., Kingsford, R.T. and Thompson, J.R. 2000. Irrigated agriculture and wildlife conservation: conflict on a global scale. Environmental Management 25: 485-512.

Levins, R. 1969. Some demographic and genetic consequences of environmental heterogeneity for biological control. Bulletin of the Entomological Society of America 15: 237-240.

Levitt, B. and March, J.G. 1988. Organizational learning. Annual Review of Sociology 14: 319-340.

Lindenmayer, D.B. 2000. Factors at multiple scales affecting distribution patterns and their implications for animal conservation - Leadbeater's Possum as a case study. Biodiversity and Conservation 9: 15-35.

Lindenmayer, D.B., Cunningham, R.B., MacGregor, C., Tribolet, C. and Donnelly, C.F. 2001. A prospective longitudinal study of landscape matrix effects on fauna in woodland remnants: experimental design and baseline data. Biological Conservation 101: 157-169.

Lindenmayer, D.B., Cunningham, R.B. and Pope, M.L. 1999. A large-scale "experiment" to examine the effects of landscape context and habitat fragmentation on mammals. Biological Conservation 88: 387-403.

Lindenmayer, D.B. and Fischer, J. 2003. Sound science or social hook - a response to Brooker's application of the focal species approach. Landscape and Urban Planning 62: 149-158.

Lindenmayer, D.B. and Franklin, J.F. 2002. Conserving forest biodiversity: A comprehensive multi-scaled approach. Island Press, Washington.

Lindenmayer, D.B. and Lacy, R.C. 1995. Metapopulation viability of Leadbeater Possum, *Gymnobelideus leadbeateri*, in Fragmented Old-Growth Forests. Ecological Applications 5: 164-182.

Lindenmayer, D.B., Manning, A.D., Smith, P.L., Possingham, H.P., Fischer, J., Oliver, I. and McCarthy, M.A. 2002. The focal-species approach and landscape restoration: a critique. Conservation Biology 16: 338-345.

Livingston, J.A. 1994. Rogue primate: An exploration of human domestication. Key Porter, Toronto.

Lode, T. 2000. Effect of a motorway on mortality and isolation of wildlife populations. Ambio 29: 163-166.

Lomas, J. 1993. Diffusion, dissemination, and implementation: who should do what? Annals of the New York Academy of Sciences 703: 226-235; discussion 235-227.

Ltd., W.W.P. (2004). 'Macquarie Marsh River Red Gum Survey.' Prepared for the Department of Environment and Conservation, Castle Hill.

Luck, G.W., Ricketts, T.H., Daily, G.C. and Imhoff, M. 2004. Alleviating spatial conflict between people and biodiversity. Proceedings of the National Academy of Sciences of the United States of America 101: 182-186.

Ludwig, D., Hilborn, R. and Walters, C. 1993. Uncertainty, resource exploitation, and conservation - lessons from history. Science 260: 17-&.

Lutz, M. and Bastian, O. 2002. Implementation of landscape planning and nature conservation in the agricultural landscape - a case study from Saxony. Agriculture Ecosystems & Environment 92: 159-170.

Lybeck, L. 1981. Archimedes in the classroom. A subject-didactic narrative /Arkimedes i klassen En ämnespedagogisk berättelse. Access through: http://www.ped.gu.se/biorn/phgraph/civil/graphica/oth.ab/lybeck.html 2004.

Lykke, A.M. 2000. Local perceptions of vegetation change and priorities for conservation of woody-savanna vegetation in Senegal. Journal of Environmental Management 59: 107-120.

Lynam, T., Bousquet, F., Le Page, C., d'Aquino, P., Barreteau, O., Chinembiri, F. and Mombeshora, B. 2002. Adapting science to adaptive managers: Spidergrams, belief models, and multi-agent systems modeling. Conservation Ecology 5.

Magill, R.A. 1998. Motor learning: Concepts and applications. McGraw-Hill, Boston.

Magrath, M.J.L. (1991). 'Waterbird breeding in the Macquarie Marshes 1989.' Environmental Studies Unit, NSW Department of Water Resources.

Malouin, F., Belleville, S., Richards, C.L., Desrosiers, J. and Doyon, J. 2004. Working memory and mental practice outcomes after stroke. Archives of Physical Medicine and Rehabilitation 85: 177-183.

Margules, C.R. and Pressey, R.L. 2000. Systematic conservation planning. Nature 405: 243-253.

Martin, T.G., Kuhnert, P.M., Mengersen, K. and Possingham, H.P. In press. The power of expert opinion in ecological models: a bayesian approach to examining the impact of cattle grazing on birds. Ecological Applications.

Marton, F. and Booth, S. 1997. Learning and awareness. Lawrence Erlbaum Associates, Malwah, N.J.

Marton, F. and Saljo, R. 1976. Qualitative differences in learning .1. Outcome and process. British Journal of Educational Psychology 46: 4-11.

Marton, F. and Saljo, R. 1976. Qualitative differences in Learning .2. Outcome as a function of learners conception of task. British Journal of Educational Psychology 46: 115-127.

Marton, F. and Wenestam, C.G. 1988. Qualitative differences in retention when a text is read several times. In: Gruneberg, M.M., Morris, P.E. and Sykes, R.N. (eds), Practical Aspects of Memory: Current research and issues. Wiley, Chichester, pp. 370-376.

Masman, K. and Johnstone, M. 2000. Reedbed country: the story of the Macquarie Marshes. Macquarie Marshes Management Committee, Tamworth.

McCarthy, M.A., Keith, D., Tietjen, J., Burgman, M.A., Maunder, M., Master, L., Brook, B.W., Mace, G., Possingham, H.P., Medellin, R., Andelman, S., Regan, H., Regan, T. and Ruckelshaus, M. 2004. Comparing predictions of extinction risk using models and subjective judgement. Acta Oecologica-International Journal of Ecology 26: 67-74.

McCulloch, M., Fallon, S., Wyndham, T., Hendy, E., Lough, J. and Barnes, D. 2003. Coral record of increased sediment flux to the inner Great Barrier Reef since European settlement. Nature 421: 727-730.

McIntyre, S., McIvor, J. G., Macleod, N. D. 2000. Principles for sustainable grazing in eucalypt woodlands: Landscape-scale indicators and the search for thresholds. In: Hale, P., Petrie, A., Moloney, D. and Sattler, P. (eds), Management for sustainable ecosystems. Centre for Conservation Biology, University of Queensland, Brisbane, pp. 92-100.

McIntyre, S. 2003. The landscape game: A learning tool demonstrating landscape design principles. Ecological Management and Restoration 4: 103-109.

McManus, D.J., Snyder, C.A. and Wilson, L.T. 2003. The knowledge management imperative. Access through: http://www.learnerfirst.com/kho/papers.htm.

Meegan, R.P. and Maehr, D.S. 2002. Landscape conservation and regional planning for the Florida panther. Southeastern Naturalist 1: 217-232.

Meffe, G.K. 2001. Crisis in a crisis discipline. Conservation Biology 15: 303-304.

Metzner, R. 1995. The psychopathology of the human-nature relationship. In: Roszak, T., Gomes, M.E. and Kanner, A.D. (eds), Ecopsychology. Sierra Club Books, San Francisco, pp. 55-67.

Mills, L.S. and Allendorf, F.W. 1996. The one-migrant-per-generation rule in conservation and management. Conservation Biology 10: 1509-1518.

Mills, L.S., Soule, M.E. and Doak, D.F. 1993. The keystone-species concept in ecology and conservation. Bioscience 43: 219-224.

Mimnagh, C.J. 2002. Towards capturing implicit knowledge: a practical application of intranet development. Advances in Clinical Knowledge Management 5.

Miner, A.S. and Mezias, S.J. 1996. Ugly duckling no more: Pasts and futures of organizational learning research. Organization Science 7: 88-99.

Mooney, H.A. and Sala, O.E. 1993. Science and sustainable use. Ecological Applications 3: 564-566.

Murray, B.G. 2001. Are ecological and evolutionary theories scientific? Biological Reviews 76: 255-289.

Musters, C.J.M., Kruk, M., De Graaf, H.J. and Ter Keurs, W.J. 2001. Breeding birds as a farm product. Conservation Biology 15: 363-369.

Naot, Y.B.H., Lipshitz, R. and Popper, M. 2004. Discerning the quality of organizational learning. Management Learning 35: 451-472.

Newell, B. and Wasson, R. 2002. Social system vs solar system: Why policy makers need history. In: Castelein, S. and Otte, A. (eds), Conflict and cooperation related to international water resources: historical perspectives. UNESCO, Grenoble, pp. 3-17.

NHMRC 2000. How to review the evidence: Systematic identification and review of the scientific literature. National Health and Medical Research Council, Canberra.

Nickols, F. 2000. The knowledge in knowledge management. In: Cortada, J.W. and Woods, J.A. (eds), The knowledge managemen yearbook 2000-2001. Butterworth-Heinemann, Boston, pp. 12-21.

North, S.G., Bullock, D.J. and Dulloo, M.E. 1994. Changes in the vegetation and reptile populations on Round-Island, Mauritius, following eradication of rabbits. Biological Conservation 67: 21-28.

Noss, R.F. 1996. The naturalists are dying off. Conservation Biology 10: 1-3.

Noss, R.F. 2000. Science on the bridge. Conservation Biology 14: 333-335.

Novacek, M.J. and Cleland, E.E. 2001. The current biodiversity extinction event: Scenarios for mitigation and recovery. Proceedings of the National Academy of Sciences of the United States of America 98: 5466-5470.

Nowotny, H., Scott, P. and Gibbons, M. 2001. Re-thinking science: Knowledge and the public in an age of uncertainty. Polity Press, Cambridge.

NPANSW 2004. Proposed cloud seeding in Kosciuszko National Park, briefing paper. National Parks Association of New South Wales, Australia. http://www.npansw.org.au/web/conservation/kosciuszko/Cloud_seeding_briefing_note.htm.

NPWS (1993). 'Macquarie Marshes Nature Reserve Plan of Management.' New South Wales National Parks and Wildlife Service.

O'Connell, M.J. 2003. Detecting, measuring and reversing changes to wetlands. Wetlands Ecology and Management 11: 397-401.

O'Connor, J. and McDermott, I. 1997. The art of systems thinking. Thorsons, London.

OED 2002. The Concise Oxford English Dictionary. Oxford University Press, New York.

Olsson, P. and Folke, C. 2001. Local ecological knowledge and institutional dynamics for ecosystem management: A study of Lake Racken Watershed, Sweden. Ecosystems 4: 85-104.

Olsson, P., Folke, C. and Berkes, F. 2004. Adaptive comanagement for building resilience in social-ecological systems. Environmental Management 34: 75-90.

Ormerod, S.J., Barlow, N.D., Marshall, E.J.P. and Kerby, G. 2002. The uptake of applied ecology. Journal of Applied Ecology 39: 1-7.

Ormerod, S.J., Pienkowski, M.W. and Watkinson, A.R. 1999. Communicating the value of ecology. Journal of Applied Ecology 36: 847-855.

Ortenblad, A. 2002. Organizational learning: a radical perspective. International Journal of Management Reviews 4: 87-100.

Palmer, C. and Drake, C. 1997. Monitoring and planning capacities in the acquisition of music performance skills. Canadian Journal of Experimental Psychology 51: 369-384.

Perkins, D., Jay, E. and Tishman, S. Unpublished. A dispositional theory of learning. A report written as part of a project funded by the John D. and Catherine T. MacArthur Foundation. Access through: http://learnweb.harvard.edu/alps/thinking/docs/merrill.htm.

Peters, R.H. 1991. A critique for ecology. Cambridge University Press, Cambridge.

Pettit, N.E., Froend, R.H. and Davies, P.M. 2001. Identifying the natural flow regime and the relationship with riparian vegetation for two contrasting Western Australian Rivers. Regulated Rivers: Research and Management 17: 201-215.

Pickett, S.T.A., Kolasa, J. and Jones, C.G. 1994. Ecological understanding: the nature of theory and the theory of nature. Academic Press, London.

Platt, W.J. and Peet, R.K. 1998. Ecological concepts in conservation biology: Lessons from Southeastern US ecosystems. Ecological Applications 8: 907-908.

Polanyi, M. 1958. Personal knowledge: Towards a post-critical philosophy. Routledge & Kegan Paul, London.

Polanyi, M. 1997. Tacit knowledge. In: Prusak, L. (eds), Knowledge in Organizations. Butterworth-Heinemann, Boston, p. Chapter 7.

Pramling, I.L.t.L.N.Y.S.V. 1990. Learning to learn. Springer Verlag, New York.

Proust, K. (2004). Learning from the past for sustainability: Towards an integrated approach. PhD Thesis thesis, Australian National University.

Pullin, A.S. and Knight, T.M. 2001. Effectiveness in conservation practice: Pointers from medicine and public health. Conservation Biology 15: 50-54.

Pullin, A.S. and Knight, T.M. 2003. Support for decision making in conservation practice: an evidence-based approach. Journal for Nature Conservation 11: 83-90.

Pullin, A.S., Knight, T.M., Stone, D.A. and Charman, K. 2004. Do conservation managers use scientific evidence to support their decision-making? Biological Conservation 119: 245-252.

Pywell, R.F., Bullock, J.M., Hopkins, A., Walker, K.J., Sparks, T.H., Burke, M.J.W. and Peel, S. 2002. Restoration of species-rich grassland on arable land: assessing the limiting processes using a multi-site experiment. Journal of Applied Ecology 39: 294-309.

QCC, ACF and TWS (2001). 'New data reveal Australian landclearing rates 22% worse.' Queensland Conservation Council, Australian Conservation Foundation, The Wilderness Society.

Raesly, E.J. 2001. Progress and status of river otter reintroduction projects in the United States. Wildlife Society Bulletin 29: 856-862.

Ramus, C.A. and Steger, U. 2000. The roles of supervisory support behaviors and environmental policy in employee "ecoinitiatives" at leading-edge European companies. Academy of Management Journal 43: 605-626.

Richards, M. 1996. Protected areas, people and incentives in the search for sustainable forest conservation in Honduras. Environmental Conservation 23: 207-217.

Richter, B.D., Baumgartner, J.V., Powell, J. and Braun, D.P. 1996. A method for assessing hydrologic alteration within ecosystems. Conservation Biology 10: 1163-1174.

Richter, I. 1998. Individual and organizational learning at the executive level - Towards a research agenda. Management Learning 29: 299-316.

Ripple, W.J., Larsen, E.J., Renkin, R.A. and Smith, D.W. 2001. Trophic cascades among wolves, elk and aspen on Yellowstone National Park's northern range. Biological Conservation 102: 227-234.

Robertson, H.A. and McGee, T.K. 2003. Applying local knowledge: the contribution of oral history to wetland rehabilitation at Kanyapella Basin, Australia. Journal of Environmental Management 69: 275-287.

Roshier, D.A., Robertson, A.I. and Kingsford, R.T. 2002. Responses of waterbirds to flooding in an arid region of Australia and implications for conservation. Biological Conservation 106: 399-411.

Rubino, M.J. and Hess, G.R. 2003. Planning open spaces for wildlife 2: modeling and verifying focal species habitat. Landscape and Urban Planning 64: 89-104.

Rushmer, R., Kelly, D., Lough, M., Wilkinson, J.E. and Davies, H.T.O. 2004. Introducing the learning practice - III. Leadership, empowerment, protected time and reflective practice as core contextual conditions. Journal of Evaluation in Clinical Practice 10: 399-405.

Sackett, D.L., Strauss, S.E., Richardson, W.S., Rosenberg, W. and Haynes, B. 2000. Evidence-based medicine: How to practice and teach EBM. Churchill Livingstone, Edinburgh.

Salafsky, N., Margoluis, R., Redford, K.H. and Robinson, J.G. 2002. Improving the practice of conservation: a conceptual framework and research agenda for conservation science. Conservation Biology 16: 1469-1479.

Salisbury, J. and Fazey, I. (2002). 'Evidence-based environmental management: What can medicine and public health tell us?' Unpublished report, National Institute for the Environment, Australian National University, Canberra.

Salvatori, V., Okarma, H., Ionescu, O., Dovhanych, Y., Find'o, S. and Boitani, L. 2002. Hunting legislation in the Carpathian Mountains: implications for the conservation and management of large carnivores. Wildlife Biology 8: 3-10.

Schmiegelow, F.K.A. and Monkkonen, M. 2002. Habitat loss and fragmentation in dynamic landscapes: Avian perspectives from the boreal forest. Ecological Applications 12: 375-389.

Schneider, W. 1985. Toward a model of attention and the development of automatic processing. In: Posner, I. and Martin, O.S.M. (eds), Attention and performance XI. Erlbaum, Hillsdale, N.J., pp. 474-492.

Schneider, W. and Shiffrin, R. 1985. Categorization (restructuring) and automatization - 2 separable factors. Psychological Review 92: 424-428.

Schön, D.A. 1996. Educating the reflective practitioner: Toward a new design for teaching and learning in the professions. Jossey-Bass, Inc., San Farncisco.

Seigel, R.A. and Dodd, C.K. 2002. Translocations of amphibians: Proven management method or experimental technique? Conservation Biology 16: 552-554.

Senge, P.M. 1990. The fifth discipline: The art and practice of the learning organisation. Random House, Sydney.

Shank, C.C. 1999. The Committee On the Status of Endangered Wildlife In Canada (COSEWIC): A 21-year retrospective. Canadian Field-Naturalist 113: 318-341.

Shea, J.B. and Morgan, R.L. 1979. Contextual interference effects on the acquisition, retention, and transfer of a motor skill. Journal of Experimental Psychology-Human Learning and Memory 5: 179-187.

Simberloff, D. 1998. Flagships, umbrellas, and keystones: Is single-species management passe in the landscape era? Biological Conservation 83: 247-257.

Simon, H.A. 1980. Problem solving and education. In: Tuma, D.T. and Reif, R. (eds), Problem solving and education: Issues in teaching and research. Erlbaum, Hillsdale, N.J., pp. 81-96.

Simon, H.A. and Chase, W.G. 1973. Skill in chess. American Scientist 61: 394-403.

Smallwood, K.S., Beyea, J. and Morrison, M.L. 1999. Using the best scientific data for endangered species conservation. Environmental Management 24: 421-435.

Smith, D.I. 1998. Water in Australia: resources and management. Oxford University Press, Melbourne.

Soehartono, T. and Newton, A.C. 2001. Conservation and sustainable use of tropical trees in the genus Aquilaria II. The impact of gaharu harvesting in Indonesia. Biological Conservation 97: 29-41.

Soulé, M.E. 1985. What is Conservation Biology. Bioscience 35: 727-734.

Steiner, K.G. 1998. Using farmers' knowledge of soils in making research results more relevant to field practice: Experiences from Rwanda. Agriculture Ecosystems & Environment 69: 191-200.

Sterman, J.D. 2000. Business dynamics - systems thinking and modeling for a complex world. McGraw Hill, Boston.

Stinchcombe, J., Moyle, L.C., Hudgens, B.R., Bloch, P.L., Chinnadurai, S. and Morris, W.F. 2002. The influence of the academic conservation biology literature on endangered species recovery plannning. Conservation Ecology 6: article 15.

Strauss, A. and Corbin, J. 1990. Basics of qualitative research: Grounded theory procedures and techniques. Sage Publications, London.

Strayer, D.L., Power, M.E., Fagan, W.F., Pickett, S.T.A. and Belnap, J. 2003. A classification of ecological boundaries. Bioscience 53: 723-729.

Sutherland, W.J., Pullin, A.S., Dolman, P.M. and Knight, T.M. 2004. The need for evidence-based conservation. Trends in Ecology and Evolution 19: 305-308.

Taylor, B., Kremsater, L. and Ellis, R. (1997). 'Adaptive management of forests in British Columbia.' British Columbia Ministry of Forests, Forest Practices Branch., Victoria, British Columbia.

Telfer, S., Holt, A., Donaldson, R. and Lambin, X. 2001. Metapopulation processes and persistence in remnant water vole populations. Oikos 95: 31-42.

Terborgh, J. 1977. Bird species diversity on an Andean elevational gradient. Ecology 58: 1007-1019.

Ueno, N., Arimoto, N. and Fujita, G. 1990. Conceptual models and points of view: Learning via making a new stage., Boston.

UNEP 1992. United Nations Environment Program, Convention on biological Diversity. Nairobi, Kenya.

van Merrienboer, J.J.G., deCroock, M.B.M. and Jelsma, O. 1997. The transfer paradox: Effects of contextual interference on retention and transfer performance of a complex cognitive skill. Perceptual and Motor Skills 84: 784-786.

van Reekum, R., Streiner, D.L. and Conn, D.K. 2001. Applying Bradford Hill's criteria for causation to neuropsychiatry: Challenges and opportunities. Journal of Neuropsychiatry and Clinical Neurosciences 13: 318-325.

vanMerrienboer, J.J.G., deCroock, M.B.M. and Jelsma, O. 1997. The transfer paradox: Effects of contextual interference on retention and transfer performance of a complex cognitive skill. Perceptual and Motor Skills 84: 784-786.

Vennix, J.A.M. 1996. Group model building: Facilitating team learning using system dynamics. Wiley, Chichester, West Sussex.

Waddell, C. 2001. So much research evidence, so little dissemination and uptake: mixing the useful with the pleasing. Evidence Based Mental Health 4: 3-5.

Walters, C.J. and Holling, C.S. 1990. Large-scale management experiments and learning by doing. Ecology 71: 2060-2068.

Waltz, K.N. 1997. Evaluating theories. American Political Science Review 91: 913-917.

Watanabe, S. 1975. A historico-dynamical view of theory change. Synthese 32: 113-134.

Weick, K. 1995. Sensemaking in organizations. Sage, Thousand Oaks, California.

Weinberg, S. 1992. Dreams of a final theory. Pantheon books, New York.

Westley, F., Carpenter, S.R., Brock, W.A., Holling, C.S. and Gunderson, L.H. 2002. Why systems of people and nature are not just social and ecological systems. In: Gunderson, L.H. and Holling, C.S. (eds), Panarchy: Understanding transformations in human and natural systems. Island Press, Washington D.C.,

Whelan, R.J., Rodgerson, L., Dickman, C.R. and Sutherland, E.F. 2002. Critical life cycles of plants and animals: developing a process-based understanding of population changes in fire-prone landscapes. In: Bradstock, R.A., Williams, J.E. and Gill, M.A. (eds), Flammable Australia: the fire regimes and biodiversity of a continent. Cambridge University Press, Cambridge, p. 462.

Whiteman, G. and Cooper, W.H. 2000. Ecological embeddedness. Academy of Management Journal 43: 1265-1282.

Whiteman, G., Forbes, B.C., Niemela, J. and Chapin, F.S. 2004. Bringing feedback and resilience of high-latitude ecosystems into the corporate boardroom. Ambio 33: 371-376.

Whitten, T., Holmes, D. and MacKinnon, K. 2001. Conservation biology: a displacement behavior for academia? Conservation Biology 15: 1-3.

Wiens, A.W. 1995. Landscape mosaics and ecological theory. In: Hansson, L., Fahrig, L. and Merriam, G. (eds), Mosaic landscapes and ecological processes. Chapman & Hall, London, pp. 1-26.

With, K.A. 1997. The theory of conservation biology. Conservation Biology 11: 1436-1440.

Wolfgang, C.A. (2000). Hydrogeology of the Pilliga sandstone aquifer in the Western Coonamble embayment and its implications for water resource management. Australian National University.

Woodwell, G.M. 1989. On causes of biotic impoverishment. Ecology 70: 14-15.

Wulf, G. and Shea, C.H. 2003. Feedback: The good, the bad, and the ugly. In: Williams, M., Hodges, N., Scott, M. and Court, M. (eds), Skill acquisition in sport: Research, theory and practice. Routledge, London,

Young, T.P. 2000. Restoration ecology and conservation biology. Biological Conservation 92: 73-83.

APPENDICES

The appendices were all produced during study for the thesis. While they do not relate directly to the main theme of the thesis, they have contributed to developing understanding about the nature of the discipline of environmental conservation and conservation theory. All the appendices are "in press".

Appendix 1

WHO DOES ALL THE RESEARCH IN CONSERVATION BIOLOGY?

Citation: Fazey, I., Fischer, J., Lindenmayer, D.B. (2005). Who does all the research in conservation biology? Biodiversity and Conservation. 14: 917-934

A1.0 Summary

Much of the world's biodiversity is located within countries with developing economies. We therefore examine how well developing nations and their scientists are represented in three international conservation biology journals (*Conservation Biology*, *Biological Conservation*, *Biodiversity & Conservation*). We found: (1) That 28% of studies were from lower income countries and only 15% of all papers had primary authors from these nations. Of papers from lower income countries, although 80% had at least one local author, only 47% had primary authors from the country where the study was conducted. (2) Lower income countries had more research with a strong applied focus compared to research from high-income countries. (3) In lower income countries research was often funded by international sources but the primary authors of these studies were from affluent nations. (4) The three journals differed in how well they represented lower income nations and their scientists, reflecting their editorial policies for including research from lower income nations. The main reason for the large discrepancy in a country's output of conservation research is due to the difference in a nation's ability to invest in science. However, a brief survey of authors suggests that there is a large amount of information available in lower income and non-English speaking countries that is not easily accessible to the international conservation community. Journals may therefore need to consider altering their policies if we are to improve the representation of research by scientists in lower income nations.

A1.1 Introduction

Much of the world's biodiversity is located in countries with developing economies. Estimates of the number of endemic plant and vertebrate species suggest that 70% of the world's biodiversity is found in only 17 megadiverse countries (Conservation International 2000), of which only two are classified as high-income countries (Table A1.1). Other trans-national estimates of globally important areas for biodiversity are identified by species endemism and by the degree of threat to the habitats and ecosystems that harbour them (Myers *et al.* 2000). Using this classification, 25 hotspots have been identified. Of these globally important and threatened areas, 17 are located entirely in regions comprised of low or middle-income countries and only three are found entirely within high-income countries (Table A1.1). The high level of threat to substantial biodiversity in lower income countries means that concentrating conservation effort in these regions is particularly important.

It has been argued that more on-the-ground conservation action rather than detailed research is needed (Whitten *et al.* 2001) and that more emphasis on finding ways to protect ecosystem function is necessary, rather than just priority setting and theoretical modelling (Ginsberg 1999). Despite these criticisms, research can have an important role as a rational basis for decision-making (Kinnaird and O'Brien 2001), so long as the priorities for action and research need are clearly defined (Sheil 2001). Indeed, most conservation biologists would argue there is a fundamental lack of knowledge about many threatened species and habitats, particularly in developing nations. Importantly, lack of such basic research can have implications on how we perceive particular threats (Berger *et al.* 2001, Rodriguez *et al.* 2001) or how we make decisions (Dovers *et al.* 1996; Dovers and Mobbs 1997). Thus, while more conservation action is required, there is still a need for research that helps us understand how to conserve biota, particularly in developing countries that harbour much of the world's biodiversity (Table A1.1).

In this paper we examine how well research from lower income nations and their scientists were represented in the international conservation biology literature. The motivation for this paper stemmed from the hypothesis that widely available conservation literature is biased to regions of the world that are more affluent but of lower conservation concern, and that scientists conducting research in lower income countries are often from richer nations. We also hypothesise that the limited resources available in lower income countries are more likely to be spent on conservation research that has a more applied focus, rather than on investigations of underlying patterns and processes.

Table A1.1. (A) High and Lower income megadiverse countries and (B) Biodiversity hotspots. *'High-income countries' are defined as those with a gross national income per capita equal to or greater than US$9,266 (World Bank Data, 2001). We class all other countries as 'lower income'.

A) Megadiverse Countries Defined on the basis of number of species and degree of endemism (data from Conservation International 2000).	High (H) or Lower income (L)*	The 25 Biodiversity Hotspots Defined on the basis of number of species, degree of endemism and the degree of threat to biodiversity from habitat loss (data from Myers *et al.* 2001). The hotspots are in decreasing order of importance.	Part of hotspot is high-income country*	Contains only high-income country*
Australia	H	Tropical Andes	No	No
Brazil	L	Mesoamerica	Yes	No
China	L	Caribbean	Yes	No
Colombia	L	Brazil's Atlantic Forest	No	No
Democratic Republic of Congo	L	Choc/Darien/Western Ecuador	No	No
Ecuador	L	Brazil's Cerrado	No	No
India	L	Central Chile	No	No
Indonesia	L	California Floristic Province	Yes	Yes
Madagascar	L	Madagascar	No	No
Malaysia	L	Eastern Arc and Coastal Forests of Tanzania/Kenya	No	No
Mexico	L	Western African Forests	No	No
Papua New Guinea	L	Cape Floristic Province	No	No
Peru	L	Succulent Karoo	No	No
Philippines	L	Mediterranean Basin	Yes	No
South Africa	L	Caucasus	No	No
U.S.A.	H	Sundaland	Yes	No
Venezuela	L	Wallacea	No	No
		Philipines	No	No
		Indo-Burma	No	No
		South-Central China	No	No
		Western Ghats/Sri Lanka	No	No
		SW Australia	Yes	Yes
		New Caledonia	No	No
		New Zealand	Yes	Yes
		Polynesia/Micronesia	Yes	No

To quantify how well scientists and their research from lower income countries are represented in the international literature we surveyed three prominent conservation biology journals. From this sample of publications, we ask four questions: 1) Where are the studies conducted and who carries out the research? 2) Does funding come from international or local sources? 3) Does research in countries with higher incomes have a more applied focus than research from countries with lower incomes? 4) Do journals differ in the degree to which they represent studies from lower income countries and their scientists? In the discussion, we: (1) examine whether research in lower income countries is inaccessible to the international conservation community, (2) consider the importance of involving local scientists in research, and (3) suggest how journals might alter their policies to include more authors from lower income countries.

A1.2 Methods

A1.2.1 Selection of publications for the survey

Because 'conservation biology' is a widely used term that encompasses a wide range of disciplines in an applied and theoretical context, for the purposes of our study, it was important to clearly define what was meant by 'conservation biology'. We defined 'conservation' to be the "management of human use of the biosphere that provides the greatest sustainable benefit to current generations while maintaining its potential to meet the needs of future generations" (UNEP 1992). This definition embraces "preservation, maintenance, sustainable use, restoration and enhancement of the natural environment" (UNEP 1992). Thus 'conservation biology' refers to the conservation of all biological entities, i.e. all aspects of biodiversity (genes, species, communities, ecosystems), and the way that different components of biodiversity interact with each other and with the physical environment.

With the exception of letters and book reviews, we read all publications from three international conservation biology journals in 2001 (total number of papers = 547). The journals were *Biodiversity & Conservation* (volume 10) with 124 publications, *Biological Conservation* (volumes 97-102) with 210 publications and *Conservation Biology* (volume 15) with 213 publications.

The journals were selected on the basis that they were the highest impact biological journals with '*conservation*' in their title, and that together they provided a good representation of the global scientific literature in conservation biology. While the review of only three of many journals that are fully or partially devoted to conservation will influence the results of the study, sampling a larger number of journals with fewer papers from each is problematic. This is partly because in some of the more ecologically oriented journals (e.g. *Journal of Animal Ecology*) it is sometimes difficult to decide whether a publication should be included as a paper that is devoted to conservation biology. Other conservation related journals are often quite specific to particular issues (e.g. *Restoration Ecology*) or to a specific region (e.g. *Pacific Conservation Biology*). Thus, while the choice of the journals for this survey will influence some of the results, we believe the journals we focused on will provide a good overview of the most widely read international publications that are specific to the discipline of conservation biology.

The journals reflect a range of different types of publications and editorial policies. *Conservation Biology*, the Journal of the Society for Conservation Biology is the most frequently cited journal that is devoted entirely to biological conservation. The journal has a wide scope and represents many scientific disciplines that contribute to the study and conservation of species, habitats and ecosystems (Conservation Biology 2002). *Biological Conservation* has as its main purpose "the widest dissemination of original papers dealing with the preservation of wildlife and the conservation or wise use of biological and allied natural resources" (Biological Conservation 2002). *Biodiversity & Conservation* devotes itself to the publication of articles "on all aspects of biological diversity, its description, analysis and conservation, and its controlled rational use by mankind". Importantly, the editors of *Biodiversity & Conservation* actively encourage contributors from developing countries to attain a more global perspective on conservation (Biodiversity & Conservation 2002). The 2001 impact factors for the three journals were 2.783 for *Conservation Biology*, 1.689 for *Biological Conservation*, and 1.311 for *Biodiversity & Conservation*.

A1.2.2 Data collection and analysis

For each paper we recorded the country where studies were conducted, where authors were from (based on the address of their institution) and whether the study was funded from sources inside or outside the country of study (obtained by screening the acknowledgments). We also determined whether papers had a strong applied focus for (1) informing policy, (2) guiding management or (3) conducting biodiversity surveys. Publications were scored subjectively between zero and three for the degree with which they addressed each of the three subject areas listed above. This score was based on the questions that each study asked and the degree with which it considered each of the three subject areas in the introduction and discussion. A paper was considered to significantly address one of these subject areas if it was given a score of two or more. Some opinion papers or those that reviewed or studied some aspects of underlying biological processes scored less than two for all three categories, and were therefore deemed not to have a strong applied focus. Further, because each of the three categories were considered separately for each publication and were not mutually exclusive, 27 of the publications were considered to address more than one of the pre-defined subject areas. The classification of a publication was inevitably subjective, but we made every effort to retain consistency throughout the survey, by ensuring all papers were assessed by the primary author (IF).

For analysis, the author's country and the country of study were classed as either high-income or lower income. High-income countries are defined by the World Bank as having a gross national income per capita equal to or greater than US$ 9,266 (World Bank Data, 2001). In 2001, there were 23 high-income countries: U.S.A., Canada, Japan, Australia, New Zealand, Iceland, Norway, Switzerland and all 15 countries in the European Union. All other countries are classed by the World Bank as either low or middle income countries. For the purposes of this paper, we refer to low and middle income countries together as 'lower income countries'.

A1.3 Results

A1.3.1 Where were the studies from and who conducted them?

The largest number of publications were both written (39%) and conducted (30%) in the U.S.A., the European Union countries except U.K. (20% and 15%), Australia and New Zealand (13% and 12%) and the U.K. (8% and 6%) (Fig. A1.1). In the Carribbean, Central and South American countries (12.6% of all studies), less than half were written by primary authors from those countries. In general, more studies were written by primary authors from high-income countries than the number of studies in high-income countries, and less studies were written by primary authors from lower income countries than the number of studies that were conducted there. This indicates that scientists from more affluent nations frequently conduct research in poorer countries.

More studies were conducted in high-income countries (56%) than lower income countries (28%) (see Fig. A1.2a). There were also more studies written by authors from high-income countries compared to those in lower income countries (Fig. A1.2b). Only 15% of publications had a primary author from a lower income country, and only 21% of all publications had at least one author from a lower income country.

Even when the number of publications in different country classes was taken into account, primary authors from lower income countries were still not well represented in the scientific literature (Fig. A1.3). Only 74 of the 158 studies from lower income countries (47%) had primary authors from the same country as the study itself. Of these 74 studies nearly a third (n=23) were from India and South Africa. Conversely, 97% of the 306 studies from high-income countries had primary authors from the country where the study was conducted. Secondary authors from lower income countries were much better represented in the literature, with 80% of the papers from lower income countries having at least one author from the same country of study.

A1.3.2 Did funding come from international or local sources?

More studies were funded locally in high-income than in lower income countries, and more were funded from international sources in lower income than in high-income countries ($\chi^2_2 = 159$, $p < 0.001$) (Fig. A1.4a). In lower income countries, 44% of the studies relied totally on international funding sources and 15% on both international and local sources. Only 20% of the studies in lower income nations were exclusively funded locally, compared to 65% in nations with higher incomes. Of the locally funded studies in lower income countries, over half (53%) were in either India or South Africa. When South Africa and India were excluded, 90% of studies in poorer nations were solely dependent on at least some form of international funding.

For studies from lower income countries where primary authors were from high-income countries ($n = 85$), very few of these authors received funding exclusively or partially from local sources (1% and 9% respectively). Similarly, for all studies in lower income countries that relied entirely on international funding ($n = 70$), only 9 (13%) had primary authors from those countries. Thus, the majority of international funding for research conducted in lower income countries came with the researchers from richer countries that then went on to publish their work as the primary author.

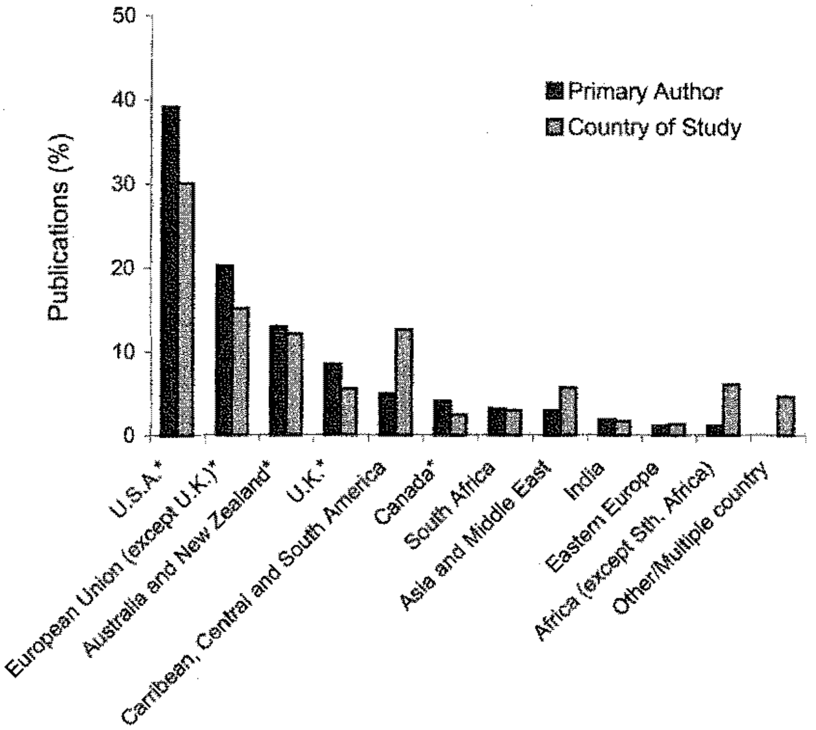


Fig. A1.1: Global distribution of primary authors and country of study. An asterisk (*) indicates high-income countries. Note that where the publication did not apply to a particular country, a publication was given the same country of study as the primary author. Total n = 547.

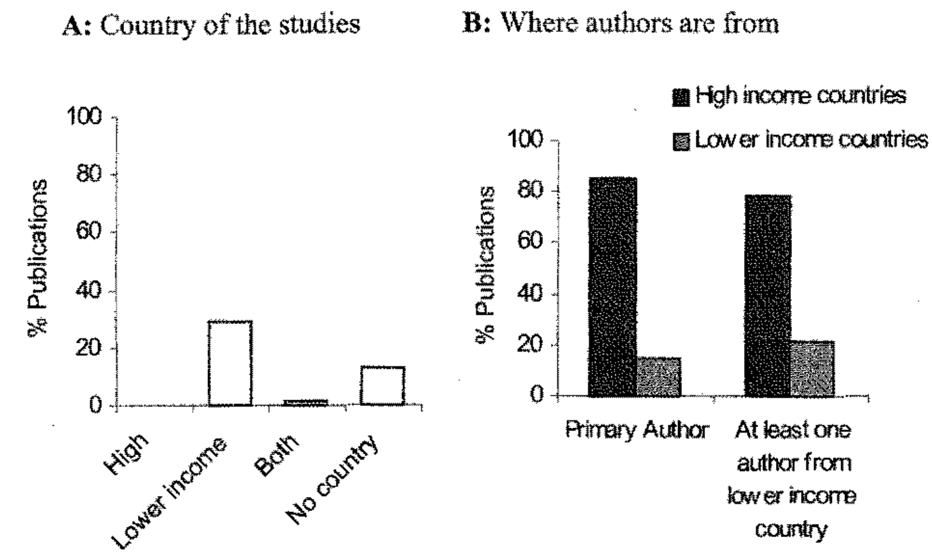


Fig. A1.2: (A) The percentage of publications from different country classes. 'No country' refers to publications that did not relate directly to any particular country such as some essays, comments or reviews. (B) The percentage of studies from high-income and lower income countries that had primary or secondary authors from those countries (n = 547).

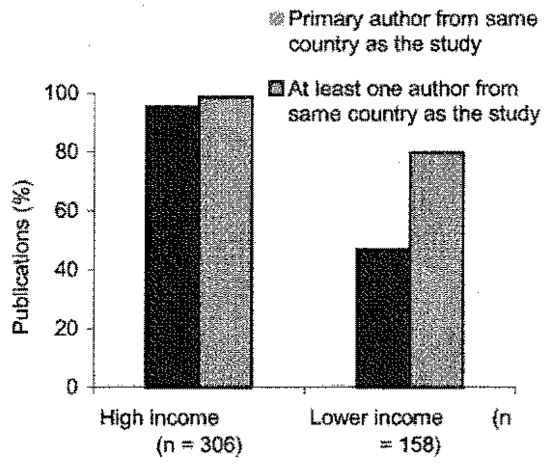


Fig. A1.3: The percentage of publications from high and lower income countries where the primary author or at least one author was from the same country where the study was conducted.

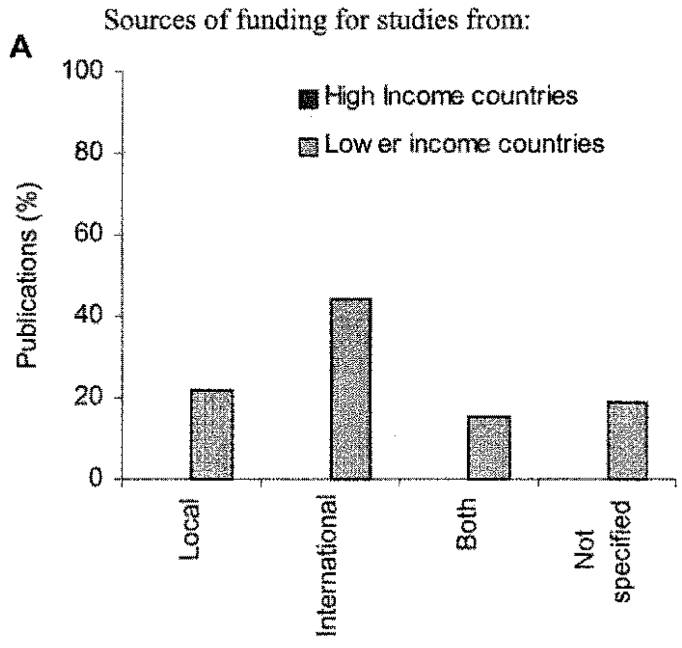
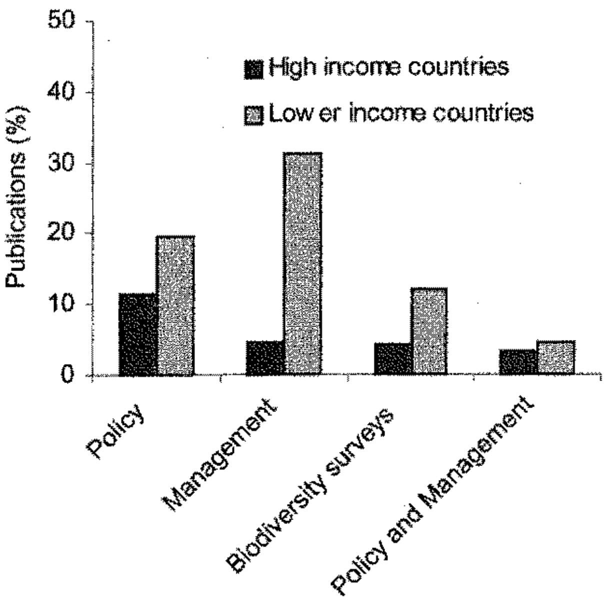


Fig. A1.4: Percentage of the different sources of funding for studies conducted in high and lower income countries (n = 307 and 158 for high and lower income countries respectively).

A1.3.3 Did research from lower income countries have a more applied focus?

There were differences in the types of studies that were conducted in high-income and lower income countries ($\chi^2_3 = 15.4$, $p < 0.005$) (Fig. A1.5a). Lower income countries had proportionately more studies than high-income countries that aimed to guide management (31% compared to 14%), inform policy (20% compared to 11%) and conduct biodiversity surveys (12% compared to 4%). However, there was no difference in the degree to which primary authors from high and lower-income countries conducted research with an applied focus in lower income countries ($\chi^2_3 = 1.873$, $p > 0.75$) (Fig. A1.5b). This suggests that the reason for more studies with an applied focus in lower income countries is likely to be because it is from such a country rather than because it is written by a primary author from that country.

A: For all publications



B: For publications from lower income countries

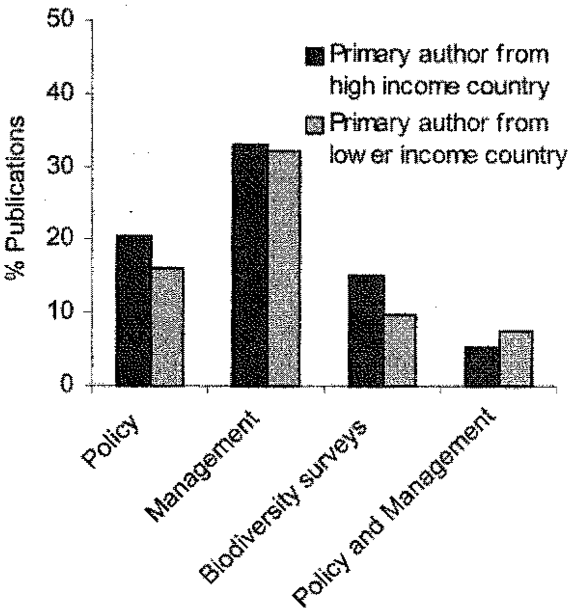


Fig. A1.5: Percentage of publications with a strong applied focus, i.e. that aimed to inform policy, guide management, or conduct biodiversity surveys: (A) For high and lower income countries (Total n = 307 and 158 respectively). (B) For primary authors from high and lower income countries (Total n = 465 and 82 respectively).

A1.3.4 Do the journals differ in the degree to which they represent lower income countries?

There were significant differences between the three journals surveyed in the distribution of studies in different country classes ($\chi^2_6 = 109.3$, p <0.001) (Fig. A1.6). Of the three journals, *Biodiversity & Conservation* had the highest proportion of studies that were conducted in lower income countries. A total of 52% of the studies in *Biodiversity & Conservation* were from lower income, compared to 42% from high-income countries. *Biological Conservation* had the greatest difference in the proportion of studies that were undertaken in high and lower income countries (75% and 20% respectively), and *Conservation Biology* the highest proportion of publications that were theoretical, opinion pieces, or comments, and therefore not associated with a particular country (Fig. A1.6).

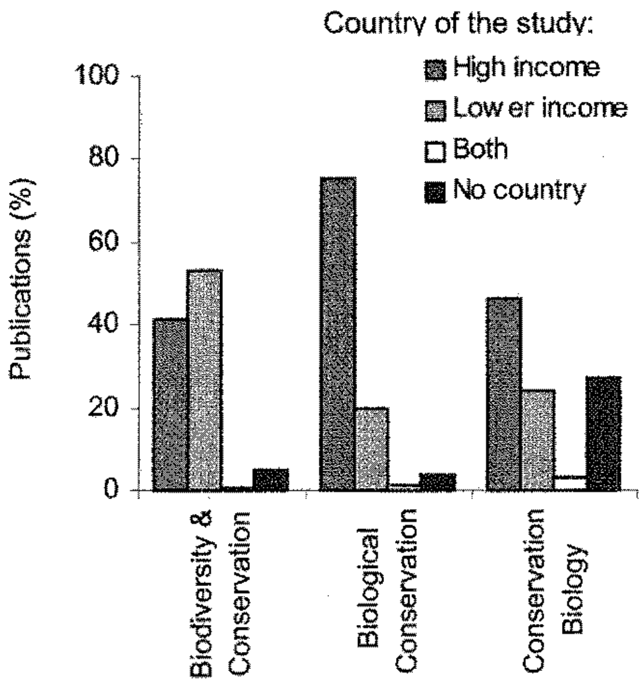


Fig. A1.6: (A) Proportion of publications in each country class for each of the journals that were surveyed. 'No country' refers to publications that did not relate directly to any particular country such as some essays, comments or reviews. Total publications were 123, 210, and 213 for *Biodiversity & Conservation*, *Biological Conservation* and *Conservation Biology* respectively.

There were also significant differences between journals in the proportion studies that had a primary author from the high or lower income country where the study was conducted ($\chi^2_2 = 13.3$, $p < 0.005$) (Fig. A1.7a). *Conservation Biology* had proportionately fewer studies written by primary authors from the same lower income country where the study was conducted (24%) compared to *Biodiversity & Conservation* (60%) and *Biological Conservation* (55%). However, the journals were similar in the proportion of studies that had at least one author from the high or lower income country where the study was conducted ($\chi^2_2 = 0.795$, $p > 0.5$) (Fig. A1.7b).

A: Primary authors from same country as the country of the study:

B: Secondary authors from same country as the country of the study:

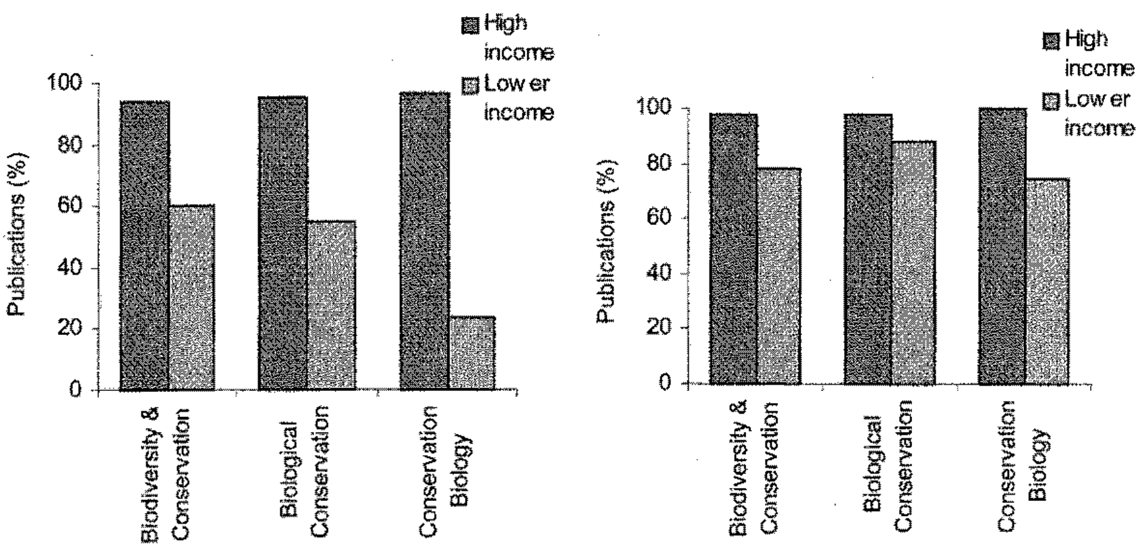


Fig. A1.7: The percentage of publications with authors from high-income and lower income countries that were from the same country where the study was conducted for each of the three journals: (A) primary authors and (B) at least one author. Total n for high-income countries in *Biodiversity & Conservation*, *Biological Conservation* and *Conservation Biology* were 51, 158, and 98 respectively. Total n for lower income countries from the three journals were 65, 42 and 51 respectively.

A1.4 Discussion

A1.4.1 Why so little research from lower income countries?

In the three journals surveyed, authors from lower income countries were not well represented. There was much less conservation research from lower income countries than from high-income countries (Fig. A1.2a). Even when there was research in lower income nations, primary authors from more affluent nations wrote over half of the publications (Fig. A1.2b). Junior authors from lower income nations were better represented, with 80% of the studies from lower income countries having at least one author from the same country as where the study was conducted (Fig. A1.3).

The main reason for the large discrepancy between the numbers of studies from high and lower income countries is likely to be due to differences in their ability to invest in science. Society invests in science because the advances in scientific knowledge benefit society (Tilman 2000), but lower income nations have fewer resources to train conservation biologists and their work. It is well known there are large differences in the scientific investment of nations (May 1998). Only 15 countries produce over 81% of the world's publications in science, engineering and medicine, with the U.S.A. accounting for 35% of all publications (May 1997). Most of these top 15 nations were high-income, and only two were lower income countries (India and the People's Republic of China). In our study we found that 28% of publications were from lower income countries, but only 15% had primary authors from these nations.

Data from this study does indicate that high income nations increase conservation research in lower income countries because few of the studies in lower income nations were funded locally (Fig. A1.4). Half of the exclusively locally funded studies in lower income countries were conducted in South Africa or India, leaving few other lower income countries that did not rely on at least some international funding. This finding suggests much of the existing international conservation biology research from lower income countries would not be conducted without the funding of authors from more affluent nations.

There may be other reasons why relatively little research is published internationally by scientists from lower income countries. For example, in Latin America, promotions and salaries are rarely tied to publishing activities (Young *et al.* 2002). In addition, a country's research output is likely to be higher if it's research base is in universities because graduates play a large role in publishing (May 1997). In the U.S.A., U.K. and Australia, many students are encouraged to publish their theses as research papers. However, in some countries where

English is not the first language, such as in Brazil, students may not actively start publishing until much later in their career (D. Tubelis *pers. comm.*). In India, some students may even feel reluctant to submit papers to international journals because they believe their research to be inferior than research from other countries, and instead choose to publish locally (N. Chettri, *pers. comm.*).

A1.4.2 Are we missing out on research from lower income nations because it is less accessible internationally?

The country of origin of an author was based on the address of the institution with which they were affiliated. It is possible the results were influenced by authors from high-income countries that were postgraduate students from lower income countries supported by international scholarships. However, some studies also appeared to be written by authors from high-income countries that were affiliated with organisations based in lower income countries (e.g. N.G.O.s). Further, some countries (e.g. Tanzania and the Democratic Republic of Congo), may not have been represented at all in the dataset if it weren't for these authors. Thus, institutional addresses are just as likely to have increased the representation of lower income countries in the literature as to decrease it.

There is no doubt that the journals we surveyed influenced the results of this study. However, as discussed in the methods section, it was difficult to sample from journals that were not entirely devoted to conservation, and we chose to limit our survey to high impact journals. Thus, we believe the three journals were likely to provide a good indication of the most widey read international publications in conservation biology, but may not be a good representation of more locally based journals, particularly publications in languages other than English. On this basis, it is important to know if there is a large body of research from lower income countries that is not easy to access internationally.

We found that lower income countries had higher proportions of research that was more directly applied to conservation (Fig. A1.5), and it is possible that authors from lower income nations are publishing their results in journals with a more applied emphasis. However, there was no difference in the type of studies that were conducted in lower income nations by primary authors from those countries and by authors from more affluent nations. While this finding does not rule out the possibility that authors from lower income nations are publishing elsewhere, it indicates that the type of research they do does not necessarily exclude them from publishing in the three journals that were surveyed in this study.

For scientists from lower income countries, language is probably the biggest barrier to publishing. Without a very good grasp of English, most will be at a disadvantage if they want to publish in an international journal, and may instead publish their work in their own language. For example, India and South Africa accounted for a considerable proportion of the studies from lower income countries, and both these countries have a large middle class that is fluent in English. Conversely, authors from Asia and the Middle East were poorly represented.

To get some indication if there is a large body of research from lower income countries that is not published internationally, and if language is a barrier to publishing in non-English speaking countries, we contacted 11 conservation biologists or ecologists from a range of lower income countries. We received replies from seven different countries (Table A1.2). English language was not considered to be a major problem for scientists in South Africa, India and Israel. In Iran it was sometimes a problem, and in Brazil and Hungary, language was thought to be a strong barrier to publishing. The comments also clearly showed there was a substantial amount of information in local journals, reports and theses in these countries, and many local journals were not published in English (Table A1.2). In some of these countries (e.g. India), access to journals, web sites and other informational infrastructure can greatly limit the accessibility of local researchers to their own work. Much of the information in these countries will therefore not be easily accessible to the wider international community.

Conferences have been one traditional way of trying to make current research more accessible, but they are often too expensive for many conservation researchers or practitioners. In addition, conferences may not have much impact to increase the presentation of research from less affluent nations even when financial support is provided. For example, during the Conference of the Society for Conservation Biology, Canterbury 2002, only 18% of the 608 papers had primary authors from lower income countries compared to the 15% in this study. This was despite travel grants for students from less affluent nations.

Pimm *et al.* (2001) stated that "we are not so limited by our lack of knowledge as our failure to synthesise and distribute it", and we believe that conservation biology has a long way to go to tackle the problem of making information and research more accessible. There have been numerous calls for improving communication between scientists and practitioners (e.g. Pullin and Knight 2001, Prendergast *et al.* 1999), and effective dissemination of research to a wide audience is imperative for this process.

Table A1.2: Impressions of conservation/ecological scientists from different countries about publishing in conservation related journals.

Country	For a conservation related paper (e.g. biogeographical, zoological, ecological etc.):		How many journals are there that are specific to conservation biology?	Do conservation biologists often publish in international journals?	Is there a lot of unpublished information in reports and theses?	Is language a major difficulty for scientists to publish in international conservation journals?	Is publishing in international journals generally encouraged?	Is publishing an important consideration for promotion or salary increases?
	How many local non – English language journals could it be sent to?	How many local English language journals could it be sent to?						
South Africa	0	5+	2	Yes	Yes	No	Yes	Yes
India (results from two scientists)	Very few, some newsletters and bulletins. Most journals in English	7+	4+	Yes	Yes	Not for the majority	Depends on institution	Yes, but not always
Hungary	4+ (also some small local journals)	5+ (two of these can have English or Hungarian papers)	1	No easy answer, but numbers increasing	Yes – major problem that many good (and bad) reports buried in national parks/ conservation authority	Yes – big problem	Yes	Not directly, but is important for promotion to senior levels
Mexico	4+	?	0	Most papers published in U.S.A. and European journals	Some	?	?	?
Iran	c.25 environmental related journals	3	5	Yes	Some	Can be a problem, but not always	Yes	Yes
Brazil	Very few	Very few	0	Some – mainly Biotropica and Tropical Ecology	Many publications in Portuguese are in museums or books. Lots unpublished theses	Yes	Yes, but not as much as in U.S.A. or Europe	In some cases
Israel	5-10	?	2	Yes	Yes	No	Yes	Yes

A1.4.3 Does it matter that international primary authors conduct so much of the research from lower income countries?

Local scientists often have important knowledge about the area studied, its biota and their threats, and often have access to relevant local publications and reports. They may also understand local communication networks or the cultural background to a particular problem (e.g. Ramanujam and Kadamban 2001). In many cases local researchers are essential to evaluate conservation policy (e.g. Soto *et al.* 2001, Long and Zhou 2001), threats to biodiversity (e.g. Silori and Mishra 2001) or conduct research on the sustainable use of species (e.g. Shinwari and Gilani 2003). They can also more easily develop partnerships with local communities (Getz *et al.* 1998), such as for social and biological monitoring programmes (Kremen *et al.* 1998). Importantly, the knowledge and expertise gained during experimental design and data collection is not lost from the country of the study when local scientists are involved.

In many conservation studies, inclusion of local scientists in conservation research will therefore be important. However, although it may be desirable to increase research output from scientists in lower income countries, the issue is complex. International primary authors work hard to secure research funding for studies in lower income countries, and they are under substantial pressure to "publish or perish". Many researchers who work overseas also use their experience positively for conservation, and as demonstrated, there would be less research from lower income countries if there was no input from international scientists. Nevertheless, because scientists from more affluent nations often have a stronger educational background, they should take their role as 'ambassadors of science' seriously in situations where knowledge of the scientific method is lacking. This includes openly sharing scientific expertise, language abilities, and skills in obtaining international funding to help local researchers publish more widely. They should also ensure they follow the 'code of ethics' for conducting research in lower income countries to help these countries build their own scientific infrastructures (Colvin 1992).

Improving collaboration between scientists is not easy, but it is important to ask whether conservation biology as a discipline can be satisfied with the trends reported in this study. Encouragingly, 80% of all publications from lower income countries had at least one author from the country where the data was collected (Fig. A1.3). This indicates a basic level of international collaboration in much of the research. However, a considerable number of studies in lower income countries did not involve local scientists. A possible reason for this trend is that some research from lower income countries does not reach the international stage because it is supplanted by research from more affluent nations that is better funded, has a stronger scientific foundation, or is more relevant to the international journal (i.e. papers submitted from lower income countries have higher rejection rates). For example, in India, unaffordable page charges can limit the choice of international journals that a paper can be sent to, and the subject of the paper may no longer be relevant to the international journals that do not have page charges (N. Chettri pers. comm.). Can refereed journals therefore do more to encourage the inclusion of authors from lower income countries?

Our findings suggest that editorial policies can have a major influence in the proportions of published papers from high and lower income countries. *Biodiversity & Conservation*, which actively encourages submission by authors from lower income nations, had higher proportions of studies and primary authors from these countries than the other journals. Conversely, *Conservation Biology* had very few studies by primary authors from lower income countries. Journals should not necessarily drastically alter their policies to include more studies from lower income countries, as many other papers that are more valuable from a different standpoint might not be published. However, it may be desirable for editorial boards to consider how they could increase the representation of scientists from lower income nations in their journals (see Table A1.3 for some suggestions). International funding bodies may also be able to increase their emphasis for scientists from high-income nations to collaborate with local researchers, and many individual researchers could do more to actively collaborate with others.

Table A1.3: Suggestions as to how journals might encourage greater inclusion of scientists from lower income countries

- Percentage space allocation to studies from primary authors from lower income countries
- Technical advice for authors
- Editorial assistance for non-English language authors
- Remove page charge policies
- Financial assistance to younger scientists for publishing or translating previous work
- Strong selection for papers that have at least one author from the lower income country where the study was conducted

In summary, our results demonstrate that although many publications of studies conducted in lower income countries had junior authors, less than half of the papers had primary authors from those countries. Further, the editorial policies of international journals clearly influenced the degree to which primary authors from lower income countries were represented. Editorial boards should therefore consider whether they can alter their policies to more adequately reflect the research on biodiversity and its threats by scientists from lower income and non-English speaking countries.

A1.5 Acknowledgements

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A1.6 References

Berger, J., A. Hoylman, and T. Weber. 2001. Perturbation of vast ecosystems in the absence of adequate science: Alaska's Arctic refuge. Conservation Biology **15**:539-541.

Biology, C. 2002. Journal of the Society of Conservation Biology. http://www.conbio.org/SCB/Publications/ConsBio/

Colvin, J. G. 1992. A Code of Ethics for Research in the 3rd-World. Conservation Biology **6**:309-311.

Biodiversity and Conservation. 2002. Biodiversity and Conservation. http://www.kluweronline.com/issn/0960-3115

Biological Conservation. 2002. Biological Conservation. http://www.elsevier.com/locate/biocon

Dovers, S. R., and C. D. Mobbs. 1997. An alluring prospect? Ecology, and the requirements of adaptive management in N. Klomp, and I. Lunt, editors. Frontiers in ecology: Building the links.

Getz, W. M., L. Fortmann, D. Cumming, J. du Toit, J. Hilty, R. Martin, M. Murphree, N. Owen-Smith, A. M. Starfield, and M. I. Westphal. 1999. Conservation - Sustaining natural and human capital: Villagers and scientists. Science **283**:1855-1856.

Ginsberg, J. 1999. Global conservation priorities. Conservation Biology **13**:5-5.

Conservation International. 2000. Megadiversity data tables. http://www.conservation.org/xp/CIWEB/home

Kinnaird, M. F., and T. G. O'Brien. 2001. Who's scratching whom? Reply. Conservation Biology **15**:1459-1460.

Kremen, C., I. Raymond, and K. Lance. 1998. An interdisciplinary tool for monitoring conservation impacts in Madagascar. Conservation Biology **12**:549-563.

Long, C. L., and Y. L. Zhou. 2001. Indigenous community forest management of Jinuo people's swidden agroecosystems in southwest China. Biodiversity and Conservation **10**:753-767.

May, R. M. 1997. The scientific wealth of nations. Science **275**:793-796.

May, R. M. 1998. The scientific investments of nations. Science **281**:49-51.

Myers, N., R. A. Mittermeier, C. G. Mittermeier, G. A. B. da Fonseca, and J. Kent. 2000. Biodiversity hotspots for conservation priorities. Nature **403**:853-858.

Pimm, S. L., M. Ayres, A. Balmford, G. Branch, K. Brandon, T. Brooks, R. Bustamante, R. Costanza, R. Cowling, L. M. Curran, A. Dobson, S. Farber, G. A. B. da Fonseca, C. Gascon, R. Kitching, J. McNeely, T. Lovejoy, R. A. Mittermeier, N. Myers, J. A. Patz, B. Raffle, D. Rapport, P. Raven, C. Roberts, J. P. Rodriguez, A. B. Rylands, C. Tucker, C. Safina, C. Samper, M. L. J. Stiassny, J. Supriatna, D. H. Hall, and D. Wilcove. 2001. Environment - Can we defy nature's end? Science **293**:2207-2208.

Prendergast, J. R., R. M. Quinn, and J. H. Lawton. 1999. The gaps between theory and practice in selecting nature reserves. Conservation Biology **13**:484-492.

Pullin, A. S., and T. M. Knight. 2001. Effectiveness in conservation practice: Pointers from medicine and public health. Conservation Biology **15**:50-54.

Ramanujam, M. P., and D. Kadamban. 2001. Plant biodiversity of two tropical dry evergreen forests in the Pondicherry region of South India and the role of belief systems in their conservation. Biodiversity and Conservation **10**:1203-1217.

Rodriguez, J. P. 2001. Exotic species introductions into South America: an underestimated threat? Biodiversity and Conservation **10**:1983-1996.

Sheil, D. 2001. Conservation and biodiversity monitoring in the tropics: Realities, priorities, and distractions. Conservation Biology **15**:1179-1182.

Shinwari, Z. K., and S. S. Gilani. 2003. Sustainable harvest of medicinal plants at Bulashbar Nullah, Astore (Northern Pakistan). Journal of Ethnopharmacology **84**:289-298.

Silori, C. S., and B. K. Mishra. 2001. Assessment of livestock grazing pressure in and around the elephant corridors in Mudumalai Wildlife Sanctuary, south India. Biodiversity and Conservation **10**:2181-2195.

Soto, B., S. M. Munthali, and C. Breen. 2001. Perceptions of the forestry and wildlife policy by the local communities living in the Maputo Elephant Reserve, Mozambique. Biodiversity and Conservation **10**:1723-1738.

Tilman, D. 2000. Causes, consequences and ethics of biodiversity. Nature **405**:208-211.

UNEP. 1992. United Nations Environment Program, Convention on biological Diversity. Nairobi, Kenya.

Whitten, T., D. Holmes, and K. MacKinnon. 2001. Conservation biology: a displacement behavior for academia? Conservation Biology **15**:1-3.

World Bank 2001. World development indicators, Washington D.C.

Young, B. E., K. R. Lips, J. K. Reaser, R. Ibanez, A. W. Salas, J. R. Cedeno, L. A. Coloma, S. Ron, E. La Marca, J. R. Meyer, A. Munoz, F. Bolanos, G. Chaves, and D. Romo. 2001. Population declines and priorities for amphibian conservation in Latin America. Conservation Biology **15**:1213-1223.

Appendix 2

APPRECIATING ECOLOGICAL COMPLEXITY: HABITAT CONTOURS AS A CONCEPTUAL LANDSCAPE MODEL

Citation: Fischer, J., Lindenmayer, D. B. and Fazey, I. (in press). *Appreciating ecological complexity: habitat contours as a conceptual landscape model. Conservation Biology.*

A2.0 Abstract

Organisms respond to their surroundings at multiple spatial scales, and different organisms respond differently to the same environment. Existing landscape models, such as the "fragmentation model" (or patch-matrix-corridor model) and the "variegation model", can be limited in their ability to explain complex patterns for different species and across multiple scales. An alternative approach is to conceptualize landscapes as overlaid species-specific habitat contour maps. Key characteristics of this approach are that different species may respond differently to the same environmental conditions, and at different spatial scales. Although similar approaches are being used in ecological modeling, there is much scope for habitat contours as a useful conceptual tool. By providing an alternative view of landscapes, a contour model may stimulate more field investigations stratified on the basis of ecological variables other than human-defined patches and patch boundaries. A conceptual model of habitat contours also may help to communicate ecological complexity to land managers. Finally, by incorporating additional ecological complexity, a conceptual model based on habitat contours may help to bridge the perceived gap between pattern and process in landscape ecology. Habitat contours do not preclude the use of existing landscape models, but should be seen as a complementary approach most suited to heterogeneous human-modified landscapes.

A2.1 Introduction

How we conceptualize landscapes influences how we study and manage biodiversity. Human-modified landscapes are commonly perceived as a mosaic of patches situated within a more or less hostile matrix (e.g. Saunders *et al.* 1991; Forman 1995b). This predominant world view (here termed the "fragmentation model") has often led to an inappropriate neglect of small patches and habitat features not recognised as patches by humans (Joyal *et al.* 2001; Haila 2002). Partly because of this, McIntyre and Barrett (1992) suggested the "variegation model" as an alternative way of conceptualizing modified landscapes. Their model recognized gradients in habitat suitability, and emphasized the complementary value of semi-isolated trees present throughout many Australian grazing landscapes (Barrett *et al.* 1994). We are not aware of other models explicitly designed to conceptualize modified landscapes.

Recent work suggests that the fragmentation and variegation models by themselves are a weak conceptual foundation for conservation research and management in heterogeneous human-modified landscapes. For example, studies on countryside biogeography in Costa Rica demonstrated that a large number of birds, moths, and butterflies persisted in a severely modified tropical landscape, including in areas outside of remnant patches, and with markedly different responses between different organisms (e.g., Daily *et al.* 2001; Ricketts *et al.* 2001; Hughes *et al.* 2002; Horner-Devine *et al.* 2003). Similarly, studies in the Nanangroe grazing landscape of southeastern Australia have highlighted that different species responded to their environment at different scales, and in response to different habitat attributes (Lindenmayer *et al.* 2001a; *et al.* 2004, In press a). Given the range of possible responses by different organisms to a given set of environmental conditions, we feel a new conceptual landscape model is needed that guides our thinking to be less anthropocentric, and that can accommodate species-specific characteristics.

The aim of this paper is to present an alternative conceptual model of biodiversity patterns in heterogeneous human-influenced landscapes. Our approach is based on habitat contours, and as such has similarities with recent quantitative habitat modeling approaches (Guisan and Zimmerman 2000; Guisan *et al.* 2002). Despite these similarities, the primary objective of our paper is not to provide a quantitative modeling approach. Rather, we hope our conceptual model may help to facilitate change in the way ecologists and land managers perceive modified landscapes. We briefly review the fragmentation and variegation models, and then outline a new conceptual model that is based on habitat contours. Potential uses of this model as a research and communication tool are highlighted, and a brief case study on the greater glider (*Petauroides volans*) in the Central Highlands of Victoria (Australia) is used to demonstrate parallels to modern empirical modeling approaches.

A2.2 The fragmentation and variegation models

The fragmentation model is derived from the theory of island biogeography (MacArthur and Wilson 1967). Despite its original focus on true island systems, the theory is often applied to terrestrial ecosystems (Haila 2002). In the 1970s and 1980s, island biogeography formed the basis for a range of guidelines for the design of reserve networks (Diamond 1975; Davey 1989). By the 1990s, the fragmentation paradigm had gained considerable momentum, and the existence of patches embedded within a somewhat hostile matrix was a widely accepted way of conceptualizing modified environments (Haila 2002; Table A2.1). Users of the fragmentation model often define habitat patches on the basis of their vegetation cover and refer to the dominant background patch type as the matrix (Forman and Godron 1986). Although some have emphasised that within-patch conditions can be heterogeneous (e.g., Forman 1995b), in practice, the distinction between patches and the matrix can often lead to a binomial classification of land into habitat and non-habitat (e.g., Vos *et al.* 2001; Westphal and Possingham 2003). This classification can be powerful in some environments – especially for organisms that are totally restricted to certain vegetation types and in landscapes where vegetation occurs in neatly delineated areas (e.g. Sarre *et al.* 1995). However, in some cases, organisms are not tightly related to pre-defined patches of different vegetation types, and the fragmentation model may be overly simplistic.

McIntyre and Barrett (1992) recognised the limitations of the fragmentation model in the New England Tablelands of New South Wales (Australia). They found the density of vegetation cover changed gradually, which made it difficult to delineate "patches" in a meaningful way. On this basis, they suggested an alternative approach to conceptualizing landscapes, i.e., the variegation model. McIntyre and Barrett (1992) considered a variegated landscape was characterised by a gradual change in vegetation cover, which matched the distribution of some fauna, such as woodland birds (Table A2.1). Although the variegation model has received less attention than the fragmentation model, several authors found it a useful alternative to fragmentation (e.g., Ingham and Samways 1996; Fischer and Lindenmayer 2002). McIntyre and Hobbs (1999) further examined the relationship between the fragmentation and variegation models, and suggested there was a temporal component to landscape change. Different landscape alteration states meant landscapes could be classified as intact, variegated, fragmented or relictual, and this temporal sequence corresponded to a decrease in available habitat and an increase in disturbance and edge effects.

The most important difference between the fragmentation and variegation models is their ability to deal with spatial continua in habitat quality or vegetation type. The fragmentation model does not generally deal with gradual changes (apart from edge effects that may extend deeply into a patch; see Laurance 1991b, 2000), whereas the variegation model was developed explicitly to incorporate gradients (Table A2.1). However, neither the fragmentation nor the variegation model can easily deal with species-specific differences in response to a given landscape because both models are based on biophysical patterns deemed to be relevant by humans. Indeed, McIntyre and Hobbs (1999) conceded that many landscape models were somewhat biased towards an anthropocentric perspective of the world.

Some workers have attempted to overcome this problem by labeling species according to their use of a modified landscape – such labels include "forest-interior species" (Tang and Gustafson 1997; Zanette *et al.* 2000), "edge species" (Bender *et al.* 1998; Euskirchen *et al.* 2001), "generalist species" (Andrén 1994; Williams and Hero 2001), or more generally the notion that different species utilize areas between patches to different extents (Andrén *et al.* 1997). Similarly, attempts have been made to describe the matrix in more detail because in some cases labeling it as non-habitat was considered simplistic. Gascon and Lovejoy (1998) considered the likelihood of a given species to move through the matrix depended on the vegetation structure in the matrix. They likened the matrix to a filter with a certain pore size that influenced its permeability (see also Forman 1995b). Although refinements in labeling species or matrix types will sometimes be sufficient to explain ecological patterns in modified landscapes, in some cases it may be useful to start from more neutral grounds and consider a more flexible landscape model. Such a conceptual model is explained below and it may be particularly useful in heterogeneous landscapes, and when multiple species are considered simultaneously.

Table A2.1: Comparison of key characteristics of the fragmentation, variegation and contour-based landscape models (based on Forman and Godron 1986; McIntyre and Barrett 1992; Forman 1995b; Wiens 1995; McIntyre and Hobbs 1999; this paper).

	Fragmentation Model	Variegation Model	Contour model
Features and terminology	patches; matrix; corridors	gradual changes from habitat to non-habitat	peaks and troughs; contour-spacing
Model summary	patches of habitat located in a somewhat hostile matrix of non-habitat; patches may be connected through corridors	gradual changes from habitat to non-habitat; may be related to vegetation cover (e.g., gradual decline in tree density)	each species has its own habitat-contour map with peaks and troughs; spacing of contours represents the change of habitat suitability through space
Degree of realism	high to low, depending on species and landscapes	high to low, depending on species and landscapes	high
Degree of complexity	Low	medium	high
Ability to deal with multiple species	low, unless species are very similar	low, unless species are very similar	high, even if species are very different
Ability to deal with multiple spatial scales	high, can consider the area covered by patches at multiple spatial scales	medium, model deals primarily with gradual changes in woodland vegetation	high, nested contours and choices about contour resolution are possible
Ease of quantifying patterns	high, presence or abundance data need to be collected from patches and the matrix	medium, presence and abundance data needs to be collected across a gradient	low, detailed data on multiple habitat features and species is required at multiple spatial scales
Ease of communication	High	medium	medium

A2.3 A contour-based landscape model

Ecological complexity is difficult to summarize in simple graphical representations, which often form a useful basis for conceptual tools. Multiple species, multiple spatial scales, and a wide range of ecological processes interact in complex ways to give rise to emergent patterns. Humans are inherently bad at conceptualizing continua (Anderson 2001). In the ecological sciences, this is highlighted by many cases in which continua have been broken up into seemingly discrete units to help communication. Examples include landscape alteration states (from intact to relictual; McIntyre and Hobbs 1999), edge vs. forest-interior species and area-sensitive species (Villard 1998), generalists vs. specialists (e.g., McIntyre and Martin 2002), or the core of a bioclimatic domain vs. the remainder of the bioclimatic domain (e.g., Nix 1986). All these entities are extreme points along continua that are segmented to reduce complexity. Although the reduction of complexity is an important characteristic for any model, concept or theory to be widely accepted (Hoffman 2003), we are concerned that oversimplifying ecological complexity in heterogeneous landscapes can have undesired consequences for conservation (e.g., by neglecting key habitat attributes that are not part of human-defined patches). For this reason, we feel a new conceptual landscape model should convey more complexity than previous approaches.

A noteworthy tool for representing spatial continua is that of topographic contour maps. Many scientists and land managers are familiar with topographic maps that summarize a large amount of complex spatial information (elevation, slope, aspect, catchment area) in a simple graphical representation. A similar approach may be useful for conceptualizing landscapes in a conservation context. A landscape can be visualized as a map of overlaid habitat suitability contours for different species (or in the case of many species parallel habitat suitability contours) (Fig. A2.1). The properties of a contour-based landscape model can then be summarized in six key characteristics (see also Table A2.1).

6) Habitat is a species-specific concept. Hence, areas of high suitability for one species do not necessarily coincide with areas of high suitability for another species (Fig. A2.1a).

7) The spatial grain at which species respond to their environment, and at which species abundance will reach peaks and troughs, can vary between species (Kotliar and Wiens 1990). This realization can be translated onto a contour map through different spacing of contours for different species (e.g., species may have densely spaced contours with many peaks and troughs [fine spatial grain] or widely spaced contours with few peaks and troughs [coarse spatial grain; Fig. A2.1b]).

8) Species respond to ecological phenomena at a range of spatial scales (Forman 1964). Spatially nested contours can be represented, and different resolutions of contours can be used to represent responses at different spatial scales. If only the continental scale is of interest, the interval between contours can be somewhat coarse. If microhabitats are of interest, contour intervals will need to be finer.

9) A contour model can be simplified to correspond to the fragmentation model and variegation model where appropriate. The fragmentation model translates into a contour model if contours (a) are spaced widely within a given patch (continuously high suitability), (b) undergo a rapid transition from high suitability to low suitability at the edge of a human-defined "patch", and (c) are widely spaced and indicate low habitat suitability within the matrix (Fig. A2.1c). The variegation model also can be represented through habitat contours, but the "edge zone" of gradually changing contours would take up a much larger area to indicate a more gradual change (Fig. A2.1d). Hence, habitat contours are an extension, not a replacement of existing landscape models.

10) A given species' habitat contour map is the emergent pattern arising from a myriad of ecological processes operating at multiple spatial scales. Knowing a species' habitat contour map does not allow direct conclusions about the processes causing the pattern in species distribution or abundance.

11) A given contour map is set in geographical space and does not have a temporal component. This may require the consideration of multiple 'snapshots' of contour maps at various different times (e.g., some species have changing habitat requirements at different stages of their life cycle [Palomares 2000; Lehtinen *et al.* 2003]).

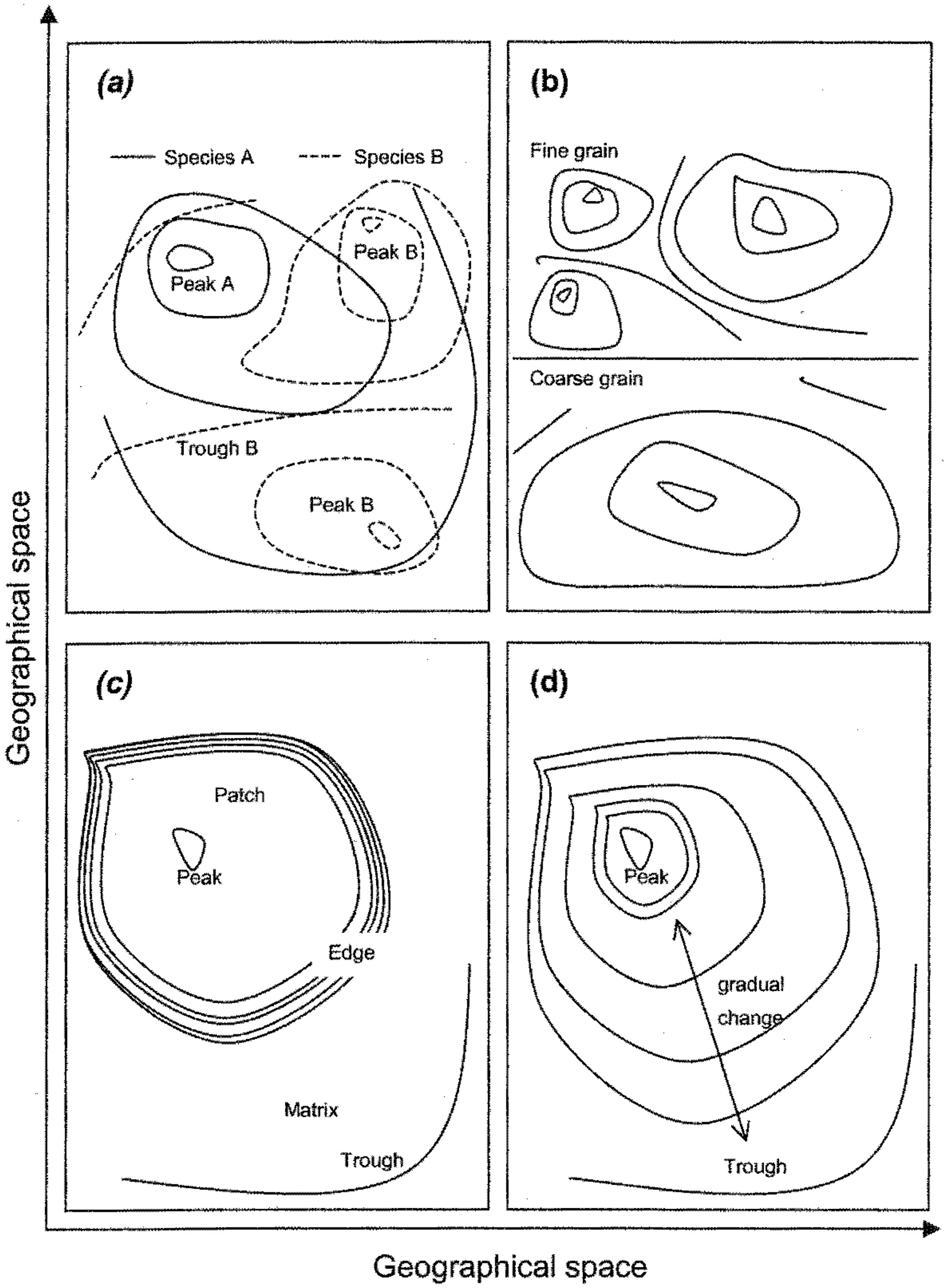

Fig. A2.1: Graphical presentation of a conceptual landscape model based on habitat contours. Key model features are that it (a) allows for species to differ in what constitutes suitable habitat, (b) recognises differences in the spatial grain of species, (c) contains the fragmentation model, and (d) contains the variegation model. Further characteristics and limitations are outlined in the text.

A2.3.1 Four potential uses of habitat contours as a conceptual model

A2.3.1.1 Facilitating change in the way we think about landscapes

The primary usefulness of habitat contours is that they provide an alternative – and potentially more holistic – way of thinking about ecological complexity, especially in human-influenced landscapes. It is becoming increasingly clear that an exclusive focus on patches is not sufficient to conserve many species in many modified landscapes (e.g., Semlitsch and Bodie 1998; Joyal *et al.* 2001; Fischer and Lindenmayer 2002; Luck and Daily 2003), and the variegation model alone is unlikely to be a viable alternative in all situations. A more holistic way of thinking about ecological complexity may improve the design of future research projects as well as communication among scientists and land managers.

A2.3.1.2 Realistic experimental design and interpretation of field studies

Many ecological studies in modified landscapes are centred around a paradigm of fragmentation. Some ecological questions can be answered well on this basis (e.g., for species that are closely associated with human perceptions of "patches"). Other ecological questions would be better addressed with a more flexible approach. This is especially the case when various species are considered simultaneously or when anthropocentric scales are meaningless. For example, Hazell *et al.* (2001) examined landscape use by frogs in an agricultural landscape in southeastern Australia. The occurrence of frog species was related to moisture gradients in the landscape as well as woodland patches. Because factors other than vegetation cover affected the occurrence of frogs, Hazell (2002) concluded landscape models useful for mammals or birds may be of limited value for frogs. Clearly, considering a priori the limitations of pre-defined patches to reflect all species' habitat requirements will be useful in many landscapes.

Considering different species and spatial scales presents a challenge to the statistical design of ecological studies. Patches lend themselves to a rigorous stratification. However, other ecological variables can also be used as the basis of a sound experimental design, such as aspect, topographic position or habitat structure in a certain area (e.g., Fischer *et al.* 2004). In addition, a contour model highlights the importance of incorporating multiple spatial scales, especially (but not only) if a range of different species are considered. A range of tools are available to study multiple spatial scales (summarized in Meentemeyer and Box 1987; Mackey and Lindenmayer 2001). Although we focused largely on the landscape scale (e.g., tens of square kilometres), the inherent ability of a contour model to incorporate multiple scales means it also may incorporate larger, or indeed smaller, scales. At least in the first instance, considering landscapes or regions as overlaid species-specific contour-maps may be a better way of thinking about ecological complexity than considering them as mosaics of patches. If it is decided that other, simpler landscape models adequately describe the patterns and processes of interest, it may be preferable to revert to a simpler model (see Table A2.1 for trade-offs between realism and simplicity).

A2.3.1.3 Communication between different strands of ecology

By acting as a communication tool, the habitat contours model may help bridge the perceived gap between pattern and process in landscape ecology (Hobbs 1997). Wu and Hobbs (2002) argue that landscape ecologists who focus on emergent patterns have made little progress in relating emergent patterns to ecological processes. Similarly, studies that investigate processes directly have had only limited success in applying their findings to real landscapes. This may be partly because the traditional reductionist goal of focusing on smaller and smaller scales (Meentemeyer and Box 1987) may be in stark contrast with landscape-scale research and conservation management. On this basis, Hobbs (1997) argued that linking pattern and process was an important requirement for landscape ecology to prove itself as a useful science.

A contour-based landscape model may be a useful tool to generate spatially explicit hypotheses, which may be tested with respect to patterns and processes (Fig. A2.2). A contour-based landscape model may be built from first principles on the basis of known ecological processes (bottom-up approach). This approach is compatible with the ideas of Wiens (1995), who suggested visualizing space as cost-benefit contours, and it may lead to testable predictions of likely emergent patterns for one or multiple species. Conversely, large-scale field studies may be used to generate maps of known emergent patterns and create hypotheses with respect to potential ecological processes that may have caused these patterns (top-down approach; see case study on the greater glider below). Thus, a contour model may be a possible starting point to aid communication between traditional reductionist science and more pattern-based field research in landscape ecology.

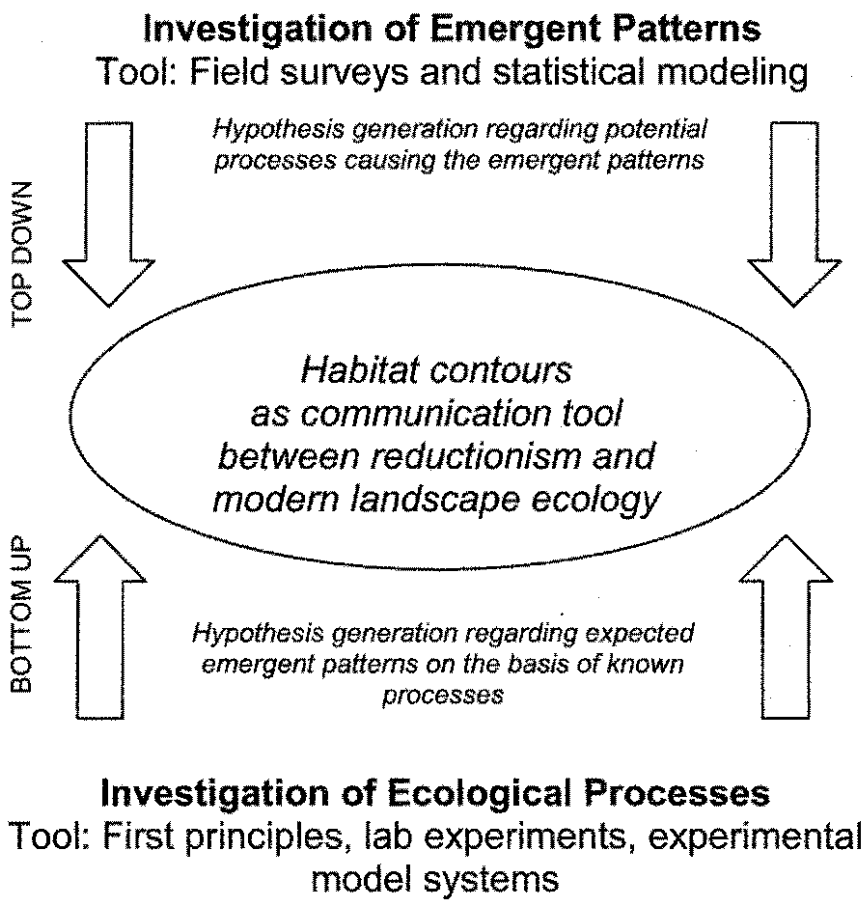

Fig. A2.2: Graphical representation of how a conceptual model of habitat contours may assist communication between traditional reductionist science and pattern-based landscape ecology.

A2.3.1.4 Communication with land managers and land-use planning

Conceptual models are vital to communicate ideas among scientists and land managers. The fragmentation model has been greatly successful as a communication tool. For example, general principles such as "a bigger patch is better for biodiversity conservation than a smaller patch" (e.g., Diamond 1975) are widely accepted among land managers, such as Australian farmers (e.g., Bennett *et al.* 2000). Although general principles based on traditional landscape models have helped conservation in many modified landscapes (e.g., large patches may be targeted for exclusion from grazing) some conservation issues cannot be adequately addressed from the basis of the fragmentation (or variegation) model. For example, several endangered lizard species in eastern Australia are reliant on grasslands (e.g., Osborne *et al.* 1995; Dorrough and Ash 1999; Milne and Bull 2000). However, native grasslands are rarely conceptualised as patches, and as a result surveys of farmers have shown that grasslands are not highly valued for conservation (unlike clearly recognisable patches of trees) (Williams and Cary 2001). Exploring ecological complexity with land managers through the use of a contour-based landscape model may be helpful because the simple analogy of topographic maps helps explain why it is that whole landscapes need to be managed, rather than certain patches in isolation. As a result, the focus of conservation practices in some modified landscapes may be more successfully targeted to the requirements of species of concern and will be more likely to simultaneously consider a wide range of organisms with different habitat requirements. In this context, hands-on attempts at habitat contour mapping may be of direct practical value. For example, in a planning context, existing maps or aerial photographs may form the background for actual attempts to draw possible habitat relationships for various species. Although the direct quantification of contour lines often will be impossible due to a lack of empirical data, the very process of thinking about species-specific continua may be a useful exercise to visualize the complexity of ecological systems – as opposed to seeing them as a patchwork of neatly delineated habitat patches, or one-way habitat gradients.

A2.3.2 Making the link to quantitative ecological modeling

Predicting habitat suitability through the use of quantitative models (empirical or non-empirical) has been an important aspect of ecological modeling for some time. There are many different approaches to modeling habitat suitability for one or several species (e.g., Guisan and Zimmermann 2000; Guisan *et al.* 2002; Ohmann and Gregory 2002; Zaniewski *et al.* 2002). Here, we use a case study to illustrate parallels and possible future connections between the conceptual model described above and empirical investigations.

A2.3.2.1 The greater glider in the Victorian Central Highlands

The greater glider is a forest-dependent arboreal marsupial, and has been the target of a range of ecological studies in a 6700 ha wood production block in the Central Highlands of Victoria (Lindenmayer 2002). A key part of this work has been to identify the habitat requirements of the species. To establish habitat associations for the species, more than 150 field sites were surveyed throughout the montane ash forests of the Central Highlands. These sites covered a broad range of environmental conditions (Lindenmayer *et al.* 1990, 1995). Numerous measures of vegetation structure and plant species composition were gathered at the survey sites. Logistic regression analysis showed that the presence of the greater glider was related to two habitat attributes. The species was significantly more likely to occur in old growth stands and stands characterized by large numbers of trees with hollows.

The two significant explanatory variables in the regression were mapped spatially from aerial photographs and stored in a GIS database. The habitat model was then linked to spatial data for the two attributes to make a prediction of the probability of occurrence of the greater glider throughout the entire Ada Forest Block (6700 ha), an area designated for wood production (Fig. A2.3; see Lindenmayer *et al.* 1995 for more details). Although Fig. A2.3 shows spatial predictions based on mean probability values, it also would be possible to make predictions based on values for the upper and lower bounds of the 95% confidence interval associated with the mean.

The statistical relationship was based on significant explanatory habitat attributes, and did not consider other ecological variables that may also affect the probability of detecting the greater glider. Such variables may include predation by large forest owls, parasites, the spatial juxtaposition of suitable habitat and other factors. Habitat suitability, here represented by contours of occurrence probability, represents the potential distribution of the target species in a given area whereas other factors like those listed above may further limit the species' actual occurrence on the ground.

Spatial patterns of animal distribution are necessarily dynamic. For example, patches of forest, if undisturbed, may eventually reach a stage of maturity where they would provide suitable habitat for the greater glider. Therefore, a spatial prediction of suitable habitat now may be quite different from that made in 100 years as some forest stands age and others are logged. Similarly, the collapse of hollow trees also will lead to temporal changes in habitat suitability (Lindenmayer *et al.* 1997). In this case, both these changes in the significant explanatory habitat attributes of the greater glider can be tracked by aerial mapping, and it would be possible to produce contour maps of the predicted probability of occurrence at regular intervals in the future.

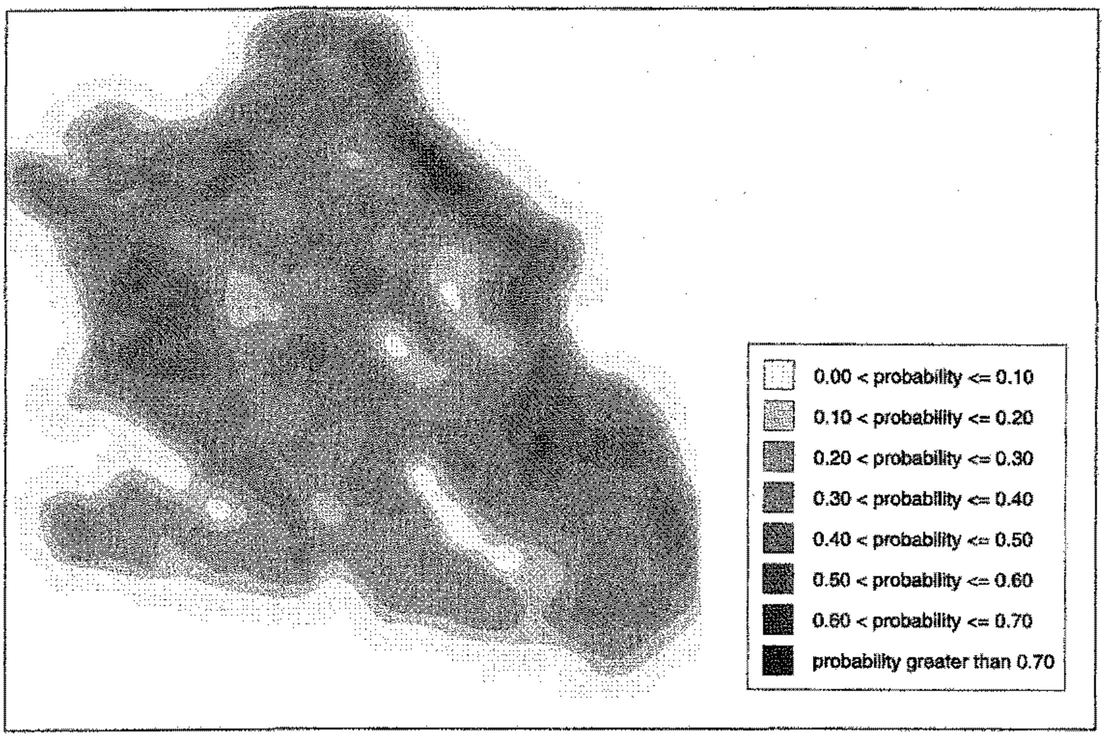

Fig. A2.3: The predicted probability of detecting the greater glider in the Ada Forest Block (6700 ha) in the Central Highlands of Victoria, Australia.

A2.3.2.2 Potential future applications of empirical modeling

The above case study demonstrated clear parallels between the conceptual model we proposed and existing empirical modeling approaches. There is ample scope to expand current modeling approaches to examine the relationships between biodiversity and environmental variables in more detail. Two key areas for future work may include: (1) the consideration of multiple species simultaneously to identify groups of species with similar responses, and species with different responses (see also Vos *et al.* 2001), and (2) the investigation of relevant scenarios of habitat change and their effect on predicted habitat suitability maps (e.g., Schröder 2000). Together, these two areas for future work may result in mapped predictions of future occurrence patterns for various groups of organisms under different management regimes, and thus could provide useable scientific input for scenario planning as a conservation tool (Peterson *et al.* 2003).

A2.4 Conclusions

Concepts like the contour model can be useful to facilitate a transformation in the way we perceive ecological complexity. We acknowledge there are obvious limitations to representing the contour model in diagrammatic form – e.g., it is difficult to imagine that dozens of parallel habitat contour maps for different species will ever actually be drawn. Similarly, the data required for quantification of the contour model often will be unavailable. However, these limitations do not preclude the usefulness of habitat contours as a tool for generating hypotheses, communicating ecological complexity, and changing the way scientists and land managers think about landscapes.

Metapopulation theory is an interesting analogy in the usefulness of concepts to instigate a different way of thinking (e.g., Hanski and Simberloff 1997). Although there are many quantitative examples of metapopulation modeling (e.g., Lindenmayer and Possingham 1996; Vos *et al.* 2001), an important contribution of metapopulation theory to conservation has been its ability to act as a conceptual tool (e.g., Telfer *et al.* 2001). Because the theory is fairly easy to understand at a generic level, it has been taken up readily outside the academic community (Stinchcombe *et al.* 2002), and has successfully changed the way practitioners and non-ecologists perceive populations and landscapes. As a result, in parts of the United Kingdom, it is now more widely accepted that a landscape scale approach is needed to achieve effective conservation outcomes (I. Fazey, personal observation).

The way we think about human-influenced landscapes affects which research we deem to be important, how we communicate ecological complexity, and which conservation strategies are considered to be most effective. In many landscapes, the fragmentation paradigm will be overly simplistic, and the variegation model alone is unlikely to provide a satisfactory alternative in all situations. Habitat contours may be a flexible way of thinking about and planning for biodiversity conservation in heterogeneous landscapes.

A2.5 Acknowledgments

We are grateful to many colleagues who have inspired us to think about how to conceptualize the ecological complexity of landscapes, including A. Manning, A. Gilmore, and D. Hazell. Comments by four anonymous referees greatly helped to clarify parts of the paper.

A2.6 References

Anderson, J. L. 2001. Stone-age minds at work on 21st century science. Conservation Biology in Practice **2**:20-27.

Andrén, H. 1994. Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat - a review. Oikos **71**:355-366.

Andrén, H., A. Delin, and A. Seiler. 1997. Population response to landscape changes depends on specialization to different landscape elements. Oikos **80**:193-196.

Barrett, G. W., H. A. Ford, and H. F. Recher. 1994. Conservation of woodland birds in a fragmented rural landscape. Pacific Conservation Biology **1**:245-256.

Bender, D. J., T. A. Contreras, and L. Fahrig. 1998. Habitat loss and population decline: a meta-analysis of the patch size effect. Ecology **79**:517-529.

Bennett, A. F., S. Kimber, and P. Ryan 2000. Revegetation and wildlife. Research report 2/00. Bushcare National Projects Reserach and Development Program. Environment Australia, Canberra.

Daily, G. C., P. R. Ehrlich, and G. A. Sanchez-Azofeifa. 2001. Countryside biogeography: Use of human-dominated habitats by the avifauna of southern Costa Rica. Ecological Applications **11**:1-13.

Davey, S. M. 1989. Thoughts towards a forest wildlife management strategy. Australian Forestry **52**:56-67.

Diamond, J. M. 1975. The island dilemma: lessons of modern biogeographic studies of for the design of natural reserves. Biological Conservation **7**:129-145.

Dorrough, J., and J. E. Ash. 1999. Using past and present habitat to predict the current distribution and abundance of a rare cryptic lizard, Delma impar (Pygopodidae). Australian Journal of Ecology **24**:614-624.

Euskirchen, E. S., J. Q. Chen, and R. C. Bi. 2001. Effects of edges on plant communities in a managed landscape in northern Wisconsin. Forest Ecology and Management **148**:93-108.

Fischer, J., D. B. Lindenmayer, and A. Cowling. 2004. The challenge of managing multiple species at multiple scales: reptiles in an Australian grazing landscape. Journal of Applied Ecology:In press.

Fischer, J., and D. B. Lindenmayer. 2002. The conservation value of paddock trees for birds in a variegated landscape in southern New South Wales. 1. Species composition and site occupancy patterns. Biodiversity and Conservation **11**:807-832.

Forman, R. T. 1964. Growth under controlled conditions to explain the hierarchical distribution of a moss, *Tetrapis pellucida*. Ecological Monographs **34**:1-25.

Forman, R. T. 1995. Land mosaics: the ecology of landscapes and regions. Cambridge University Press, New York.

Forman, R. T. T., and M. Godron 1986. Landscape ecology. John Wiley and Sons, New York.

Gascon, C., and T. E. Lovejoy. 1998. Ecological impacts of forest fragmentation in central Amazonia. Ecology **101**:273-280.

Guisan, A., T. C. J. Edwards, and T. Hastie. 2002. Generalized linear and generalized additive models in studies of species distributions: setting the scene. Ecological Modelling **157**:89-100.

Guisan, A., and N. E. Zimmermann. 2000. Predictive habitat distribution models in ecology. Ecological Modelling **135**:147-186.

Haila, Y. 2002. A conceptual genealogy of fragmentation research: From island biogeography to landscape ecology. Ecological Applications **12**:321-334.

Hanski, I., and D. Simberloff. 1997. The metapopulation approach, its history, conceptual domain and application to conservation. Pages 5-26 in I. Hanski, and M. E. Gilpin, editors. Metapopulation biology. Academic Press, San Diego.

Hazell, D. 2002. Habitat use and conservation of pond-breeding frogs in an agricultural landscape. Ph.D. Thesis. Centre for Resource and Environmental Studies, The Australian National University, Canberra.

Hazell, D., R. Cunnningham, D. Lindenmayer, B. Mackey, and W. Osborne. 2001. Use of farm dams as frog habitat in an Australian agricultural landscape: factors affecting species richness and distribution. Biological Conservation **102**:155-169.

Hobbs, R. 1997. Future landscapes and the future of landscape ecology. Landscape and Urban Planning **37**:1-9.

Hoffmann, R. 2003. Why buy that theory? American Scientist **91**:9-11.

Horner-Devine, M. C., G. C. Daily, P. R. Ehrlich, and C. L. Boggs. 2003. Countryside biogeography of tropical butterflies. Conservation Biology **17**:168-177.

Hughes, J. B., G. C. Daily, and P. R. Ehrlich. 2002. Conservation of tropical forest birds in countryside habitats. Ecology Letters **5**:121-129.

Ingham, D. S., and M. J. Samways. 1996. Application of fragmentation and variegation models to epigaeic invertebrates in South Africa. Conservation Biology **10**:1353-1358.

Joyal, L. A., M. McCollough, and M. L. Hunter. 2001. Landscape ecology approaches to wetland species conservation: a case study of two turtle species in southern Maine. Conservation Biology **15**:1755-1762.

Kotliar, N. B., and J. A. Wiens. 1990. Multiple scales of patchiness and patch structure - a hierarchical framework for the study of heterogeneity. Oikos **59**:253-260.

Laurance, W. F. 1991. Edge effects in tropical forest fragments: application of a model for the design of nature reserves. Biological Conservation **57**:205-219.

Laurance, W. F. 2000. Do edge effects occur over large spatial scales? Trends in Ecology and Evolution **15**:134-135.

Lethinen, R. M., J.-B. Ramanamanjato, and J. G. Raveloarison. 2003. Edge effects and extinction proneness in a herpetofauna from Madagascar. Biodiversity and Conservation **12**:1357-1370.

Lindenmayer, D. B. 2002. Gliders of Australia. A natural history. University of New South Wales Press, Sydney.

Lindenmayer, D. B., and H. P. Possingham. 1996. Ranking Conservation and Timber Management Options For Leadbeaters Possum in Southeastern Australia Using Population Viability Analysis. Conservation Biology **10**:235-251.

Lindenmayer, D. B., R. B. Cunningham, M. T. Tanton, A. P. Smith, and H. A. Nix. 1990. The habitat requirements of the Mountain Brushtail Possum and the Greater Glider in the montane ash-type eucalypt forests of the Central Highlands of Victoria. Australian Wildlife Research **17**:467-478.

Lindenmayer, D. B., K. Ritman, R. B. Cunningham, J. D. B. Smith, and D. Horvath. 1995. A method for predicting the spatial distribution of arboreal marsupials. Wildlife Research **22**:445-456.

Lindenmayer, D. B., R. B. Cunningham, and C. F. Donnelly. 1997. Tree decline and collapse in Australian forests: implications for arboreal marsupials. Ecological Applications **7**:625-641.

Lindenmayer, D. B., R. B. Cunningham, C. MacGregor, C. Tribolet, and C. F. Donnelly. 2001. A prospective longitudinal study of landscape matrix effects on fauna in woodland remnants. I. Experimental design and baseline data. Biological Conservation **101**:157-169.

Luck, G. W., and G. C. Daily. 2003. Tropical countryside bird assemblages: Richness, composition, and foraging differ by landscape context. Ecological Applications **13**:235-247.

MacArthur, R. H., and E. O. Wilson 1967. The theory of island biogeography. Princeton University Press, Princeton, New Jersey.

Mackey, B. G., and D. B. Lindenmayer. 2001. Towards a hierarchical framework for modelling the spatial distribution of animals. Journal of Biogeography **28**:1147-1166.

McIntyre, S., and G. W. Barrett. 1992. Habitat variegation, an alternative to fragmentation. Conservation Biology **6**:146-147.

McIntyre, S., and R. Hobbs. 1999. A framework for conceptualizing human effects on landscapes and its relevance to management and research models. Conservation Biology **13**:1282-1292.

McIntyre, S., and T. G. Martin. 2002. Managing intensive and extensive land uses to conserve grassland plants in sub-tropical eucalypt woodlands. Biological Conservation **107**:241-252.

Meentemeyer, V., and E. O. Box. 1987. Scale effects in landscape studies. Pages 15-34 in M. G. Turner, editor. Landscape heterogeneity and disturbance. Springer-Verlag, New York.

Milne, T., and C. M. Bull. 2000. Burrow choice by individuals of different sizes in the endangered pygmy blue tongue lizard *Tiliqua adelaidensis*. Biological Conservation **95**:295-301.

Nix, H. A. 1986. A biogeographic analysis of the Australian elapid snakes. Pages 4-15 in R. Longmore, editor. Atlas of elapid snakes. Australian flora and fauna series number 7. Australian Government Publishing Service, Canberra.

Ohmann, J. L., and M. J. Gregory. 2002. Predictive mapping of forest composition and structure with direct gradient analysis and nearest-neighbor imputation in coastal Oregon, U.S.A. Canadian Journal of Forest Research **32**:725-741.

Osborne, W., K. Kukolic, and S. Jones. 1995. Management of threatened vertebrates in native grasslands: a case of clutching at straws? Pages 89-95 in S. Sharp, and R. Rehwinkel, editors. Management of relict lowland grasslands - proceedings of a workshop and public seminar. ACT Parks and Conservation Service, Canberra.

Palomares, F., M. Delibes, P. Ferreras, J. M. Fedriani, J. Calazada, and E. Revilla. 2000. Iberian lynx in a fragmented landscape: predispersal, dispersal, and postdispersal habitats. Conservation Biology **14**:809-818.

Peterson, G. D., G. S. Cumming, and S. R. Carpenter. 2003. Scenario planning: a tool for conservation in an uncertain world. Conservation Biology **17**:358-366.

Ricketts, T. H., G. C. Daily, P. R. Ehrlich, and J. P. Fay. 2001. Countryside biogeography of moths in a fragmented landscape: Biodiversity in native and agricultural habitats. Conservation Biology **15**:378-388.

Sarre, S., G. T. Smith, and J. A. Meyers. 1995. Persistence of two species of gecko (*Oedura reticulata* and *Gehrya variegata*) in remnant habitat. Biological Conservation **71**:25-33.

Saunders, D. A., R. J. Hobbs, and C. R. Margules. 1991. Biological consequences of ecosystem fragmentation: a review. Conservation Biology **5**:18-32.

Schröder, B. 2000. Zwischen Naturschutz und theoretischer Oekologie: Modelle zur Habitateignung und raeumlichen Populationsdynamik fuer Heuschrecken im Niedermooor. Institut fuer Geographie und Geooekologie der Technischen Universitaet Braunschweig, Braunschweig, Germany.

Semlitsch, R. D., and J. R. Bodie. 1998. Are small, isolated wetlands expendable? Conservation Biology **12**:1129-1133.

Stinchcombe, J., L. C. Moyle, B. R. Hudgens, P. L. Bloch, S. Chinnadurai, and W. F. Morris. 2002. The influence of the academic conservation biology literature on endangered species recovery plannning. Conservation Ecology **6**:15. [online] URL: http://www.consecol.org/vol16/iss12/art15.

Tang, S. M., and E. J. Gustafson. 1997. Perception of scale in forest management planning: Challenges and implications. Landscape and Urban Planning **39**:1-9.

Telfer, S., A. Holt, R. Donaldson, and X. Lambin. 2001. Metapopulation processes and persistence in remnant water vole populations. Oikos **95**:31-42.

Villard, M.-A. 1998. On forest-interior species, edge avoidance, area sensitivity, and dogmas in avian conservation. The Auk **115**:801-805.

Vos, C. C., J. Verboom, P. F. M. Opdam, and C. J. F. Ter Braak. 2001. Toward ecologically scaled landscape indices. The American Naturalist **157**:24-41.

Westphal, M. I., and H. P. Possingham. 2003. Applying a decision-theory framework to landscape planning for biodiversity: Follow-up to Watson *et al.* Conservation Biology **17**:327-329.

Wiens, J. A. 1995. Landscape mosaics and ecological theory. Pages 1-26 in L. Hansson, L. Fahrig, and G. Merriam, editors. Mosaic landscapes and ecological processes. Chapman & Hall, London.

Williams, K., and J. Cary. 2001. Perception of native grassland in southeastern Australia. Ecological Management and Restoration **2**:139-144.

Williams, S. E., and J. M. Hero. 2001. Multiple determinants of Australian tropical frog biodiversity. Biological Conservation **98**:1-10.

Wu, J. G., and R. Hobbs. 2002. Key issues and research priorities in landscape ecology: An idiosyncratic synthesis. Landscape Ecology **17**:355-365.

Zanette, L., P. Doyle, and S. M. Tremont. 2000. Food shortage in small fragments: Evidence from an area- sensitive passerine. Ecology **81**:1654-1666.

Zaniewski, A. E., A. Lehmann, and J. M. Overton. 2002. Predicting species spatial distributions using presence-only data: a case study of native New Zealand ferns. Ecological Modelling **157**:261-280.

APPENDIX 3

MAKING THE MATRIX MATTER: CHALLENGES IN AUSTRALIAN GRAZING LANDSCAPES

*Citation: Fischer, J., Fazey, I., Briese, R. and Lindenmayer, D. B. (*In press*). Making the matrix matter: Challenges in Australian grazing landscapes. Biodiversity and Conservation.*

A3.0 Abstract

Many ecological theories are based on the concept of patches. Patches are a useful starting point for conservation efforts, but a focus on patches alone will not always achieve desired conservation outcomes. Conservation strategies in the grazing landscapes of south-eastern Australia suggest that large patches of trees are widely regarded as "habitat" while other forms of habitat are largely ignored. We provide data on birds and reptiles from the Nanangroe grazing landscape that illustrate the potential habitat value of areas located between large patches of trees – i.e. the matrix. Despite evidence on its potential value, present conservation strategies rarely consider the matrix. Possible reasons for this bias relate to the economics of farming and the history of land use, the current environmental law framework, and also the reluctance of ecologists to study the matrix. More scientific evidence on the role of the matrix will be crucial if conservation strategies are to consider not only patches, but entire landscapes. However, for science to be relevant to land management, there is a need for new research approaches. First, an increased consideration of environmental policy and law will increase the likelihood of scientific findings being adopted by policy makers. Second, at an applied level, more practical on-ground research into farming practices and clearer communication are necessary to achieve more sustainable matrix management in Australian grazing landscapes.

A3.1 Introduction

The concept of "patches" is central to many ecological theories (Stephens and Krebs 1986; Wiens *et al.* 1993; Antrop 2001) and conservation strategies (e.g. Diamond 1975). At the global scale, networks of large patches that are reserved from production (e.g. national parks) are widely regarded as an important backbone of successful biodiversity conservation (Diamond 1975; Higgs and Usher 1980; Kitchener *et al.* 1982; Margules and Pressey 2000). Similarly, at the landscape scale, patches of remnant vegetation are considered important for conservation efforts in modified landscapes (Saunders *et al.* 1987). However, an exclusive focus on patches of trees may lead to suboptimal conservation outcomes in some modified landscapes. This is because areas outside patches – i.e. the "matrix" – often play an important complementary role for a range of organisms (Daily 2001; Luck and Daily 2003).

In this paper, we consider a case study from a grazing landscape in south-eastern Australia, and highlight key ecological functions of the matrix for birds and reptiles. In addition, we discuss potential barriers to improved matrix management and how they may be overcome. We conclude that for conservation biology to make a useful contribution to improved matrix management, more interdisciplinary investigations are needed. For example, an increased understanding of environmental law will help influence the environmental policy framework, and detailed on-ground research examining the effect of farming practices on matrix condition will help identify more sustainable management regimes. Finally, the clear communication of ecological complexity will be important to highlight that habitat is more than large patches of trees, and that a "soft matrix" can provide habitat for a range of organisms.

A3.2 Reptiles and birds in the Nanangroe grazing landscape

The Nanangroe area is located in southern New South Wales, south-eastern Australia (34°58'S, 148°29'E). It has a temperate climate with relatively hot summers (daily maxima often above 30° C), and cool winters with occasional night-time frost events. Prior to European settlement, much of the Nanangroe area was covered by native eucalypt woodlands, particularly those dominated by Yellow Box/Blakely's Red Gum (*Eucalyptus melliodora/E. blakelyi*) and White Box (*E. albens*; Yates and Hobbs 1997). Today, native tree cover is reduced to approximately 15%, and most cover takes the form of relatively small woodland remnants (generally less than 15 hectares), or semi-isolated trees in the pastures (termed "paddock trees"). Isolation distances between habitat remnants or semi-isolated trees range from dozens to hundreds of metres. The area is best described as variegated (*sensu* McIntyre and Barrett 1992; McIntyre and Hobbs 1999). That is, the matrix between substantial woodland remnants is characterised by gradual changes in vegetation cover and scattered paddock trees rather than sharp boundaries.

The Nanangroe grazing area incorporates several private grazing properties, covering a total area of approximately 200 km^2. Several bird and reptile surveys were conducted over the last four years (Tables A3.1, A3.2). Birds were surveyed using point count techniques (Table A3.1). Reptiles were surveyed using pitfall trapping and active searching at 144 ten by ten metre plots, and artificial coverboards (*sensu* Grant *et al.* 1991) at 125 additional locations (Lindenmayer *et al.* 2001a; Fischer *et al.*, unpublished data) covering a range of environments. Each fauna survey was accompanied by surveys of habitat structure, which included the quantification of fallen timber, rocks and various vegetation attributes.

Table A3.1 Synthesis of recent research on birds in the Nanangroe area that demonstrated the benefits of a soft matrix for birds.

Research topic	Area surveyed	Methods	Key findings	Interpretation	References
Use of small patches by birds	The entire Nanangroe study area	105 patches surveyed using point interval count method with multiple observers (Cunningham *et al.* 1999; Lindenmayer *et al.*, unpublished data)	91 species detected in patches between 0.4 ha and 16 ha; 74 species used patches smaller than 1 hectare	Small patches were a valuable complement to large patches. Because by themselves small patches cannot support many bird species, small patches must have been part of a habitat continuum for many bird species.	Fischer and Lindenmayer (2002a)
Use of paddock trees by birds	Two properties (appr. 10 km^2)	70 paddock trees sites (single trees and small clumps of trees) surveyed by one observer for 20 min at a time	Over 40 species of birds were observed to use paddock trees	A substantial proportion of bird species is not restricted to woodland patches, and may benefit from scattered trees in the matrix.	Fischer and Lindenmayer (2002b)
Paddock trees as stepping stones for birds	As above	As above; but arrival and departure direction of birds was recorded	Birds tended to depart in the direction opposite to their arrival direction; some species followed areas where trees were scattered relatively densely	Paddock trees may serve a stepping stone purpose for some birds.	Fischer and Lindenmayer (2002c)

Table A3.2 Overview of the reptiles observed in the Nanangroe area (Lindenmayer *et al.* 2001a; Fischer *et al.* unpublished data). The table is a subjective summary that indicates which species used woodland patches or the matrix respectively. An asterisk indicates species that were observed too infrequently to comment on their use of the matrix.

Species	Use of landscape elements	Important habitat features in the matrix
Olive Legless Lizard (*Delma inornata*)	Largely matrix	Half-buried rocks were used for shelter
Bearded Dragon (*Pogona barbata*)	Largely matrix	Wooden fenceposts and logs on the ground were used for basking
Striped Skink (*Ctenotus robustus*)	Largely matrix but to some extent patches	Logs, rocks and grass tussocks were used for shelter
Common Long-necked Tortoise (*Chelodina longicollis*)	Observed rarely, only in matrix	*
Tree Skink (*Egernia striolata*)	Observed rarely, only in matrix	Observed on several occasions sheltering in a large decaying log, or under a rock
Dwyer's Snake (*Suta spectabilis dwyeri*)	Observed rarely, only in matrix	*
Cunningham's Skink (*Egernia cunninghami*)	Observed rarely, both in patches and matrix	Observed to shelter under building debris in the matrix, and in boulder outcrops in a patch
Southern Water Skink (*Eulamprus heatwolei*)	Patches and matrix	Large rocks along watercourses used for basking
Four-fingered Skink (*Carlia tetradactyla*)	Patches and matrix	Logs and shrubs were used for shelter
Boulenger's Skink (*Morethia boulengeri*)	Patches and matrix	Rocks and logs were used for shelter
Jacky Lizard (*Amphibolurus muricatus*)	Patches and matrix	*
Lace Monitor (*Varanus varius*)	Patches and matrix	Trees used as refuge, especially large hollows in White Box
Red-bellied Black Snake (*Pseudechis porphyriacus*)	Patches and matrix	*
Eastern Brown Snake (*Pseudonaja textilis*)	Patches and matrix	*
Red-throated Skink (*Bassiana platynota*)	Observed rarely, usually in patches	*
Marbled Gecko (*Christinus marmoratus*)	Largely patches	Granite outcrops and exfoliating rocks used for shelter
Stone Gecko (*Diplodactylus vittatus*)	Largely patches	*
Copper-tailed Skink (*Ctenotus taeniolatus*)	Largely patches	*
Three-toed Skink (*Hemiergis decresiensis*)	Largely patches	*

A3.3 Ecological functions of the matrix

Lindenmayer and Franklin (2002) argued there were two different, but related definitions of what constituted the "matrix": (1) the area outside reserves, or (2) the area between patches of remnant vegetation. The Nanangroe landscape is a production landscape, and as such, the entire study area is part of the matrix according to the first definition. For the remainder of this paper, we use the second definition of the matrix – i.e. we are concerned with the areas between patches of native woodland. The delineation of patch boundaries in a variegated landscape is by necessity somewhat subjective. In Nanangroe, we used aerial photographs to delineate patch boundaries, and patch sizes thus obtained ranged between 0.4 and 16 ha.

To describe the nature of the matrix, the terms "soft" and "heterogeneous" are used in this paper to reflect relatively high complexity of vegetation structure, and ground cover (see Franklin 1993). While there was substantial variability of these attributes throughout the Nanangroe landscape (Fischer *et al.*, unpublished data), the overall heterogeneity of the Nanangroe landscape was high compared to similar farming landscapes in the region (e.g. relatively high levels of fallen timber, rock cover, some native shrubs).

A3.3.1 A soft matrix can provide habitat

The matrix in the Nanangroe landscape was characterised by a relatively high amount of heterogeneity expressed through the presence of scattered trees, fallen timber, rocky patches and areas with relatively tall grass (mostly introduced species). A key function of the matrix was to provide habitat for several species of birds and reptiles. For example, more than 90 species of birds were observed in the Nanangroe study area (Table A3.1; Lindenmayer *et al.*, unpublished data), although only approximately 15% of the original woodland cover remained. Most of these species were not restricted to large woodland patches, and even small patches (< 1 ha) contributed highly to cumulative species richness across the entire study area (Table A3.1). In addition, during a survey of scattered trees in the matrix, we found that almost every second species of bird in the study area used the matrix (Table A3.1). Thus, the variegated nature of the landscape and its relatively soft matrix contributed substantially to local bird diversity. This was because many species of birds used very small woodland patches and scattered trees in the matrix as part of a larger habitat mosaic (Table A3.1).

The matrix also was used by nearly three quarters of the reptile species recorded in the Nanangroe area, and features such as rocks, logs and other tree-related habitat attributes were important refuge sites for many species (Table A3.2). Other studies in a range of different ecosystems have also shown that the matrix should not be neglected as potential habitat (reviewed by Lindenmayer and Franklin 2002). In northern Victoria, Lumsden *et al.* (2002) demonstrated that most bat species utilised the matrix for foraging, although some species were reliant on larger forest patches for roosting sites. The matrix may be equally important to complement existing patches in very different environments. For example, Fernandéz-Juricic (2000) found that wooded streets in the city of Madrid (Spain) contributed substantially to urban bird diversity. Similarly, selectively logged forests in northern Borneo have the potential to support a diverse array of butterfly species, provided habitat heterogeneity is maintained (Hamer *et al.* 2003). The ability of species to persist in the matrix can be a key factor in determining their extinction proneness (Laurance 1991a; Gascon *et al.* 1999). Hence, the maintenance of a wide range of different habitat features throughout the matrix can be important for the maintenance of regional biodiversity.

While some initial habitat relationships have been established in Australian grazing landscapes (e.g. Tables A3.1, A3.2), there is ample scope for more detailed research. A possible guiding framework may be "countryside biogeography", which recognises the need to study and manage biodiversity in human-modified landscapes (e.g. Daily *et al.* 2001; Luck and Daily 2003). A wide range of issues can be addressed using this framework. For example, a series of studies in the Las Cruces farming landscape in southern Costa Rica provides clues as to what sorts of research questions may be worth asking in Australian grazing landscapes (Daily 1999; 2001). Examples include an explicit assessment of the effect of landscape context on biodiversity (Ricketts *et al.* 2001; Horner-Devine *et al.* 2003; Luck and Daily 2003), and an appraisal of how the matrix is used by various species. For example, it can be important to know if the matrix can provide breeding habitat for native species, or if it is mainly used for foraging (e.g. in the case of birds; see Hughes *et al.* 2002).

A3.3.2 A soft matrix can enhance connectivity

An important consideration for regional conservation is to maintain habitat connectivity to facilitate movement between areas of habitat and thus maintain viable populations (Saunders and de Rebeira 1991; Taylor *et al.* 1993; Ferreras 2001). Traditionally, connectivity in modified landscapes has been thought to be best achieved through the establishment of wildlife corridors that link "habitat patches" (reviewed by Lindenmayer 1994, 1998; Beier and Noss 1998; Bennett 1998). However, wildlife corridors will have certain physical attributes and link certain habitat types at one or few spatial scales that may suit some, but not all species. Given these and other limitations of corridors (see Simberloff *et al.* 1992), it is important to consider the potential of a soft matrix to increase connectivity for species across a range of scales and habitat types.

At Nanangroe, we found some indication that scattered trees in the matrix were particularly important landscape elements that contributed to landscape connectivity for various species of birds. For example, some bird species were more likely to travel through the landscape in directions where trees were scattered relatively densely (Table A3.1). In addition, after landing in a semi-isolated tree in the matrix, many birds returned to their point of origin, or departed in the direction opposite to their arrival direction, which indicated the potential role of scattered trees as stepping stones for birds (Table A3.1). Additional habitat features may be needed to assist other organisms to move through the matrix. For example, decaying logs and half-buried rocks were used by several species of reptiles that used both the matrix and patches (Table A3.2). It is possible that without these features in the matrix, currently continuous populations of some reptile species may become isolated. Importantly, the permeability of the matrix (*sensu* Gascon and Lovejoy 1998) can depend on different habitat features for different species. Hence, the creation or conservation of a heterogeneous matrix can benefit a range of species.

Landscape context and heterogeneity also have been found to be important in other parts of the world (e.g. McGarigal and McComb 1995; Villard *et al.* 1999; Hamer *et al.* 2003). The role of the matrix as a connecting landscape element has been noted in various studies, e.g. for many vertebrates in the Amazon basin (Gascon *et al.* 1999; Laurance *et al.* 2002), the Iberian Lynx (*Lynx pardinus*) in Spain (Ferreras 2001), or small mammals in an agricultural area of central-west Indiana (Nupp and Swihart 2000). While several authors have pointed out species-specific differences in their ability to tolerate the matrix (e.g. Laurance 1994; Nupp and Swihart 2000), a soft matrix can often be a starting point to enhance connectivity for organisms whose populations in different patches are otherwise isolated (Rosenberg *et al.* 1997).

A3.3.3 A soft matrix can link multiple habitats for a given species

Not all species are restricted to one habitat type throughout their life history. The most striking example of this phenomenon is semi-aquatic organisms, which typically breed in wet environments, but spend other parts of their life cycle in drier environments. At Nanangroe, outside its breeding season, the Eastern Banjo Frog (*Limnodynastes dumerilii*) was pitfall-trapped in locations several hundred metres away from the nearest potential breeding environment (Fischer *et al.*, unpublished data). Work in northern Europe also demonstrates that a soft matrix can be crucial to enable semi-aquatic species to move between breeding and non-breeding environments. For example, the Common Toad (*Bufo bufo*) may move more than 2 km every year between its aquatic breeding environment and summer or winter habitats respectively (Blab and Vogel 1996). The nature of the matrix encountered by individual toads during these migrations is crucially important to their survival – for example, deaths from road traffic are a substantial source of mortality in northern European amphibians (Blab and Vogel 1996; Hels and Buchwald 2001). A similar situation was reported for threatened turtle species in Maine (USA). Joyal *et al.* (2001) found turtles were using multiple small wetlands, and throughout the year frequently moved several hundred metres between wetlands through the landscape matrix. This finding led the authors to conclude that wetland protection by itself was insufficient to ensure the survival of turtle populations, and matrix management was a critical component of the protection of turtle habitat. Despite the special situation of semi-aquatic organisms, animals that do not undergo major biological changes throughout their life history can also undergo changes in habitat use depending on their age (e.g. pre- and post-dispersal habitat; see Palomares *et al.* 2000 for an example of the Iberian Lynx in Spain).

A3.3.4 The matrix samples the most productive parts of the environment

Human landscape modification is not a random process (Burgman and Lindenmayer 1998). Humans choose areas for production on the basis of accessibility and productivity. This bias means that many nature reserves are in steep and unproductive terrain unsuitable for other purposes (Margules and Pressey 2000; Paton 2000). Similarly, in production landscapes, most remnant vegetation occurs on the less productive hilltops (Lemckert 1998; Gibbons and Boak 2002). Given this bias, the matrix can be an important area for conservation management, because it has the potential to support different elements of biodiversity than less productive areas. Our most recent field survey of birds in Nanangroe illustrated this finding. During our reptile surveys in 2001/2002 we also surveyed 16 landscape units for birds. Each landscape unit measured approximately 2.5 ha, and landscape units were stratified on the basis of their topographic position (valley or ridge) and relative canopy cover (high or low). Repeat bird surveys were conducted for ten days at each landscape unit when pitfall traps were visited. The results of our bird surveys illustrated that productive valley environments with above average tree cover supported a higher number of bird species than less productive ridge tops with similar levels of tree cover (Fig. A3.1). Similarly, although more data would be needed for conclusive evidence, valley environments with below average tree cover tended to support more bird species than ridge environments with below average tree cover (Fig. A3.1). These considerations highlight the potential value of restoring parts of the landscape matrix because it often coincides with the most productive parts of the landscape, and thus can provide ecological benefits that less productive environments cannot offer.

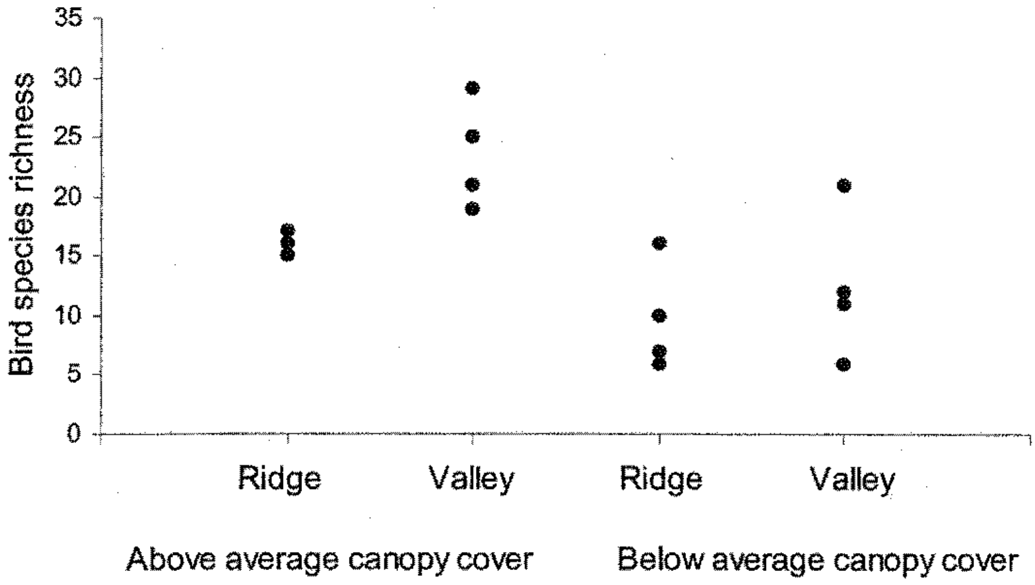

Fig. A3.1 Results of bird surveys conducted at sixteen landscape units in the Nanangroe area in 2001/2002 (Fischer *et al.* unpublished data – see text for details). The data illustrate that bird species richness tended to be higher in more productive valley environments than on ridge tops.

A3.4 Current conservation practices and the future of the matrix

A soft matrix can provide habitat and facilitate connectivity, and will often sample the most productive parts of the environment. However, most conservation strategies in the grazing landscapes of south-eastern Australia do not target the matrix, but focus solely on patches of remnant woodland. The two most widespread conservation activities are (1) fencing off selected woodland areas from grazing, and (2) tree planting in fenced off areas (Bennett *et al.* 2000). These practices are a useful starting point, since they aim to ensure that some habitat can recover from grazing pressure, and create new habitat in other places. However, we are concerned that while these activities take place, much habitat and ecological continuity will be lost because of continuing and severe degradation of the landscape matrix.

In many grazing landscapes of south-eastern Australia, the neglect of the matrix will lead to a lack of tree regeneration due to grazing pressure. For example, large parts of the Nanangroe landscape are characterised by an almost complete lack of natural tree regeneration. In 144 ten by ten metre plots established for pitfall trapping, 94 trees were measured, and there were no trees shorter than 150 cm, and only two trees with a diameter at breast height of less than 5 cm. A similar finding was made by Spooner *et al.* (2002) in a more extensive investigation of tree regeneration in the south-west slopes of south-eastern Australia. These workers found no tree regeneration in 87% of unfenced woodland remnants. A recent study by Saunders *et al.* (2003) demonstrated that the threat of a rapid future loss of tree cover was equally pertinent in Western Australia. Repeat surveys of all individual trees in a 15 ha grazed woodland remnant showed a significant decline in tree condition between 1978 and 1998. In addition, Saunders *et al.* (2003) noted there had been no tree regeneration throughout the entire remnant since grazing commenced in 1929. In the absence of tree regeneration in the wheat-sheep regions of Australia, there will be a severe decrease in tree-associated habitat features in the areas between fenced off patches. A lack of tree regeneration will lead to a deterioration in matrix heterogeneity, and may mark the transition of currently variegated landscapes into fragmented or relictual landscapes (*sensu* McIntyre and Hobbs 1999).

A3.5 Barriers to matrix management

Despite repeated calls for more integrated landscape management in production landscapes (e.g. Noss 1983; Hobbs *et al.* 1993; Barrett *et al.* 1994; Morton *et al.* 1995), on-ground changes have been few in the grazing landscapes of south-eastern Australia. Achieving fundamental changes is not straightforward – there are important socio-economic, historical, policy, and legal constraints that need to be overcome to achieve more sympathetic matrix management in the future.

A3.5.1 Economic and historical constraints

Land managers have tangible economic reasons to be interested in the short-term output of produce from their land. Conservation considerations are a relatively recent concern to these stakeholders – for example, in Australia, the clearing and "improvement" of land was for many years rewarded by the government through tax incentives (Saunders 1994; State of the Environment Advisory Council 1996).

The allocation of land for production or conservation respectively (rather than landscape scale matrix management) is currently the most popular way of conservation management since it requires no fundamental changes to land management practices (Lindenmayer and Franklin 2002). For example, fencing off certain patches to be "sacrificed" for conservation is costly in terms of the funds required for labour and materials (Fenton 1997), but these measures can be implemented without fundamental changes to land management elsewhere on the property. This natural tendency towards solving conservation issues through land allocation strategies is enhanced by the fact that clearing has been biased in the past – i.e. the most productive areas are often already cleared (Lemckert 1998; Gibbons and Boak 2002), and the largest patches of semi-natural vegetation are often located in areas that are relatively unsuitable for production anyway. Thus, excluding these areas from production is a sacrifice that may be costly in terms of materials and labour, but can be integrated relatively easily with existing farming practices. Further, Bennett *et al.* (2000) showed that most revegetation activities on Australian farms aimed to establish linear strips of vegetation, which could be easily integrated with current paddock boundaries and were easiest to work around during farming operations (e.g. cropping). Indeed, Bennett *et al.* (2000) found the primary reason for revegetation activities was to enhance production, not to aid biodiversity conservation.

Unlike fencing off patches or establishing linear plantings, sympathetic matrix management may be more difficult to reconcile with many existing management strategies because it requires heterogeneity across the entire landscape – e.g. it may involve changes to stocking/cropping regimes, or the establishment of additional temporary or permanent fences, and coordination of multiple landholders. Thus, while there is considerable momentum in the farming community to work towards sustainable management practices with respect to nature conservation (e.g. Davidson 1995; King 1995; Milne 1995; Fenton 1997), there are short-term economic and historical barriers that work against changes to matrix management. Future research in this area is critical to establish ways to manage entire landscapes more sustainably. What exactly are the economic barriers to more sustainable matrix management? What are the short- and long-term costs and benefits from various different conservation and production activities? Do ecologically diverse systems provide a larger amount of ecosystem goods and services (Daily 1999, 2001)? The answers to these and related questions may provide useful ways forward because they may highlight economic incentives to sustainably manage agricultural land that have been overlooked to date.

A3.5.2 Legal constraints

The ecologically undesirable paradigm of land use allocation to address issues of biodiversity conservation is also apparent in current environmental legislation. The disregard for the matrix in existing legislation most likely arises from a degree of ignorance about its importance, and political pressure to avoid conservation measures that are unpopular. Australia's land clearing rate is still among the highest in the world, partly because of high clearing rates in the state of Queensland (Glanznig 1995; Glanznig and Kennedy 2000). Nevertheless, other states also continue to clear land, and current environmental legislation highlights the disregard for the potential value of remnant vegetation scattered throughout the landscape matrix.

The New South Wales Native Vegetation Conservation Act 1997 aims to provide for the management of native vegetation in accordance with the principles of ecologically sustainable development. While it generally prohibits the clearing of native vegetation without development consent, it contains several exemptions which allow clearing of native vegetation. Current practices falling under these exemptions include the clearing of up to two hectares of native vegetation every year on an individual property. Similarly, seven trees per hectare may be removed in any given year for on farm purposes. Finally, all tree regeneration in the matrix that is younger than ten years of age may be cleared (Department of Land and Water Conservation 1999; Sundstrom 2001; Bates 2002). These exemptions demonstrate which aspects of native vegetation are considered worthwhile conserving – small patches and recently regenerated trees in the matrix are essentially deemed worthless for nature conservation. Hence, the current legal framework in New South Wales contrasts starkly with the actual ecological importance of small patches and scattered trees in the landscape matrix. Similarly, the legal frameworks for native vegetation conservation in other Australian jurisdictions contain a wide range of exemptions that are rarely grounded in ecological reality (Bates 2002).

In addition to deficiencies in legislation to adequately account for the value of the matrix, a lack of sufficient law enforcement may render existing provisions ineffective. For example, in New South Wales, there is some concern that the number of cases where illegal clearing has been successfully prosecuted is negligible (Department of Infrastructure, Planning and Natural Resources, unpublished information). Thus, there is at least some suggestion that for legislation to be effective, prosecution may need to be more rigorous.

A3.5.3 Scientific constraints

Economic, historical and legal constraints to more sympathetic matrix management can be further enhanced through the uncritical adoption of existing scientific paradigms. For example, the theory of island biogeography (MacArthur and Wilson 1967) was an important foundation of conservation biology (Diamond 1975; reviewed by Haila 2002). The resulting concept of patchy landscapes easily lent itself to a binomial classification of land into habitat and non-habitat (Lindenmayer *et al.* 2003), and thus was consistent with a conservation approach based on land use allocation. In addition, traditional scientific thinking is strongly based on hypothetico-deductive investigations, and therefore most scientists are likely to feel most comfortable dealing with clearly defined categories as provided by theoretical tools such as the patch-matrix model (Wiens 1995). However, while a binomial classification of land may be useful in some landscapes, more integrated management considering entire landscapes will be important in many cases.

An additional reason why scientists have been reluctant to act in accordance with calls for more integrated landscape management, may be the perceived political reality they find themselves in. Given a certain political climate, conciliatory approaches with land managers that do not require fundamental changes to land management sometimes appear more likely to be worthwhile than approaches that are more challenging to the land manager and advocate more fundamental changes. However, while a sense of realism with respect to the political climate is important, only ecologists will have the necessary information and a firm basis from which to argue for more sympathetic matrix management – indeed, economic and historical realities that may be of primary relevance to other stakeholders will not allow changes to matrix management unless ecologists clearly state well-founded reasons for an abandonment of the *status quo* and argue strongly for changes to matrix management.

A3.6 Ways forward

For conservation biologists to be effective in bringing about changes to matrix management in Australian grazing landscapes, more scientific research is necessary, but this alone is not sufficient. Three additional factors complementing scientific work may be of key importance: (1) an improved understanding of the current policy framework, and the opportunities it provides for change, (2) improved communication with all stakeholders involved, and (3) more practical on-ground research that highlights potential avenues for more sustainable management practices.

A3.6.1 Opportunities for change: understanding the legal framework

While the clearing exemptions in New South Wales highlight the current neglect of the matrix, a more detailed examination of the legal framework highlights several potential avenues through which change may be achieved. First, the exemptions under the Native Vegetation Conservation Act 1997 are transitional provisions remaining from earlier legislation (State Environmental Planning Policy No. 46: Protection and Management of Native Vegetation). These exemptions may be removed or altered by either Regional Vegetation Management Plans or Native Vegetation Codes of Practice (Bates 2002). The Nanangroe area falls under one of two Regional Vegetation Management Plans that have already been gazetted, the Riverina Highlands Regional Vegetation Management Plan 2003. While this Plan modifies the exemptions discussed above to some extent, subject to some conditions, it still allows for the annual removal of up to ten trees per hectare and all regrowth younger than ten years of age. Hence, the changes brought about in this case were somewhat insignificant with respect to their effect on matrix management. However, there are 19 Regional Vegetation Management Plans at various stages of development, to which input can still be made. Communicating the important role of a soft matrix to the relevant Regional Vegetation Committees may be a possible avenue to improve the legal protections accorded to the matrix. Indeed, provision of robust scientific data to these Committees is essential to assist them to adequately discharge their responsibilities (Thompson 2001).

Second, the *Native Vegetation Conservation Act 1997* also contains provision for property agreements. These are voluntary but enforceable agreements made between landholders and the Department of Infrastructure, Planning and Natural Resources, which include the development of a strategy for native vegetation management on individual or multiple properties, in conjunction with the provision of technical and financial assistance to the landholder (Department of Land and Water Conservation 1998; Farrier *et al.* 1999). Again, communicating the importance of a soft matrix to the NSW Department of Infrastructure, Planning and Natural Resources, which administers these property agreements, and the farming community could result in the inclusion of more integrated matrix management into native vegetation management strategies. The advantage of this second example is that it also addresses to some extent the economic implications of a shift towards sympathetic matrix management.

While understanding the policy framework that governs matrix management can be useful to identify avenues for improvement, it is important to realise that achieving changes in environmental policy is not a straightforward task. There is a clear need for more interdisciplinary work examining the links between science, policy development and institutional structures to improve the implementation of scientific findings into policy frameworks (Ison and Russell 2000; Lindenmayer and Franklin 2002).

A3.6.2 Communicating complexity and urgency

To achieve changes in matrix management, scientists will have to communicate with other scientists, government agencies and land managers. It will be important to explicitly distinguish between different audiences that scientists want to reach. The potentially important role of habitat features that do not coincide with large patches of remnant woodland needs to be communicated widely to land managers – it will be important to emphasise that habitat is more than trees, and that a soft matrix can provide habitat for a range of animals. However, confronting individual farmers and "demanding" they implement integrated matrix management is bound to fail and is unrealistic given the economic realities with which individual farmers have to deal. Indeed, Fischer and Lindenmayer (2002a) argued that it was important to realise that even small conservation efforts could be worthwhile, and should be encouraged. Conversely, the true complexity of ecological systems including the role of the matrix will need to be communicated to other scientists, to the farming community as a whole, and to politicians and policy makers. Sustainability as a goal of environmental management has become a popular catch phrase, but it is important to recognise that different levels of diversity may be conserved as a result of different conservation approaches. In the grazing landscapes of south-eastern Australia, an approach of land use allocation will lead to "patchy" landscapes, which may look somewhat reminiscent of northern Europe. On the other hand, a more integrated approach may lead to the conservation of different types of landscapes representing a range of different alteration states (see McIntyre and Hobbs 1999). Both approaches may eventually lead to a stable level of biodiversity, but the absolute amount of diversity supported is likely to be substantially higher if a more integrated approach to land management is employed that considers not only patches, but also the matrix. Given these considerations, it is by no means clear that ecological researchers are doing better, i.e. conserving more biological diversity, by following a non-confrontational pragmatic approach to conservation through land use allocation. Indeed, in the context of the global reserve network, it is recognised that a global target of setting aside ten percent of all land for conservation is likely to be vastly insufficient (Rodrigues and Gaston 2001).

A3.6.3 The need for practical research

New research methods that complement reductionist approaches may be helpful to derive effective management tools. An increased use of systems dynamics approaches may be a useful starting point to assist us to better conceptualise complex environmental systems (Senge 2001), and may help integrate the knowledge and perspectives of a wide range of disciplines (Jackson *et al.* 2001). Multidisciplinary investigations will be necessary to consider the range of ecological, economic and social issues associated with changes in matrix management. At an applied level, future projects may include investigations into various grazing regimes and their effect on matrix condition, and the identification or establishment of "model farms" that are managed sustainably.

A3.7 Conclusions

Our case study illustrated that the concept of patches is deeply embedded in conservation strategies used in Australian grazing landscapes, and the role of the matrix is largely ignored. This finding highlights the potential negative effects that can arise from over- or misapplying ecological theories (see also Haila 2002). While much of our case study focused directly on New South Wales, the problem of undervaluing the matrix is not unique to Australia. For example, research in the United States of America suggests that small wetlands may be undervalued in a similar way to small woodland patches in Australia (Semlitsch and Bodie 1998; Joyal *et al.* 2001). Addressing conservation issues in the matrix will require a sound scientific understanding of the matrix. However, insights from non-scientific disciplines also will be important.

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A3.9 References

Antrop, M. 2001. The language of landscape ecologists and planners - a comparative content analysis of concepts used in landscape ecology. Landscape and Urban Planning 55: 163-173.

Barrett, G.W., Ford, H.A. and Recher, H.F. 1994. Conservation of woodland birds in a fragmented rural landscape. Pacific Conservation Biology 1: 245-256.

Bates, G. 2002. Environmental law in Australia. Reed International Books, London.

Beier, P. and Noss, R.F. 1998. Do habitat corridors provide connectivity? Conservation Biology 12: 1241-1252.

Bennett, A.F. 1998. Linkages in the landscape: the role of corridors and connectivity in wildlife conservation. IUCN, Gland, Switzerland.

Bennett, A.F., Kimber, S. and Ryan, P. 2000. Revegetation and Wildlife. Research Report 2/00. Bushcare National Projects Reserach and Development Program. Environment Australia, Canberra.

Blab, J. and Vogel, H. 1996. Amphibien und Reptilien erkennen und schuetzen: Alle mitteleuropaeischen Arten. BLV Verlagsgesellschaft, Munich.

Burgman, M.A. and Lindenmayer, D.B. 1998. Conservation biology for the Australian environment. Surrey Beatty & Sons, Chipping Norton, New South Wales.

Cunningham, R.B., Lindenmayer, D.B., Nix, H.A. and Lindenmayer, B.D. 1999. Quantifying observer heterogeneity in bird counts. Australian Journal of Ecology 24: 270-277.

Daily, G.C. 1999. Developing a scientific basis for managing Earth's life support systems. Conservation Ecology 3: 14. [online] URL: http://www.consecol.org/vol13/iss12/art14.

Daily, G.C. 2001. Ecological forecasts. Nature 411: 245.

Davidson, R.L. 1995. Farmers as conservators of a sustainable production base. In: Bradstock, R.A., Auld, T.D., Keith, D.A., Kingsford, R.T., Lunney, D. and Sivertsen, D.P. (eds), Conserving biodiversity: threats and solutions. Surrey Beatty and Sons, Chipping Norton, pp. 43-54.

Department of Land and Water Conservation 1998. Native Vegetation Conservation Act Factsheet No.4: Property Agreements. NSW Department of Land and Water Conservation, Sydney.

Department of Land and Water Conservation 1999. Guidelines for clearing vegetation under the Native Vegetation Conservation Act 1997. NSW Department of Land and Water Conservation, Parramatta.

Diamond, J.M. 1975. The island dilemma: lessons of modern biogeographic studies of for the design of natural reserves. Biological Conservation 7: 129-145.

Fenton, J. 1997. A primary producer's perspective on nature conservation. In: Hale, P. and Lamb, D. (eds), Conservation outside nature reserves. University of Queensland, Brisbane, pp. 3-9.

Fernández-Juricic, E. 2000. Avifaunal use of wooded streets in an urban landscape. Conservation Biology 14: 513-521.

Farrier, D., Lyster, R., Pearson, L. and Lipman, Z. 1999. The environmental law handbook. Redfern Legal Publishing, Sydney.

Fischer, J. and Lindenmayer, D.B. 2002a. Small patches can be valuable for biodiversity conservation: two case studies on birds in southeastern Australia. Biological Conservation 106: 129-136.

Fischer, J. and Lindenmayer, D.B. 2002b. The conservation value of paddock trees for birds in a variegated landscape in southern New South Wales. 1. Species composition and site occupancy patterns. Biodiversity and Conservation 11: 807-832.

Fischer, J. and Lindenmayer, D.B. 2002c. The conservation value of paddock trees for birds in a variegated landscape in southern New South Wales. 2. Paddock trees as stepping stones. Biodiversity and Conservation 11: 833-849.

Franklin, J.F. 1993. Preserving biodiversity: species, ecosystems, or landscapes? Ecological Applications 3: 202-205.

Gascon, C. and Lovejoy, T.E. 1998. Ecological impacts of forest fragmentation in central Amazonia. Ecology 101: 273-280.

Gascon, C., Lovejoy, T.E., Bierregaard, R.O.J., Malcolm, J.R., Stouffer, P.C., Vasconcelos, H.L., Laurance, W.F., Zimmerman, B., Tocher, M. and Borges, S. 1999. Matrix habitat and species richness in tropical forest remnants. Biological Conservation 91: 223-229.

Gibbons, P. and Boak, M. 2002. The value of paddock trees for regional conservation in an agricultural landscape. Ecological Management and Restoration In press.

Glanznig, A. 1995. Native vegetation clearance, habitat loss and biodiversity decline. Department of the Environment, Sport and Territories, Canberra.

Glanznig, A. and Kennedy, M. 2000. From words to action: addressing biodiversity loss, land degradation and native vegetation clearance in the 1990s - the Australian experience. http://www.nccnsw.org.au/member/cbn/projects/Policy_and_Law/vegman.html, visited April 2001.

Grant, B.W., Tucker, A.D., Lovich, J.E., Mills, A.M., Dixon, P.M. and Gibbons, J.W. 1991. The use of coverboards in estimating patterns of reptile and amphibians biodiversity. In: McCullough, D.R. and Barrett, R.H. (eds), Wildlife 2001: populations. Elsevier Applied Science, London, pp. 379-403.

Haila, Y. 2002. A conceptual genealogy of fragmentation research: From island biogeography to landscape ecology. Ecological Applications 12: 321-334.

Hamer, K.C., Hill, J.K., Benedick, S., Mustaffa, N., Sherratt, T.N., Maryati, M. and Chey, V.K. 2003. Ecology of butterflies in natural and selectively logged forests of northern Borneo: the important of habitat heterogeneity. Journal of Applied Ecology 40: 150-162.

Hels, T. and Buchwald, E. 2001. The effect of road kills on amphibian populations. Biological Conservation 99: 331-340.

Higgs, A.J. and Usher, M.B. 1980. Should nature reserves be large or small? Nature 285: 568-569.

Hobbs, R.J., Saunders, D.A. and Arnold, G.W. 1993. Integrated landscape ecology: a Western Australian perspective. Biological Conservation 64: 231-238.

Horner-Devine, M.C., Daily, G.C., Ehrlich, P.R. and Boggs, C.L. 2003. Countryside biogeography of tropical butterflies. Conservation Biology 17: 168-177.

Hughes, J.B., Daily, G.C. and Ehrlich, P.R. 2002. Conservation of tropical forest birds in countryside habitats. Ecology Letters 5: 121-129.

Ison, R.L. and Russell, D.B. 2000 (eds). Agricultural extension and rural development: breaking out of traditions. Cambridge University Press, Cambridge.

Jackson, J.B.C., Kirby, M.X., Berger, W.H., Bjorndal, K.A., Botsford, L.W., Bourque, B.J., Bradbury, R.H., Cooke, R., Erlandson, J., Estes, J.A., Hughes, T.P., Kidwell, S., Lange, C.B., Lenihan, H.S., Pandolfi, J.M., Peterson, C.H., Steneck, R.S., Tegner, M.J. and Warner, R.R. 2001. Historical overfishing and the recent collapse of coastal ecosystems. Science 293: 629-638.

Joyal, L.A., McCollough, M. and Hunter, M.L. 2001. Landscape ecology approaches to wetland species conservation: a case study of two turtle species in southern Maine. Conservation Biology 15: 1755-1762.

King, G. 1995. The contribution of farm organizations to wildlife conservation and management of private land. In: Bennett, A., Backhouse, G. and Clark, T. (eds), People and nature conservation. Surrey Beatty and Sons, Chipping Norton, NSW, pp. 201-203.

Kitchener, D.J. 1982. Predictors of vertebrate species richness in nature resreves in the Western Australian Wheatbelt. Australian Wildlife Research 9: 1-7.

Laurance, W.F. 1991. Ecological correlates of extinction proneness in Australian tropical rain forest mammals. Conservation Biology 5: 79-89.

Laurance, W.F. 1994. Rainforest fragmentation and the structure of small mammal communities in tropical Queensland. Biological Conservation 69: 23-32.

Laurance, W.F., Lovejoy, T.E., Vasconcelos, H.L., Bruna, E.M., Didham, R.K., Stouffer, P.C., Gascon, C., Bierregaard, R.O., Laurance, S.G. and Sampaio, E. 2002. Ecosystem decay of Amazonian forest fragments: A 22-year investigation. Conservation Biology 16: 605-618.

Lemckert, F. 1998. A survey for threatened herpetofauna of the south-west slopes of New South Wales. Australian Zoologist 30: 492-500.

Lindenmayer, D.B. 1994. Wildlife corridor mitigation of logging impacts on fauna in wood-production forests in south-eastern Australia: a review. Wildlife Research 21: 323-340.

Lindenmayer, D.B. 1998. The design of wildlife corridors in wood production forests. NSW National Parks and Wildlife Service, Hurstville, NSW.

Lindenmayer, D.B., Cunningham, R.B., MacGregor, C., Tribolet, C. and Donnelly, C.F. 2001. A prospective longitudinal study of landscape matrix effects on fauna in woodland remnants. I. Experimental design and baseline data. Biological Conservation 101: 157-169.

Lindenmayer, D.B. and Franklin, J. 2002. Conserving forest biodiversity. Island Press, Covelo.

Lindenmayer, D.B., McIntyre, S. and Fischer, J. 2003. Birds in eucalypt and pine forests: landscape alteration and its implications for research models of faunal habitat use. Biological Conservation 110: 45-53.

Luck, G.W. and Daily, G.C. 2003. Tropical countryside bird assemblages: richness, composition, and foraging differ by landscape context. Ecological Applications 13: 235-247.

Lumsden, L.F., Bennett, A.F. and Silins, J.E. 2002. Location of roosts of the lesser long-eared bat Nyctophilus geoffroyi and Gould's wattled bat Chalinolobus gouldii in a fragmented landscape in south-eastern Australia. Biological Conservation 106: 237-249.

MacArthur, R.H. and Wilson, E.O. 1967. The theory of island biogeography. Princeton University Press, Princeton, New Jersey.

Margules, C.R. and Pressey, R.L. 2000. Systematic conservation planning. Nature 405: 243-253.

McGarigal, K. and McComb, W.C. 1995. Relationships between landscape structure and breeding birds in the Oregon coast range. Ecological Monographs 65: 235-260.

McIntyre, S. and Barrett, G.W. 1992. Habitat variegation, an alternative to fragmentation. Conservation Biology 6: 146-147.

McIntyre, S. and Hobbs, R. 1999. A framework for conceptualizing human effects on landscapes and its relevance to management and research models. Conservation Biology 13: 1282-1292.

Milne, B. 1995. Broadening the basis for enhancing biodiversity - a farmer's perspective. In: Bennett, A., Backhouse, G. and Clark, T. (eds), People and nature conservation. Surrey Beatty and Sons, Chipping Norton, NSW, pp. 204-208.

Morton, S.R., Stafford Smith, D.M., Friedel, M.H., Griffin, G.F. and Pickup, G. 1995. The stewardship of arid Australia: ecology and landscape management. Journal of Environmental Management 43: 195-217.

Noss, R.F. 1983. A regional landscape approach to maintain diversity. Bioscience 33: 700-706.

Nupp, T.E. and Swihart, R.K. 2000. Landscape-level correlates of small-mammal assemblages in forest fragments of farmland. Journal of Mammalogy 81: 512-526.

Orr, D.W. 2002. Four challenges of sustainability. Conservation Biology 16: 1457-1460.

Palomares, F., Delibes, M., Ferreras, P., Fedriani, J.M., Calazada, J. and Revilla, E. 2000. Iberian lynx in a fragmented landscape: predispersal, dispersal, and postdispersal habitats. Conservation Biology 14: 809-818.

Paton, D.C. 2000. Disruption of bird-plant pollination systems in southern Australia. Conservation Biology 14: 1232-1234.

Ricketts, T.H., Daily, G.C., Ehrlich, P.R. and Fay, J.P. 2001. Countryside biogeography of moths in a fragmented landscape: Biodiversity in native and agricultural habitats. Conservation Biology 15: 378-388.

Rodrigues, A.S.L. and Gaston, K.J. 2001. How large do reserve networks need to be? Ecology Letters 4: 602-609.

Rosenberg, D.K., Noon, B.R. and Meslow, E.C. 1997. Biological corridors: Form, function, and efficacy. Bioscience 47: 677-687.

Saunders, D.A. 1994. Can we integrate nature conservation with agricultural production? Landscape and Urban Planning 28: 55-62.

Saunders, D.A., Arnold, G.W., Burbidge, A.A. and Hopkins, A.J.M. 1987 (eds). Nature conservation: the role of remnants of native vegetation. Surrey Beatty and Sons, Chipping Norton, New South Wales.

Saunders, D.A. and de Rebeira, C.P. 1991. Values of corridors to avian populations in a fragmented landscape. In: Saunders, D.A. and Hobbs, R.J. (eds), Nature conservation 2: the role of corridors. Surrey Beatty and Sons, Chipping Norton, New South Wales, pp. 221-240.

Saunders, D.A., Smith, G.T., Ingram, J.A. and Forrester, R.I. 2003. Changes in a remnant of salmon gum *Eucalyptus salmonophloia* and York gum *E. loxophleba* woodland, 1978 to 1997. Implications for woodland conservation in the wheat-sheep regions of Australia. Biological Conservation 110: 245-256.

Semlitsch, R.D. and Bodie, J.R. 1998. Are small, isolated wetlands expendable? Conservation Biology 12: 1129-1133.

Senge, P.M. 2001. The fifth descipline, the art and practice of the learning organisation. Random House Australia, Sydney.

Simberloff, D.A., Farr, J.A., Cox, J. and Mehlman, D.W. 1992. Movement corridors: conservation bargains or poor investments? Conservation Biology 6: 493-504.

Spooner, P., Lunt, I. and Robinson, W. 2002. Is fencing enough? The short-term effects of stock exclusion in remnant grassy woodlands in southern NSW. Ecological Management and Restoration 3: 117-126.

State of the Environment Advisory Council 1996. State of the environment Australia 1996. CSIRO Publishing, Collingwood.

Stephens, D.W. and Krebs, J.R. 1986. Foraging Theory. Princeton University Press, Princeton, Jew Jersey.

Sundstrom, A. 2001. A licence to clear? An assessment of the effectiveness of clearing control laws in NSW. National Parks Journal 45: 10-11.

Taylor, P.D., Fahrig, L., Henein, K. and Merriam, G. 1993. Connectivity is a vital element of landscape structure. Oikos 68: 571-573.

Thompson, D. 2001. Flying blind with native vegetation conservation? Australian Farm Journal October: 66-69.

Villard, M.-A., Trzcinski, M.K. and Merriam, G. 1999. Fragmentation effects on forest birds: relative influence of woodland cover and configuration on landscape occupancy. Conservation Biology 13: 774-783.

Wiens, J.A. 1995. Landscape mosaics and ecological theory. In: Hansson, L., Fahrig, L. and Merriam, G. (eds), Mosaic landscapes and ecological processes. Chapman & Hall, London, pp. 1-26.

Wiens, J.A., Stenseth, N.C., Vanhorne, B. and Ims, R.A. 1993. Ecological mechanisms and landscape ecology. Oikos 66: 369-380.

Yates, C.J. and Hobbs, R.J. 1997. Temperate eucalypt woodlands: a review of their status, processes threatening their persistence and techniques for restoration. Australian Journal of Botany 45: 949-973.