1 · *The science of understanding landscape change: setting the scene for the Tumut Fragmentation Study*

The body of work that comprises the Tumut Fragmentation Study is perhaps different from other projects around the world in that a wide range of questions have been posed and many kinds of work have been undertaken in the same place. The aim of this short book is to draw together some of the key insights from this work and outline some of the lessons learned. The hope is that a synthesis from publications scattered around in different journals and books might be more than the 'sum of its parts'. At its heart, the Tumut Fragmentation Study is all about understanding landscape change and biodiversity.

Landscape change and habitat fragmentation are processes that pose a major threat to many species. Because of this, an enormous number of studies worldwide have investigated how flora and fauna respond to them. Many of these studies have attempted to determine ways in which conservation can be more effective in areas extensively modified by humans. Themes associated with landscape change and habitat fragmentation have therefore become a major focus of conservation biology and landscape ecology (McGarigal and Cushman, 2002; Fahrig, 2003; Hobbs and Yates, 2003) and are now two of the most frequently studied processes threatening species persistence (Fazey *et al.*, 2005; Lindenmayer and Fischer, 2006).

A huge range of studies and an enormous variety of topics fall under the broad umbrella of landscape change and habitat fragmentation. Research can be focused on single-species responses, communities or aggregate species richness. Single-species investigations often highlight the fact that each individual species responds uniquely to landscape change. However, a detailed focus on the response of an individual species may tell us little about the overall pattern of change in larger assemblages of species, and the management reality is that it is rarely possible to consider

Box 1.1. What's in a name?

The initial (aerial) perspective of the landscape at Tumut was an impression of patches of remnant native forest surrounded by stands of exotic Radiata Pine plantation. From a human perspective, the original forest cover had been broken into patches – a process often termed 'fragmentation' or 'habitat fragmentation' by conservation biologists. The obvious name for the research programme was the Tumut Fragmentation Study. While the name has stuck, its validity has become problematic as new insights from the work have been gained over more than a decade of research. This is because the landscape is clearly not 'fragmented' for some species which readily live in the pine stands – they may even be more common in pine plantations than in eucalypt forests. Thus, for some species, the eucalypt remnants may not behave as 'fragments' of forest in a 'sea of inhospitable pine stands'. In essence, the human perspective of a 'fragmented landscape' may not be one shared by many elements of the biota. We return to this important insight several times throughout this book because it has major implications for the different kinds of conceptual models that can be employed. Despite these problems concerning the name 'Tumut Fragmentation Study', its use has been retained for the sake of simplicity throughout this book.

more than a handful of species in any given area. Thus, the identification of general patterns involving many species can be useful from a management perspective, although this often makes highly simplifying assumptions about species co-occurrence patterns (Lindenmayer and Fischer, 2007).

Research on landscape change and habitat fragmentation can also be focused on either spatial patterns or ecological processes. This is because landscape change can result in altered patterns of native vegetation cover and altered ecological processes. Both processes and patterns can be significantly correlated with various measures of biota. Patterns are directly observable because they are made up of the configuration of one or more entities. By contrast, processes can only be inferred indirectly through the patterns they produce. Nevertheless, a better understanding of the processes giving rise to emergent patterns may help with the understanding of how best to extrapolate findings from one landscape to another that has not previously been studied (Lindenmayer and Fischer, 2007).

Within the continuum of themes of individual species and assemblage-level responses, and patterns and processes, the past decade of research at Tumut has encompassed many different kinds of work. These have included studies of:

- **Individual species**, such as the response of individual mammal or reptile taxa to landscape context effects (Lindenmayer *et al.*, 1999a; Fischer *et al.*, 2005; Chapter 5);
- **Assemblages of species**, e.g. frogs (Parris and Lindenmayer, 2004; Chapter 5);
- **Overall species richness**, e.g. vascular plant species richness (Smith, 2006; Chapter 5);
- **Ecological patterns**, e.g. the nestedness of vertebrate assemblages (Fischer and Lindenmayer, 2005a; Chapter 7);
- **Ecological processes**, e.g. the mechanisms of population recovery following patch-level perturbation (Lindenmayer *et al.*, 2005a; Peakall and Lindenmayer, 2006; Chapter 9).

The work at Tumut has also involved an array of approaches such as:

- **True experiments** in which active manipulations of the landscape or vertebrate populations within patches have taken place (e.g. the Edge Experiment, Lindenmayer *et al.*, 2008a; Chapter 10);
- **Natural experiments** where active manipulation has occurred but was not controlled by the researcher (e.g. the Nanangroe Natural Experiment, Lindenmayer *et al.*, 2008b; Chapter 10);
- **Observational studies**, e.g. the Nest Predation Study (Lindenmayer *et al.*, 1999b);
- **Simulation modelling**, e.g. testing the accuracy of predictions made from models for population viability analysis (Lindenmayer *et al.*, 2003a; Chapter 8);
- The **integration of demographic and genetic methods**, e.g. to better understand dispersal (Peakall and Lindenmayer, 2006; Taylor *et al.*, 2007).

The various research foci and the methods of study have sometimes involved simply describing what patterns of biotic response have occurred in the heavily modified landscape at Tumut. At other times, the focus has been on testing and examining the efficacy of models (Lindenmayer and Lacy, 2002) or testing hypotheses derived from ecological theory, e.g. threshold theory (Lindenmayer *et al.*, 2005b). Clearly, there are many and diverse facets of the research. One of the unifying themes is that all of the work has been focused around the Tumut region, and particularly within and immediately adjacent to the 50,000-ha softwood plantation

Box 1.2. The Tumut Study – a true or a natural experiment?

The vast majority of studies of landscape change and habitat fragmentation are observational investigations. These do not use active interventions (e.g. manipulation of sites or other areas) to guide the quantification of biotic responses (or other response variables) to landscape change (reviewed by McGarigal and Cushman, 2002). Typically, observational studies sample a range of existing kinds of sites in a given landscape at one point in time. Such cross-sectional investigations usually lack the replication of site types and/or the 'controls' that characterise true experiments or natural experiments (Lindenmayer and Fischer, 2006).

In contrast to the plethora of observational studies, 'true experiments' that examine the impacts of habitat loss and/or the fragmentation of patches of native vegetation are comparatively rare (Debinski and Holt, 2000). This is perhaps because it is difficult, time-consuming and expensive to manipulate large areas, and difficult to find sufficient replicates, particularly for large patches. Although experiments are a powerful way of investigating the impacts of landscape change on biota, most experiments occur at spatial scales that are too small to provide the practical insights necessary to inform real-world resource management and conservation. While small-scale experiments can reveal interesting findings in some situations (e.g. Golden and Crist, 1999; Lenoir *et al.*, 2003), they can be of limited value for other situations, such as studies of wide-ranging bird and mammal species (Wiens, 1997; Lindenmayer and Fischer, 2006).

'Natural experiments' overlay an experimental design on an ecosystem where change or active manipulation has occurred or is planned (Carpenter *et al.*, 1995). They can be broadly similar to 'true' experiments (Diamond, 1986), but landscape changes are not controlled by the researcher. They usually occur at larger scales than true experiments.

The Tumut Fragmentation Study began in 1995 as a large-scale natural experiment. However, as will become clear throughout this book, the work at Tumut quickly expanded beyond the natural experiment to include many other facets of research, including true experiments, observation studies, integrated demographic and genetic research and simulation modelling.

dominated by stands of Radiata Pine (*Pinus radiata*) that comprise the Buccleuch State Forest.

A guide to using the book

Publication in book form enables more detail to be presented than is typically allowed in standard journal articles, where fierce competition for space invariably means than only the most cursory of background details can be described. References to published papers from the work at Tumut are made throughout the book to direct readers to further details of studies where they are required.

However, some readers might have a particular interest in one particular aspect of the Tumut Fragmentation Study. With this in mind, the book has been divided in a series of logically linked chapters that should enable the reader to navigate to their area of interest quickly.

Chapter 2: **The theory** contains a short overview of theory relating to landscape change and habitat fragmentation, particularly as it connects to the various major bodies of work at Tumut. It is not an exhaustive treatise on these massive topics, as this has been covered by others (Saunders *et al.*, 1987; Forman, 1995; Lindenmayer and Fischer, 2006; Fischer and Lindenmayer, 2007). However, Chapter 2 provides some background for the chapters that follow.

Chapter 3: **The field laboratory** describes the characteristics of the study region, and its flora and fauna.

Chapter 4: **Setting up the study** takes the reader through the many steps associated with the design and implementation of the major cross-sectional study conducted at Tumut, and would be of interest to anyone who is thinking of establishing a large-scale ecological study.

Chapter 5: **The core findings** discusses the results of the major cross-sectional study for nine groups of animals and plants.

Chapter 6: **Patch use** describes the results of additional studies undertaken to explore the way in which animals actually used remnant patches, with a focus on the home ranges of arboreal marsupials, bird movements, bird calling behaviour and the breeding behaviour of the Agile Antechinus.

Chapter 7: **Theory against data** examines how the results from the Tumut Fragmentation Study supported or challenged a number of relevant ecological theories and concepts.

Chapter 8: **Testing PVA models with real data** continues the discussion on data and theory, with a focus on testing the accuracy of predictions from simulation models for population viability analysis (PVA).

Chapter 9: **Genes in the landscape** outlines an interesting component of the research at Tumut, which was to explore more deeply the ecological processes of dispersal and movement through integrating genetic and demographic work.

Chapter 10: **Refining and extending the research programme** describes how deficiencies in the original cross-sectional studies of landscape context effects at Tumut spawned a set of additional investigations that looked at edge effects, nest predation and landscape changes over time.

Chapter 11: **Recommendations for plantation managers** discusses how the research findings have significant implications for the way in which plantations are managed. Although short, this chapter is valuable because of the rapid expansion of plantation estates around the world and the fact that biodiversity conservation is often considered to be one of the management objectives of these kinds of areas.

Chapter 12: **Lessons on running large-scale research studies**. This final chapter outlines some ideas for future work. It also highlights some of the many challenges associated with maintaining a large-scale, long-term project. This is an important chapter because many additional lessons can be learned through maintaining a project for a prolonged period of time and some of the most interesting insights emerge only after many years of sustained work.

The chapters in this book vary substantially in length because they cover different amounts of work. Chapter 5, on landscape context effects, for example, is quite long relative to the other chapters because it was a primary focus of the research for many years.

A few caveats

In an age where it is utterly impossible for any one person (or even group of people) to keep up with the exponential increase in the published literature, one aim in putting this book together was to keep it as short as possible. Nevertheless, there was some unavoidable overlap in topics between chapters. This was, in part, because data on particular groups (such as birds) were used in several kinds of studies and to tackle different questions.

This book contains many citations to publications from the work at Tumut (including considerable self-citation). This will frustrate some readers but, given that this is based on published scientific literature, it was unavoidable.

Finally, despite the best efforts of the team of statisticians and ecologists who have been involved in the work at Tumut, the studies completed to date are far from perfect. The perfect ecological study does not exist – even in the minds of the strictest theoreticians! Some limitations of the work are obvious, but others will have undoubtedly been overlooked. Criticisms of the work are welcome so that future research at Tumut (and possibly future editions of this book) might be improved.

2 · *The theory: an overview of landscape change and habitat fragmentation*

A vast array of topics fall under the umbrella of landscape modification and habitat fragmentation. These include (but are not limited to): conceptual models of landscape cover, habitat loss, habitat degradation, habitat subdivision, edge effects, connectivity, metapopulation dynamics, landscape heterogeneity, threshold effects, extinction cascades, nestedness of biotic assemblages, patch size relationships and landscape genetics. These topics are strongly interrelated and boundaries between them are somewhat artificial (Lindenmayer *et al.*, 2007a) (Figure 2.1).

Many of the individual topics shown in Figure 2.1 have been reviewed in depth over the past two decades, such as connectivity (Bennett, 1990, 1998, Hilty *et al.*, 2006) and edges (Ries *et al.*, 2004; Harper *et al.*, 2005). There also have been major overarching reviews of landscape modification and habitat fragmentation per se (Saunders *et al.*, 1991; Zuidema *et al.*, 1996; Fahrig, 2003; Hobbs and Yates, 2003, Lindenmayer and Fischer, 2006; Fischer and Lindenmayer, 2007). The aim of this chapter is not to produce yet another focused review of a particular topic or of the massively increasing body of work on landscape change and habitat fragmentation; rather, it is to provide brief summaries of topics that were tackled as part of the work at Tumut. These summaries therefore prepare the ground for subsequent chapters that describe the research findings from Tumut.

The 'species-orientated' to 'patterns-based' continuum

Landscape modification and habitat fragmentation can produce a wide range of effects across several spatial scales and levels of biological organisation. They can alter many ecological processes, change spatial patterns of vegetation cover in landscapes and influence individual species and assemblages of taxa. Such complexity is reflected by the frequent use of the term 'habitat fragmentation' as an umbrella term for many ecological processes, patterns of vegetation cover and biotic responses that accompany alteration of landscapes by humans (Lindenmayer and Fischer, 2007).

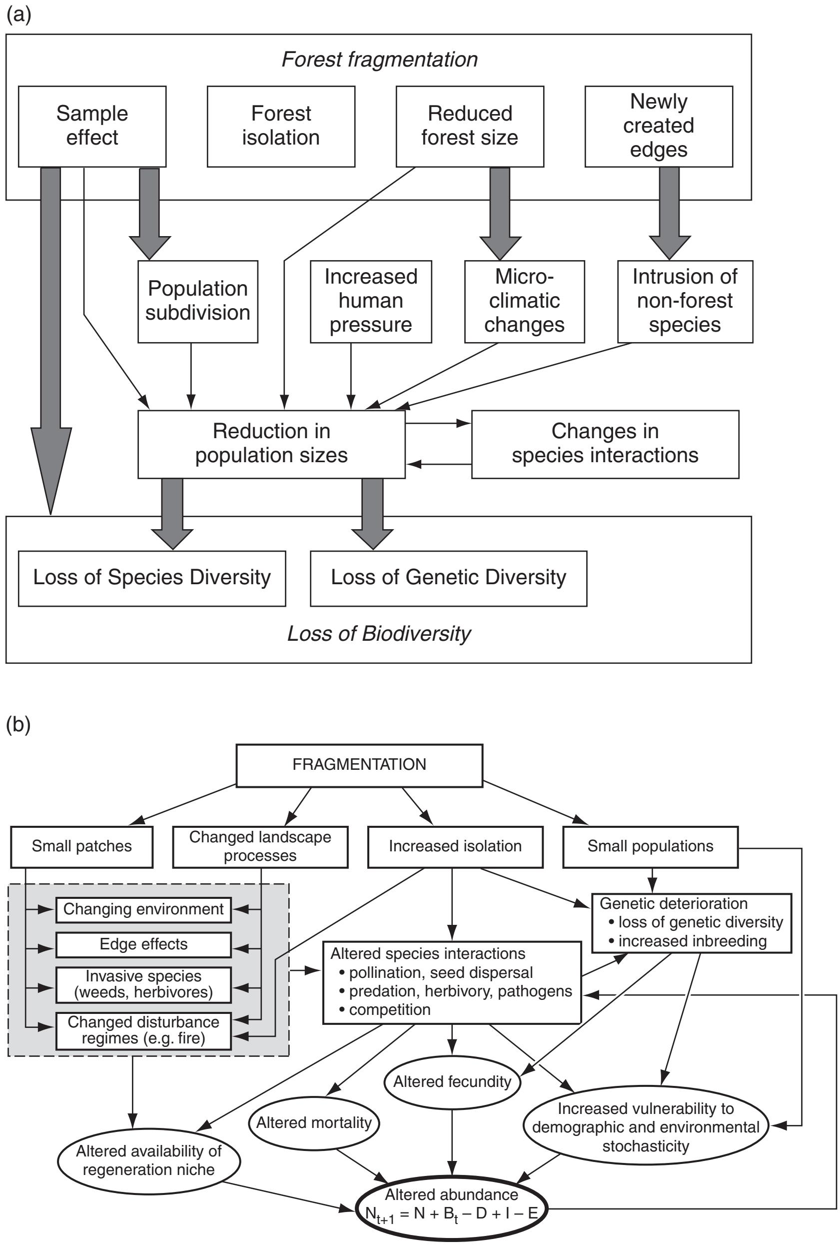

Figure 2.1 Different conceptual models of landscape modification and habitat fragmentation, emphasising links between key topics and areas of research, (a) redrawn from Zuidema *et al.*, 1996; (b) redrawn from Hobbs and Yates, 2003; (c) redrawn from Fischer and Lindenmayer, 2007; (d) redrawn from Lindenmayer *et al.*, 2007a.

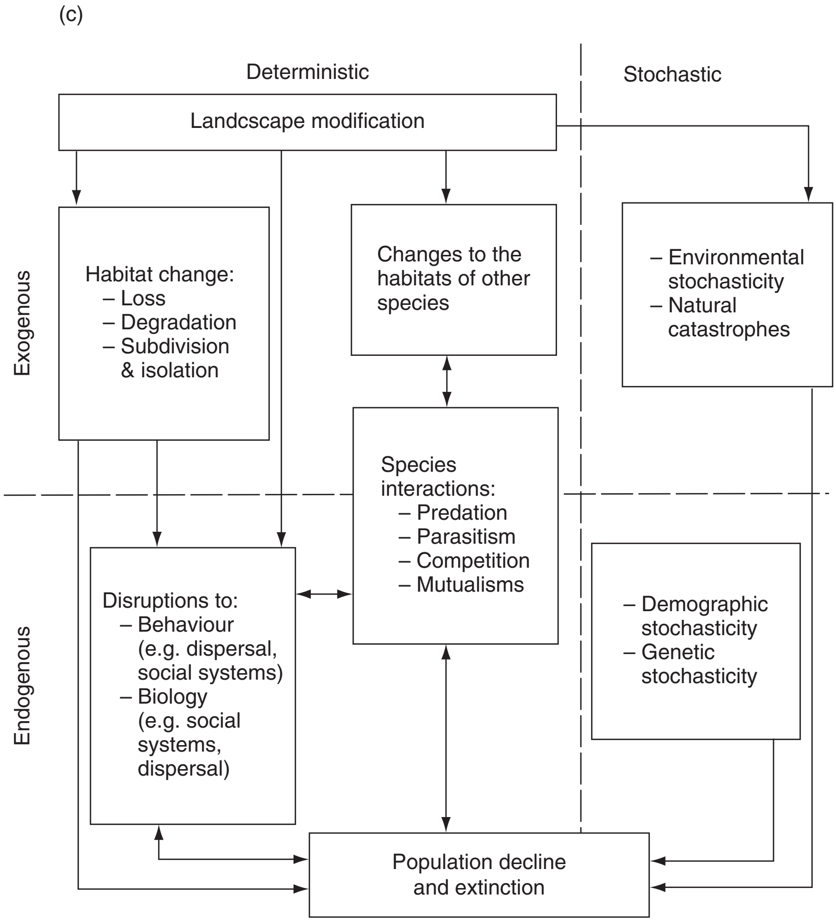

Figure 2.1. (cont.)

Fischer and Lindenmayer (2007) argued that the separate treatment of the different subcomponents of landscape change has led to a range of parallel research paradigms. Two extremes can be identified along a continuum of approaches to understanding the effects of landscape modification on species and assemblages. At one end of the continuum are species-oriented approaches, centred around the response of individual species to landscape change. These approaches are underpinned by recognition of the fact that each species responds individually to landscape change in ways that are broadly related to requirements for nutrients, space, shelter and specific climatic conditions. Interspecific processes such as competition, predation and mutualisms are also important (Fischer and