



Libraries and Learning Services

University of Auckland Research Repository, ResearchSpace

Copyright Statement

The digital copy of this thesis is protected by the Copyright Act 1994 (New Zealand).

This thesis may be consulted by you, provided you comply with the provisions of the Act and the following conditions of use:

- Any use you make of these documents or images must be for research or private study purposes only, and you may not make them available to any other person.
- Authors control the copyright of their thesis. You will recognize the author's right to be identified as the author of this thesis, and due acknowledgement will be made to the author where appropriate.
- You will obtain the author's permission before publishing any material from their thesis.

General copyright and disclaimer

In addition to the above conditions, authors give their consent for the digital copy of their work to be used subject to the conditions specified on the [Library Thesis Consent Form](#) and [Deposit Licence](#).

A spatio-temporal approach for exploring human-wildlife conflict using the kea (*Nestor notabilis*) as a case study



Erin Margaret Kennedy

A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy in Biological Sciences, the University of Auckland, 2017.

This thesis is dedicated to my amazing mother

To be likened to you in any way is the greatest compliment I could ever hope to receive

ABSTRACT

Globally, human-wildlife conflict is one of the main threats to the continued persistence of numerous species. In my thesis, I developed a spatio-temporal framework with the aim that it inform management of conflict-prone animal species such as the kea (*Nestor notabilis*). My specific research aims were to: 1.) characterise the movement and behavioural patterns of kea; 2.) quantify the nature and extent of kea interactions with anthropogenic infrastructure in their environment; 3.) explore how human activity may be affecting kea behavioural patterns; and 4.) assess the impact of human-wildlife conflict on kea population dynamics relative to other important threats. Applying a spatial framework to explore human-wildlife conflict requires the collection of spatio-temporal data to describe movement patterns and their relation to human features in the landscape. First, I assessed the use of animal-borne GPS telemetry as a means of collecting movement data from kea. I observed: no apparent adverse effect of the loggers on the condition of the kea; no damage to the devices that impaired their function; and that the operational performance provided high-resolution data sufficient characterising the movement patterns of wild kea. The high proportion of GPS fixes recorded in human areas and strength of habitat preference revealed that the kea in my study were attracted to human areas. Using a switching Monte-Carlo Markov-Chain model I was able to assign behavioural states to the GPS fixes, revealing that kea spent significantly more time on ground-based behaviours than flight. Kea demonstrated strong temporal variation in proximity to humans areas, and generally were in/or close to human areas at times of the day when human activity was highest. My results showed that individual kea clearly differ substantially in their movement patterns; most probably because of differences in age or reproductive status. Temporal variation in patterns of behaviour indicated that, for some individuals, durations of area-restricted behaviour varied as a function of proximity to human areas. The outcomes of a stochastic stage-based model used in a population viability analysis indicate that the biggest threat to kea populations is predation by introduced mammals, but as human populations continue to grow in kea habitats human-induced mortality could become a major threat in the future. My results suggest the spatial approach adopted here is an effective means of describing fundamental aspects of human-wildlife interactions and potential conflict. As technology and the associated analytical toolkit continue to improve, I believe the use of spatio-temporal approach will prove to be a vital tool for exploring and mitigating human-wildlife conflict in a range of species.

ACKNOWLEDGEMENTS

An African proverb states that “It takes a village to raise a child”. I would argue that the same applies to producing a PhD thesis, and thankfully for me, I had an amazing village.



First of all I would like to thank my talented supervisory team: Todd Dennis, George Perry, and Josh Kemp. Each has made a unique contribution of their particular skills which, together, have guided me to the completion of my thesis. Todd, thank you, for leading me to toward working with kea, I could not have asked for a better project. I really appreciate the excitement and energy you inspired, as well as the support you

provided when I was struggling to keep my spirits up. George, in my mind you are a super hero; every comment you made about my work, every reference you suggested I check out, was spot on. The advice you gave me, provided me with a lighted path towards the finish line. Josh, thank you for being prepared to spend a week tinkering about with GPS devices with me and imparting so much technical advice- I never knew there was so many different kinds of hardware stores! Thank you all for sharing your wisdom with me.

My research consisted of long field seasons and would not have been possible without the help of two amazing people: Jacinda and Corey. You both provided me with invaluable training and assistance. Corey, thank you for showing me the ropes and taking the time to help me develop the attachment design; your roasts were not half bad too. Thank you both for taking the time to share all you know about these amazing creatures, it added so much value to my research. I am grateful for Meng, Craig, and Britney for coming and assisting me in the field.

I was supremely fortunate to share this crazy experience with a bunch of the most amazing people you could hope to meet, people I consider as my “cohort”: Megan, Craig, Hendrik, and Jingjing. First of all I have to thank you all for the amazing support you provided. I do not think it would be possible to get through this experience without the coffee dates, pep talks and strolls to Munchy Mart. I will always marvel that I managed to meet so many, talented and fun people. Our writing group was so helpful to me, thank you for taking the time to consider my work and provide helpful comments and suggestions. I really appreciated having a group of people to brain storm with in an environment that is often too solitary. I have to give particular thanks to Craig and Jingjing for the extra time they took to share their modelling expertise with me; I would have been lost without you.

To the Thomas building basement lab, I feel lucky to have been part of a group of such clever, interesting and fun students. Thanks for the supportive environment, all the laughs, and after work drinks. I would like to make particular mention of Leilani, Chrissy, Ivan, Rachael, James and Josie (even though she is a Tamaki peep). I am Grateful for Alex, taking time out of her busy schedule to help proof-read my work. I must give Kate a special shout out, as she was so willing to be a sounding board and support during my writing up phase. I think I may have gone a little crazy without her steadying hand.

On a personal note, I would like to thank my family and friends. Helen, you are such a joy to be friends and I am really proud of what you have achieved with your research and can only hope to follow suit. Becca, we met at quiz night but we sealed the deal with all those delightful brunches. You have been a constant source of fun and I hope we continue our adventures for years to come. Meng, you are pretty much the best friend a girl could hope to procure for herself. Thank you for all your support over the years, and providing the best kinds of distraction from all my thesis woes. Last, but definitely not

least I need to thank my mother. Without you this would not have been possible. Thank you from the bottom of my heart for all your insightful comments about my work (and all that proof reading), the amazing non-stop emotional support, and the financial help you provided.



TABLE OF CONTENTS

ABSTRACT	iii
ACKNOWLEDGEMENTS.....	iv
TABLE OF CONTENTS.....	vii
LIST OF FIGURES	x
LIST OF TABLES	xi
1 GENERAL INTRODUCTION	1
1.1 Human-wildlife conflict	1
1.2 Increasing magnitude of human-wildlife conflict.....	4
1.3 Emerging field of human-wildlife conflict management.....	4
1.4 Animal movement patterns	6
1.4.1 Data capture of animal locations and movements.....	7
1.4.2 Movement modelling.....	8
1.5 Influence of HWC on population dynamics	9
1.6 The kea (<i>Nestor notabilis</i>).....	10
1.7 Human-kea conflict.....	11
1.7 Thesis objective.....	12
1.8 Thesis structure	13
2 A FEASIBILITY STUDY ON THE USE OF GPS TELEMETRY FOR PARROTS: A CASE STUDY WITH THE KEA (<i>Nestor notabilis</i>)	16
2.1 Introduction.....	16
2.2 Methods.....	18
2.2.1 Study species	18
2.2.2 Study area	19
2.2.3 Tracking devices.....	21
2.2.4 Capture, handling, and evaluation of performance	22
2.3 Results.....	24
2.3.1 Effects on study animals	24
2.3.2 Retrieval and damage assessment of GPS loggers and harnesses.....	24
2.3.3 Performance of GPS loggers	25
2.4 Discussion.....	29

2.4.1 Effect on behaviour and physical condition.....	29
2.4.2 Damage of tracking gear	30
2.4.3 Operational performance of the GPS loggers.....	30
2.4.4 Future directions.....	32
3 A SPATIALLY EXPLICIT APPROACH FOR D HUMAN-WILDLIFE INTERACTIONS AND CONFLICT IN THE KEA (<i>Nestor notabilis</i>).....	33
3.1 Introduction.....	33
3.2 Methods.....	36
3.2.1 Study species	36
3.2.2 Study area	37
3.2.3 Tracking devices.....	39
3.2.4 Capture and handling.....	39
3.2.5 Data analysis.....	40
3.3 Results.....	44
3.3.1 Spatial distribution of GPS fixes.....	44
3.3.2 Behavioural model	46
3.3.3 Temporal variation in behaviour	49
3.3.4 Individual differences in behaviour	51
3.3.5 Spatial variation in behaviour	51
3.4 Discussion.....	55
3.4.1 Proximity and habitat selection.....	55
3.4.2 Occurrence of behaviour	56
3.4.3 Temporal patterns.....	57
3.4.4 Individual variation	58
3.4.5 Influence of proximity to human areas.....	59
3.4.6 Limitations and future directions	60
3.4.7 Summary	61
4 USING A POPULATION VIABILITY ANALYSIS TO EXPLORE HOW HUMAN-WILDLIFE CONFLICT INFLUENCES POPULATION DYNAMICS: A CASE STUDY WITH THE KEA (<i>Nestor notabilis</i>).....	63
4.1 Introduction.....	63
4.2 Methods.....	66
4.2.1 Study species	66
4.2.2 Model structure	67
4.2.3 Model parameters	70
4.2.4 Model scenarios	74

4.2.5 Model execution and analysis	76
4.2.6 Sensitivity analysis.....	76
4.3 Results	77
4.3.1 Effect of HIM rate on kea population size and growth rate.....	77
4.3.2 Effect of predation rate on kea population size and growth rate	78
4.3.3 Effect of 1080 pest control on kea population size and growth rate	78
4.3.4 Effect of HIM on extinction risk	83
4.3.5 Effect of predation on extinction risk.....	83
4.3.6 Sensitivity analysis.....	85
4.4 Discussion.....	86
4.4.1 Effect of current HIM rates on kea population dynamics.....	86
4.4.2 Influence of HIM rates increasing over time	87
4.4.3 Relative influence of predation rate and HIM rate on kea population dynamics.....	87
4.4.4 Use of 1080 for predator control.....	88
4.4.5 Limitations.....	88
4.4.6 Management implications.....	89
5 GENERAL DISCUSSION	91
5.1 Summary of findings	91
5.2 Characterising the movement and behavioural patterns of kea	92
5.3 Quantifying the nature and extent of kea interactions with anthropogenic infrastructure.....	93
5.4 The effect of human activity on Kea	94
5.5 Qualitatively assess the impact of HWC on kea population dynamics.....	94
5.6 Informing Management examples.....	95
5.7 Potential of approach for other species	96
5.8 Future directions.....	98
5.9 Concluding remarks	100
References	101

LIST OF FIGURES

Figure 1.1: A summary of the thesis, showing the topics covered by each chapter.....	14
Figure 2.1: Study area in Arthur’s Pass National Park.....	19
Figure 2.2: Schematic diagram of GPS datalogger and harness.	21
Figure 2.3: Consecutive daily GPS locations of an adult male Kea (<i>Nestor notabilis</i>) in Arthur’s Pass National Park, New Zealand, November 28 – December 3, 2012.....	27
Figure 3.1: Arthur’s Pass National Park, New Zealand, showing GPS fixes from all study birds.....	37
Figure 3.2: Cumulative proportion of GPS fixes from ten GPS-tracked kea in relation to distance from human areas.	44
Figure 3.3: Consecutive daily GPS locations of kea A over a 7-d period in Arthur’s Pass National Park, New Zealand.	46
Figure 3.4: Mean distances of kea to the nearest human area, differentiated by behavioural state (yellow= ‘State 1’ and blue= ‘State 2’) in relation to time of day.....	49
Figure 3.5: Two examples (panels A and B) of sequences of consecutive behavioural bouts of kea B in Arthur’s Pass Village.....	53
Figure 4.1: The kea’s current range (shown in red) in the South Island of New Zealand	66
Figure 4.2: Schematic representation of the age-class sub-model of kea population dynamics	68
Figure 4.3: Model outputs across the 12 kea population scenarios assessed.....	80
Figure 4.4: Population dynamics under Scenario XII showing the effect of increased adult mortality due to 1080 pest control.....	81
Figure 4.5: Extinction curves for scenarios IV, V, VI, VII, VIII, and XI.....	83

LIST OF TABLES

Table 1.1. Examples of the different types of HWC and their effect on wildlife.....	3
Table 2.1: Performance characteristics of archival GPS dataloggers recovered from 10 wild kea (adults) following field trials at Arthur’s Pass National Park.	25
Table 3.1: Jacob’s Index values showing selection of areas of human activity within 99% kernel-density estimates (KDE) of space use.	44
Table 3.2: Means and standard errors of the number, proportion, and duration of bouts of different behavioural states for the observational periods of ten kea ranging from 145 – 186 hours.	47
Table 4.1: The baseline demographic parameters used in the PVA model.....	72
Table 4.2: Range of scenarios tested with the PVA; showing specific parameter values	73
Table 4.3: Summary of results for Scenarios I-XII over 250 years and 200 simulations	78
Table 4.4: Sensitivity values for nine model parameters.....	84

Co-Authorship Form

This form is to accompany the submission of any PhD that contains published or unpublished co-authored work. **Please include one copy of this form for each co-authored work.** Completed forms should be included in all copies of your thesis submitted for examination and library deposit (including digital deposit), following your thesis Acknowledgements. Co-authored works may be included in a thesis if the candidate has written all or the majority of the text and had their contribution confirmed by all co-authors as not less than 65%.

Please indicate the chapter/section/pages of this thesis that are extracted from a co-authored work and give the title and publication details or details of submission of the co-authored work.

Chapter two

Kennedy, E.M., Kemp, J.R., Mosen, C.C., Perry, G.L., & Dennis, T.E. (2015) GPS telemetry for parrots: A case study with the Kea (*Nestor notabilis*). *The Auk*, 132, 389-396.

Nature of contribution by PhD candidate

Chapter conceptualisation and design, acquiring ethics and consent, development and design of tracking equipment, data collection, data analysis, writing, submission

Extent of contribution by PhD candidate (%)

80


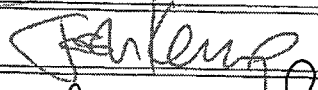

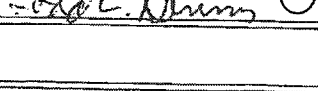
CO-AUTHORS

Name	Nature of Contribution
Corey Mosen	Development and design of tracking equipment, data collection
Josh Kemp	Acquiring ethics and permits, development and design of tracking equipment
George Perry	Chapter conceptualisation and design, editing of chapter
Todd Dennis	Chapter conceptualisation and design, development and design of tracking equipment, data analysis, editing of chapter

Certification by Co-Authors

The undersigned hereby certify that:

- ❖ the above statement correctly reflects the nature and extent of the PhD candidate's contribution to this work, and the nature of the contribution of each of the co-authors; and
- ❖ that the candidate wrote all or the majority of the text.

Name	Signature	Date
Corey Mosen		3/9/16
Josh Kemp		1.9.16
George Perry		10/11/16.
Todd Dennis		1.09.2016

1

GENERAL INTRODUCTION

1.1 Human-wildlife conflict

Human-wildlife conflict (HWC) occurs where the activities and requirements of humans and wildlife overlap, resulting in direct and/or indirect negative impacts to one or both (ICUN 2003). This definition is very broad; my thesis focuses on the effects of HWC in the context of wildlife conservation. Although the impact of HWC on humans is of great importance, it is beyond the scope of my research (see Woodroffe *et al.* 2005; Dickman 2010; Barua *et al.* 2013). The effects of HWC on wildlife can be separated into two broad categories, direct and indirect, as summarised in Table 1.1. The indirect effects are generally a by-product of human growth and expansion, resulting in a long-term impact on individual fitness and hence species persistence (Jetz *et al.* 2007). While both effects are important, I am focusing on direct HWC events where the conflict has an immediate impact on an individual animal. In this context, intentional HWC generally arises for one of two reasons. First, wildlife is killed for financial gain: it has been estimated that, in the last decade, 30,000 African elephants are being poached yearly, for their ivory tusks (UNEP *et al.* 2013). In addition, contact with wildlife can lead to economic loss via crop raiding, livestock predation, or property damage (Distefano 2004), or health impacts such as attacks causing injury or death (Woodroffe *et al.* 2005) for humans. This can result in the retaliatory killing of ‘problem animals’. In contrast, accidental HWC usually occurs simply due to humans and wildlife being in the same place at the same time, resulting in injury or death to an individual animal. It can be

more difficult to estimate accidental wildlife mortalities caused by humans; Loss *et al.* (2015) suggest that millions of birds are killed by vehicle strike every year in North America alone.

Table 1.1. Examples of the different types of HWC and their effect on wildlife.

Effect	Intent	Examples	Citations
Direct	Intentional	Exploitative Wildlife smuggling Poaching Game hunting	Zhang <i>et al.</i> 2008 Wittemyer <i>et al.</i> 2014 Loveridge <i>et al.</i> 2007
		Retaliatory Shooting Poisoning Trapping	Kissui 2008 Mateo-Tomás <i>et al.</i> 2007 Sinha <i>et al.</i> 2006
	Accidental	Vehicle strike Poisoning Electrocution	Loss <i>et al.</i> 2015 Reid <i>et al.</i> 2012 Kumar & Kumar 2015
Indirect		Habitat loss, degradation and fragmentation Climate change Introduced predators	Prugh <i>et al.</i> 2008 LaFever <i>et al.</i> 2008 Jetz <i>et al.</i> 2007 Simpkins <i>et al.</i> 2015

1.2 Increasing magnitude of human-wildlife conflict

Globally, HWC is of growing concern to conservation biologists (Messmer 2000; Dickman 2010; Manfredo 2015). While HWC has been occurring for millennia (Smilie 2002), conflict events are increasing in their frequency and severity; a trend that will likely continue (Madden 2004; Thirgood & Redpath 2008; Dickman 2010). The main factors acting to increase rates of HWC are human population growth (ICUN 2003) and land-use transformation (Vijiyan & Pati 2002; Mishra *et al.* 2003), resulting in human expansion into wildlife areas and increased competition among wildlife for natural resources (Siex *et al.* 1999). From a conservation perspective, conflicts between humans and wildlife are of particular concern when and where they lead to the harm or death of individuals which are threatened or protected species. Taxa subjected to persistent conflict(s) with humans are more vulnerable to population decreases, which ultimately may lead to their (local) extinction (Messmer 2000; Ogada *et al.* 2003). Increased mortality as a direct consequence of human activity not only affects the population viability of endangered species, but also has broader environmental impacts on ecosystem dynamics and the preservation of biodiversity (Woodroffe *et al.* 2005). With such wide-reaching potential effects it is critical for governments, local communities, researchers, and wildlife managers to recognise the problems posed by HWC and to develop effective mitigation strategies in response.

1.3 Emerging field of human-wildlife conflict management

The field of HWC management is relatively new, and much of the research conducted to this point has focused on highlighting the challenges we face and identifying the

information needed to develop effective mitigation strategies against them (Messmer 2000; Madden 2004). Historically, management of HWCs often involved the lethal culling of populations or the removal of problem individuals (Treves *et al.* 2006; Messmer 2000). More recently, however, there has been a move to use more wildlife-friendly strategies such as physical barriers, sensory deterrents, and compensation schemes (Distefano 2004; Treves, Wallace & White 2009). Nevertheless, these methods are generally costly, not widely applicable, based on inadequate data, and are often used as an alternative to the development of appropriate research (Treves *et al.* 2006; White & Ward 2010; Urban 2013). Overall, it appears that science needs to inform policy and practice better (e.g. adaptive management; Westgate *et al.* 2013); recent reviews have highlighted the need for more quantitative data of the biology underlying HWC (Thirgood & Redpath 2008).

Understanding the ecology and behaviour of a conflict-prone species is a fundamental first-step in developing effective management strategies (Conover 2001; Treves *et al.* 2006). For example, research by Harding *et al.* (2009) on the resource requirements and preferences of woodpeckers in the U.S.A was used to make recommendations about the most suitable building material to dissuade woodpeckers from damaging properties. However, despite its importance, ecological data are scarce for many conflict species, as collection of relevant data is logistically challenging and costly (White & Ward 2010; Young *et al.* 2010; Urban 2013). There has been a move towards developing overarching conceptual frameworks for the science of HWCs, with the goal of making it easier to translate research outcomes across sites and taxa in a way that is accessible for management (Morzillo *et al.* 2014).

1.4 Animal movement patterns

The study of animal movement is increasingly prominent in conservation biology (Patterson *et al.* 2008). Knowledge of animal movement and the factors that drive the variation in movement patterns are integral components of behavioural ecology, conservation and protected-area management. Considerable effort has been devoted to understanding various aspects of animal movement and the interplay between movement patterns and the factors that explain them (Cain 1985; Holyoak *et al.* 2008). The increasing availability of abiotic (e.g., geo-referenced habitat maps, fine-scale atmospheric information) and biotic information (e.g., heart rate monitors) facilitates researchers' ability to determine how these factors influence movement patterns (Nathan *et al.* 2008). For example, information derived from movement patterns has been used in a wide range of ecological research, including considerations of foraging (Votier *et al.* 2010), habitat and resource selection (Northrup *et al.* 2016; Mansson 2013), dispersal (Lopez Lopez *et al.* 2014), migration (Lendrum *et al.* 2012), and behavioural studies (Dean *et al.* 2012).

Using the movement patterns of conflict species has huge potential for providing a range of methods to assess important aspects of HWC scenarios. Knowing where animals move can be used to identify critical habitat for populations, which is important information when habitat overlaps with areas of human interest. Berger (2004), for example, used the movement patterns of pronghorn antelope (*Antilocapra americana*) to show that important migratory corridors were being threatened by oil and energy industry development. Studying animal movement can improve our understanding of the dynamics of interactions between wildlife and humans. Quantifying how movement patterns are related to human features in multi-use habitats (Cagnacci *et al.* 2010) may

support prediction of where and when conflict is likely to occur. It is also possible to quantify the impact of human activity on animal behaviour (Whittington *et al.* 2005; Sawyer *et al.* 2009); for example, in Nepal movement tracks suggest that some tigers have altered their natural activity patterns to avoid periods of high human activity (Carter *et al.* 2012).

1.4.1 Data capture of animal locations and movements

A range of methods has been used to collect geolocation data from free-ranging wildlife. Some of the older techniques, which include direct observations, mark/recapture using live traps, spool and line techniques, and VHF (very high frequency) radio-telemetry, have been used to study animal movement (White & Garrott, 1990). Although these methods have been used frequently, all have limitations that affect the quality and quantity of the resultant data (Coulombe *et al.* 2006). Direct observations are labour intensive, constrained by visibility and likely to induce biases in the behaviour of study animals (Hansen *et al.* 1992). Mark/recapture and spool-and-line techniques are limited by line length and weight, trap numbers, and the distribution and frequency with which traps are monitored. Live-trapping methods record a presence or absence in a given area, yet they tell us little about actual animal movements (Moraes & Chiarello 2005). Over the past 35 years, a number of animal-borne tracking technologies have been developed, and the most recent technological advancements have greatly improved data accuracy and resolution. Geolocators (Egevang *et al.* 2010), ARGOS satellite tags (Costa *et al.* 2010), GPS/GSM loggers (Weber *et al.* 2015), and video-tracking (Moll *et al.* 2007) have been used to track a range of species from terrestrial to marine over varying spatial (thousand-mile migrations to local movements) and temporal scales (days to years).

As Global Positioning System (GPS) devices, become miniaturised and more affordable, they are increasingly accessible to researchers and can be applied to a broader range of questions. These devices allow for the collection of location fixes with very high spatial and temporal accuracy across a wide range of species (Obbard *et al.* 1998; Cagnacci & Urbano, 2008). GPS devices can also sample at very high frequencies (one fix per second) and can collect and store large amounts of data (over 100, 000 fixes) (Cagnacci *et al.* 2010). Additionally, GPS devices give researchers the ability to remotely collect location data, which has many benefits. Firstly remote tracking allows continuous tracking over long durations in climates or terrain that is unsuitable for human observers. Remote tracking allows researchers to obtain location information for animals undergoing extensive movements outside the normal operational range of the observers (Rodgers *et al.* 1996), and provides location estimates that are free from observer biases (such as, the disruption of normal behaviour due to a human presence) (Arthur & Schwartz, 1999). Remote tracking also facilitates tracking nocturnal, cryptic, and secretive species, and it reduces researcher effort (Obbard *et al.* 1998). GPS devices have been used to study patterns of animal habitat use and resource selection (Kertson *et al.* 2011; Nelson *et al.* 2012), characterise activity patterns (Owen-Smith & Goodall 2014), identify areas important for conservation (Schofield *et al.* 2013), and respond to anthropogenic disturbances (Panzacchi *et al.* 2013).

1.4.2 Movement modelling

The movement trajectories collected by GPS tracking devices have supported the development of movement models that can help to improve the understanding of animal behaviour. The movement ecology paradigm (Nathan *et al.* 2008) states that the movement track of an animal consists of a range of definable behaviours (e.g., foraging,

dispersal, resting), which reflect both the abiotic and the biotic factors that influence the animal over its life-history. Movement rates (e.g., speed and turning angle) calculated from movement tracks can be used to determine an animal's behavioural state (Gurarie *et al.* 2009) and inferential movement models such as switching state-space models can be used to identify shifts between different behaviours (Morales *et al.* 2004). Dean *et al.* (2012) used hidden Markov models, a type of switching state-space model, to explore the at-sea behaviour of manx shearwaters (*Puffinus puffinus*) during the breeding season. Movement models enable researchers to assess quantitatively how animals are behaving in human-modified environments and may help to identify how human activities are influencing their behaviour.

1.5 Influence of HWC on population dynamics

Quantifying and characterising population dynamics, especially long-term trends in persistence and viability, is essential for the management of HWC species. Population models, for example in the form of population viability analysis (PVA), provide an effective tool for quantifying population dynamics. These mathematical models are informed by demographic data which helps wildlife modellers to explore and partition the influence of different biotic and abiotic factors on a specific population. An understanding of how elevated mortality rates, as may arise from HWC, are influencing a species' population dynamics is important for at least two main reasons. First, it can deliver information on how sensitive populations are to HWC, particularly in comparison to other risk factors; and second, it provides an opportunity to look at the relative effectiveness of alternative management strategies on the population. A PVA-based assessment of the effect of human impacts on the Lower Keys marsh rabbit

(*Sylvilagus palustris hefneri*), showed that while restoring the habitat that had been lost to human development would help populations, it would be more immediately beneficial and cost-effective to eradicate free-roaming cats from the area (LaFever *et al.* 2008). Overall, the information derived from PVA models can inform what further research is needed, rank the efficacy of alternative potential management strategies, and help managers optimise the allocation of limited resources while trying to conserve a population.

1.6 The kea (*Nestor notabilis*)

The kea is a large (45-50 cm head-tail length, 700-1000 g weight), olive-green parrot (family Strigopidae). They are the world's only mountain- and rainforest-dwelling parrot (Greer *et al.* 2015) and are found mostly in high-elevation Southern Beech (*Nothofagaceae*) forest, sub-alpine shrublands, and high-alpine basins and ridges in the South Island of New Zealand. The species is moderately sexually dimorphic, with males (900 – 1100 g) weighing approximately 20% more than females (700 – 900 g) and having longer (12-14%) upper mandibles (Higgins 1999). Kea are omnivorous and feed on a wide range of food items, although they feed predominantly on invertebrates, fruit, leaves, root, flowers (Greer *et al.* 2015). Kea are non-territorial, and form monogamous long-term pairs (Bond *et al.* 1991). They nest on the ground in crevices, usually below the elevational tree-line (McCaskill 1954). Females generally become sexually mature at 4 years of age, although in some cases they breed at 3 years (Jackson 1963). Individuals nest between July and January, with between 1 and 5 eggs being produced (Seal *et al.* 1991). After chicks fledge they will often gather at common social spots with other juveniles and sub-adults (Diamond & Bond 1999). Kea are well known for their innate

intelligence (Gajdon *et al.* 2006) and display complex social interactions, such as group foraging and play (Schwing *et al.* 2017).

1.7 Human-kea conflict

Kea are one of New Zealand's best examples of a species that suffers from HWC. Before human settlement in New Zealand, the kea home range included the North Island mountain ranges (Temple, 1996; Tennyson *et al.* 2014); they are now restricted to the South Island of New Zealand (Robertson *et al.* 2007). Kea are described as a playful, bold, curious, opportunistic, and destructive bird (Huber & Gajdon 2006) and these attributes lead to conflict with humans. Historically, high-country farmers reported incidences of kea attacking sheep to eat fat from around the kidneys, often leading to death of the sheep from sepsis (Orr-Walker & Roberts 2009; Clio Reed, pers. comm.). Consequently a bounty was instituted by the government to cull kea leading to *c.* 150,000 kea being killed over a 100 year period (Temple 1996), before they were afforded full protection under the Wildlife Act in 1986 (Seal *et al.* 1991). Nevertheless conflict remains ongoing, as kea damage human property, disrupt work sites, steal food, etc., and reports of kea strike on sheep continue. In return, kea face both direct persecution (deliberate shooting, trapping and poisoning), and indirect human-induced mortality (e.g. vehicle strike, lead poisoning, electrocution) (Seal *et al.* 1991; Department of Conservation).

The current kea population size is uncertain, but the most recent estimate of overall population size is between 1000-5000 wild birds (Anderson 1986). It is difficult to precisely estimate kea numbers due to their extensive range (largely in rugged terrain), low density, and the cryptic behaviour of adults (Orr-Walker & Roberts 2009). Recently, kea were classified as being 'Nationally Endangered' by the New Zealand

Department of Conservation (Robertson *et al.* 2013); currently the IUCN classification is 'Vulnerable', CITES Appendix II (IUCN, 2014). In some areas, kea populations appear to be in decline due to predation by or competition for resources with introduced mammals (such as stoats, rats and possums), and, to an unknown extent, direct or indirect conflicts with humans (Elliot & Kemp 2004; Gartrell & Reid 2007). There is a need for more information about kea-human conflict to help inform management decisions that can help mitigate conflict events.

1.7 Thesis objective

My thesis focuses on developing a spatio-temporal framework that will help to inform the management of conflict-prone animal populations. I use the kea as a case study species for three main reasons: 1.) there is persistent human-kea conflict, and these conflict events are likely to increase; 2.) kea are highly intelligent, which is often associated with highly developed spatial cognitive abilities, and the areas that kea live are spatially complex. This spatial complexity provides a good test for the effectiveness of using a movement approach for exploring behaviour; 3.) kea populations are declining, which has potential ramifications for alpine biodiversity if kea are not numerous enough to be effective vector of seeds in this habitat, so there is an immediate need for information that could help improve conservation efforts.

The major aims of my thesis are to:

1. Characterise the movement and behavioural patterns of kea;

2. Quantify the nature and extent of kea interactions with anthropogenic infrastructure within their environment;
3. Explore how human activity may be affecting kea behavioural patterns;
4. Assess the impact of HWC on kea population dynamics relative to other important threats.

1.8 Thesis structure

This thesis is presented as five chapters, with the three data chapters (2, 3, and 4) written as stand-alone manuscripts for publication; this has inevitably resulted in some repetition between chapters, particularly in the methods sections. Chapters 1 and 5 provide a synthesis of contextual information and discussion. References for all chapters are compiled at the end of the thesis. A brief outline of the content of each of the following chapters follows:

In chapter 2, I assess the feasibility of tracking parrots by GPS telemetry. Other than the research presented here, there are no published examples of the use of animal-borne GPS telemetry for parrots. Consequently, the development of a workable method was a big undertaking, requiring a time-consuming process of trial and error. I evaluate: (1) the effects of the GPS loggers on the behaviour and physical condition of the study subjects; (2) the extent of damage sustained to the tracking gear; (3) the loggers' operational performance; and (4) the quality of the resulting data. This chapter has been published in *The Auk* (see chapter 2 for citation).

In chapter 3, I develop a spatial framework for quantifying how kea are interacting with human features, and how human activity is potentially influencing kea behaviour.

Jacob's index is used to determine if kea are selecting human areas preferentially. A Monte-Carlo Markov-Chain algorithm (as in Morales *et al.* 2004) was used to assign a distinct behavioural state to each individual GPS location fix. Patterns of kea movements and behaviour helped to determine how kea proximity to human areas varied through time, assess individual-level differences in the locations and magnitude of human-kea interactions, and quantify how behavioural patterns changed as a function of distance to human areas.

In chapter 4, I develop an age-structured, density-dependent model of kea population dynamics. This model was implemented to evaluate the influence of human-induced mortality (HIM) on kea population dynamics, determine the relative impacts of HIM and predation on population size, and assess if some aspects of current kea management are actually detrimental for managing kea populations.

In chapter 5, I summarise the findings of chapters 2, 3, and 4 relative to the major aims of my thesis, and discuss the avenues for future research that my own work has highlighted as necessary.

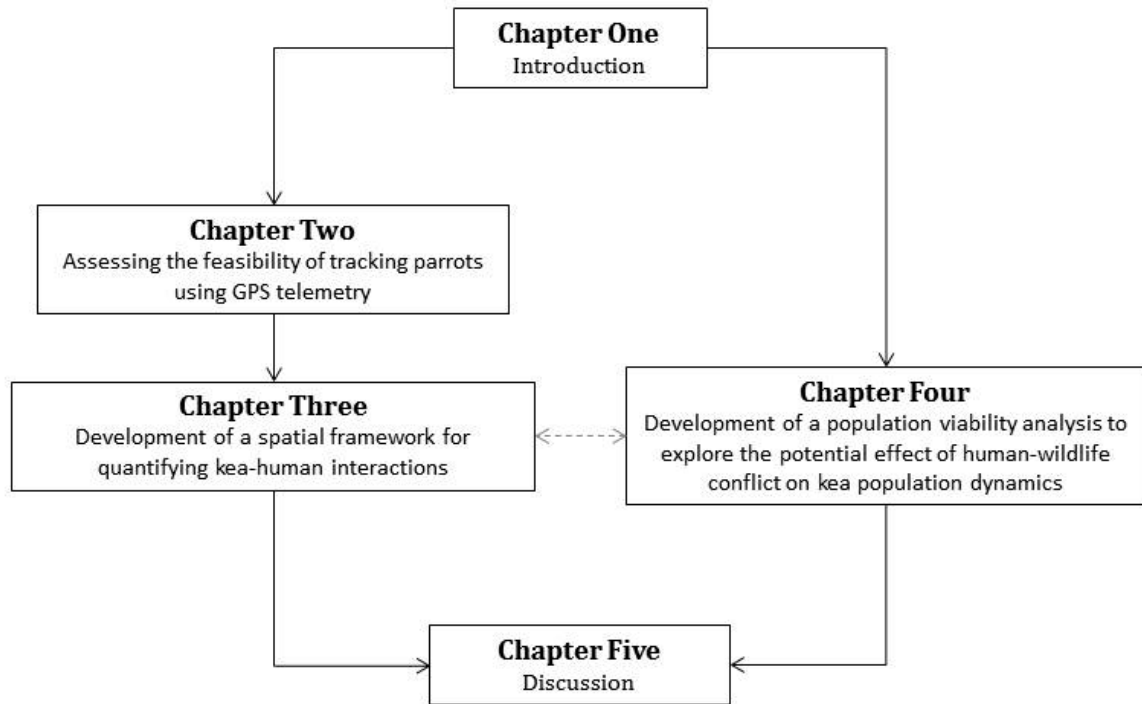


Figure 1.1: A summary of the thesis, showing the topics covered by each chapter. The black arrows represent inter-connections between chapters, while the gray dashed arrow denotes future potential connections.

2

A FEASIBILITY STUDY ON THE USE OF GPS TELEMETRY FOR PARROTS: A CASE STUDY WITH THE KEA (*Nestor notabilis*)

This chapter has been published: Kennedy, E.M., Kemp, J.R., Mosen, C.C., Perry, G.L.W., & Dennis, T.E. (2015) GPS telemetry for parrots: A case study with the kea (*Nestor notabilis*). *The Auk*, **132**, 389-396.

2.1 Introduction

Parrots are one of the most distinctive, speciose and socially complex avian lineages worldwide, yet they also are one of the most threatened groups of birds, with 171 of the 398 recognized extant species being classified as near-threatened to critically endangered (IUCN 2014). Major threats include degradation, destruction, and fragmentation of critical habitats (Snyder *et al.* 2000) and the illegal trade in wild-caught birds (Weston & Memon 2009). Conversely, in some areas parrots are considered to be major environmental pests because of the damage they cause to crops and human property (Bomford & Sinclair 2002). A number of parrot species that have been introduced outside of their original geographic ranges carry infectious diseases and/or are able to out-compete, displace, or pose other risks to indigenous wildlife (Clavero *et al.* 2009). Despite the importance of understanding the social development and structure of parrots, as well as the critical need for development of effective conservation and management strategies, little is known about the movement and space-use patterns of parrots (Herrod *et al.* 2013). Such information is required to

identify essential habitats, describe foraging and/or migratory pathways, characterise responses to human perturbation of natural ecosystems, and locate potential 'hotspots' of human-wildlife conflict that necessitate monitoring or protection.

Currently, one of the most effective means of characterising the movement patterns of free-ranging birds is satellite telemetry based on the global positioning system ('GPS'). GPS telemetry has many advantages over other animal-tracking methods such as direct observation, VHF or UHF radio-telemetry, ARGOS satellite telemetry, light-based geolocation, and RFID sensor networks. Such benefits include its typically high spatial accuracy (Hansen & Riggs 2008), capability to determine location at high sampling frequencies (>1 Hz for some devices), ability to record and store large numbers of observations (e.g. >100,000 fixes), scope to precisely register when location estimates are made, capacity to remotely collect bias-free position information in the absence of human observers (Hebblewhite & Haydon 2010), and ability to continuously track the movements of wide-ranging animals for prolonged periods, even in climatic and topographic conditions that are highly unsuitable for field staff (Arthur & Schwartz 1999).

GPS telemetry has great potential to increase knowledge of the movement and spatial ecology of parrots; however, to date no studies have been published in which this method has been employed (Herrod *et al.* 2013). Most probably this is because of concerns by researchers that the strong crushing beaks, acute manual dexterity, and high intelligence (Pepperberg 2006) of Psittaciforms may limit the durability and retention of animal-borne GPS receivers (Herrod *et al.* 2013; Le Souef *et al.* 2013). Moreover, following capture parrots may become more wary of humans (Beissinger & Snyder 1992), increasing the difficulty of recovering archival tracking devices.

Here, I assess the feasibility of tracking parrots by GPS telemetry in field trials on wild-caught kea (*Nestor notabilis*), an endangered montane parrot endemic to the South Island of New Zealand. My aims were to evaluate: (1) the effects of the GPS loggers on the behaviour and physical condition of the study subjects; (2) the extent of damage sustained to the tracking gear; (3) the loggers' operational performance; and (4) the quality of the resulting data. My study is the first reported use of animal-borne GPS telemetry for parrots; as such it offers crucial insights into the application of this tracking technology for study of the ecology, behaviour, conservation and management of this large and diverse group of birds.

2.2 Methods

2.2.1 Study species

The kea is a large, omnivorous parrot (family Strigopidae) found mostly in high-altitude Southern Beech (*Nothofagaceae*) forest, sub-alpine shrublands, and high-alpine basins and ridges in the South Island of New Zealand. The species is moderately sexually dimorphic, with males (900 – 1100 g) weighing approximately 20% more than females (700 – 900 g) and having longer (12-14%) upper mandibles (Higgins 1999). Recently, kea were classified as being 'Nationally Endangered' by the New Zealand Department of Conservation (Robertson *et al.* 2013); currently the IUCN classification is 'Vulnerable', CITES Appendix II (IUCN, 2014). In some areas populations appear to be in decline due to predation by or competition with introduced mammals, and to an unknown extent, direct or indirect conflicts with humans (Elliot & Kemp 2004; Gartrell & Reid 2007).

2.2.2 Study area

My study was undertaken at Arthur's Pass National Park (42.93°S, 171.56°E) in the Southern Alps, near Mounts Rolleston, Temple, and Cassidy (Figure 2.1). Topographic features at the study site include deeply incised glacial valleys, high alpine peaks, and steep scree slopes; elevations range from 300 – 1720 m above mean sea level. The study area has a mean annual rainfall of >4 m; mean monthly air temperatures range from a low of -2°C in July to a high of 18°C in February (Cliflo 2014).

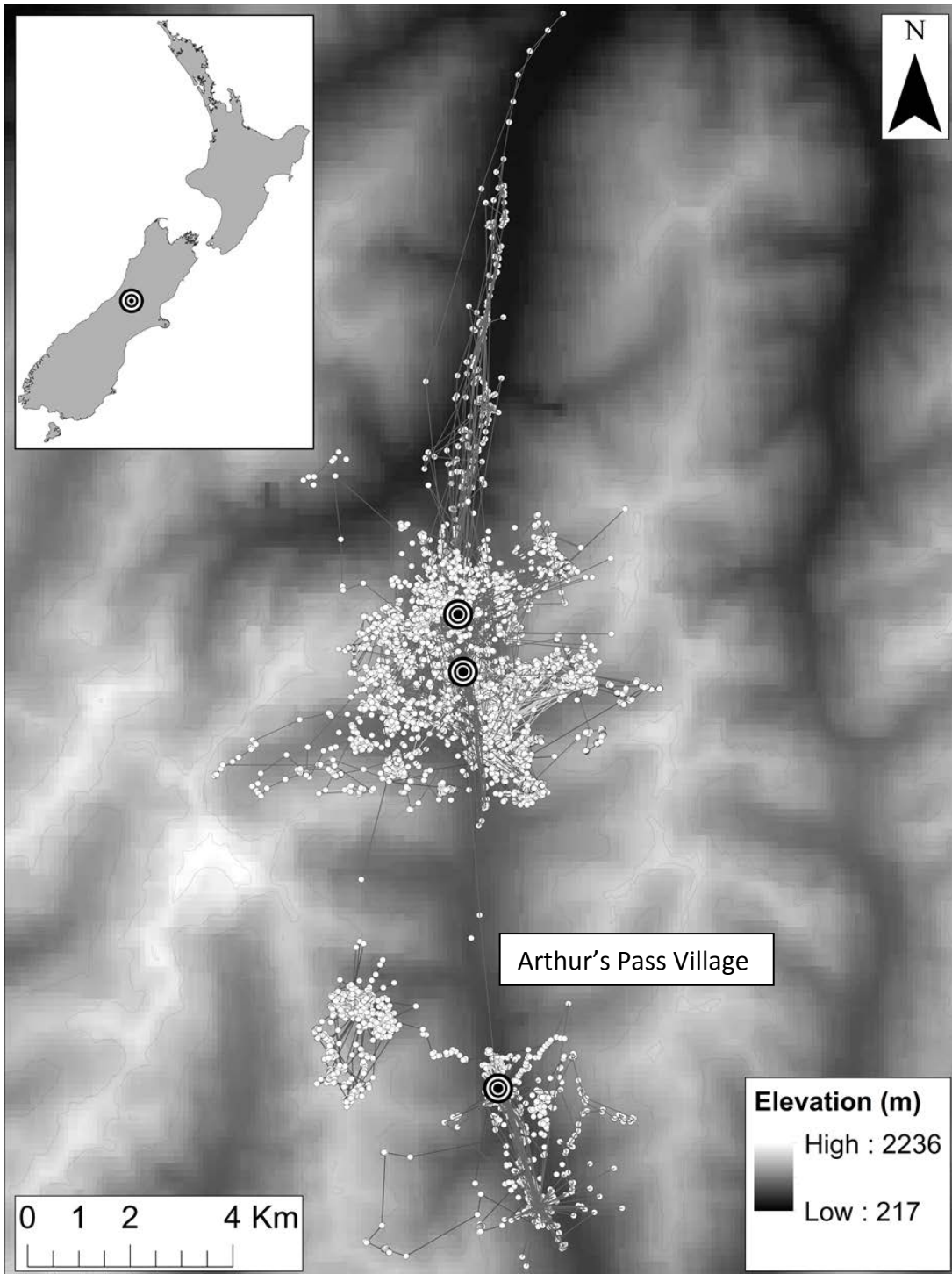


Figure 2.1: Study area in Arthur's Pass National Park showing GPS fixes from all study birds linked sequentially by medium-grey lines. Light-grey lines indicate elevation contours at 300-m intervals. The black line represents the roads and circles denote the three capture sites.

2.2.3 Tracking devices

The GPS loggers evaluated in this study comprised a commercially available 20-channel receiver (Mobile Action Technology; Xindian District, New Taipei City, Taiwan) with integrated data storage and passive ceramic aerial, powered by a 380 mAh 3.7V lithium-polymer rechargeable battery. Loggers were made weather- and bite-proof by removing the receivers from their original plastic housing and sealing them in two layers of ~0.9 mm polyolefin heat-shrink wrap (RNF-100-1, Raychem; Menlo Park/Redwood City, California, USA). Plastic tubes (6 and 4 mm external and internal diameters, respectively) for attachment of harnesses were fixed to the loggers with superglue before a third layer of shrink wrap was added and sealed. Completed devices weighed ~19 g and were ~60 mm x 27 mm x 12 mm (Figure 2.2). The GPS Loggers were configured to continuously record position fixes over a 24-hr period at a nominal sampling interval of one fix every 3 min; such a sampling regimen permitted collection of sufficient data with which to describe the birds' daily patterns of movement and behaviour in detail. The GPS microprocessors used in my study can be programmed by the user to record locations at intervals ranging from 1 fix per second to 1 fix every 2 hours; operational periods of the devices will vary accordingly.

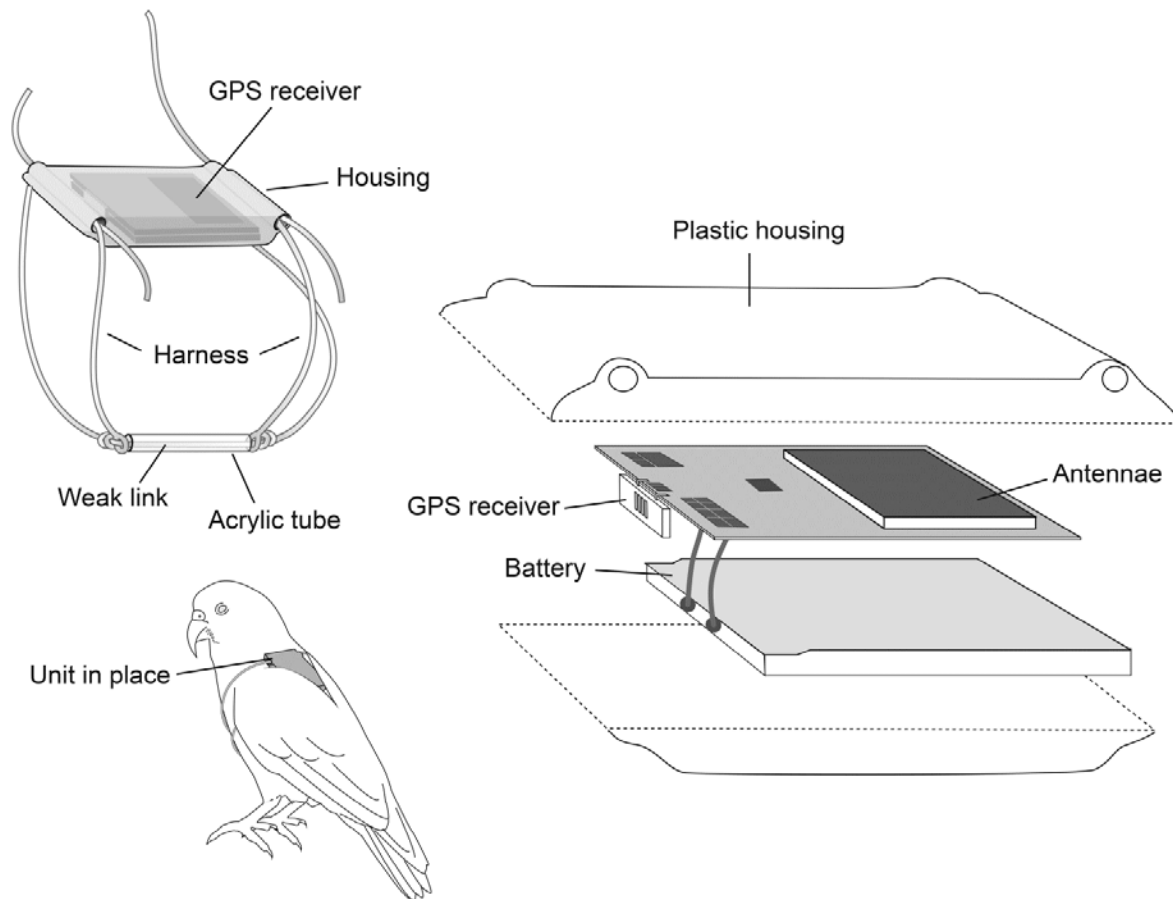


Figure 2.2: Schematic diagram of GPS datalogger and harness.

2.2.4 Capture, handling, and evaluation of performance

GPS dataloggers were deployed on 14 adult male kea intermittently between 03 September, 2012 and 08 January, 2014. Birds were deemed to be suitable candidates for the study only after they had been observed at the field site at least three times during the week prior to attempts to tag them. Individuals were captured either using a leg noose mounted on a 1-m pole, noose lines, (see Bub 2012), or with a net gun that used a 0.32-calibre blank pistol cartridge to propel a 4-m weighted net over the target. GPS loggers were attached to the birds (generally in <15 min) between the wings and above the center of gravity using backpack harnesses (2 g) constructed of 2-mm nylon cord that incorporated a cotton weak link positioned over the keel (as described in Karl & Clout 1987). Following deployment of the loggers, birds were released at their capture

locations and observed for up to 1 h to assess how they responded to handling and carrying the tracking devices. Weights of the GPS devices and harnesses ranged between 1.9% and 2.6% of the study birds' body mass (810 g – 1079 g).

The GPS loggers were retrieved by re-capturing the study birds (using the methods described above) after a minimum of 7 days – the approximate operational life of the batteries at the scheduled sampling interval. The time required to recapture individual kea once they were re-sighted following termination of the trial varied between 1 hour and 5 days. Upon recovery of the loggers, study animals were inspected for loss of body condition and damage to feathers and skin where the devices and harness had been attached. Data recorded in the on-board memory of the loggers then were downloaded to a laptop computer for subsequent analysis.

Field performance of the GPS loggers was assessed primarily through consideration of fix success rate ('FSR': the proportion of scheduled GPS observations that were actually obtained), as the accuracy of the GPS receivers is high compared to other tracking methods and is well documented, and the operational lifetime of devices is strongly dependent on battery size and sampling interval, which will vary according to study species and research objectives (Rempel & Rodgers 1997). Unless otherwise stated statistical values are reported as means \pm standard deviations (*SD*).

2.3 Results

2.3.1 Effects on study animals

Immediately after release and occasionally during deployments I observed all of the study birds resting, walking and flying while carrying the GPS loggers, and saw no obvious indications of distress, impaired movement, or change in normal patterns of behaviour. Periods over which the loggers were carried by individual birds ranged from 6 – 270 days (median = 11 days); the maximum deployment period was an extreme case in which the individual disappeared from the study area for a prolonged time before it eventually returned and the tracking device was recovered. At the time of recapture none of the kea exhibited signs of substantial wear or damage to feathers or skin where the GPS loggers had been fitted; in most cases the loggers and harnesses had been well preened into the body feathers. After a visual inspection all birds were found to have healthy amounts of muscle mass around the keel and none exhibited noticeable loss of body condition.

2.3.2 Retrieval and damage assessment of GPS loggers and harnesses

Twelve of the 14 GPS units eventually were recovered, all of which had sustained only minor damage to the outer layer of heat-shrink wrap (particularly at the ends), most probably because of attempts by the birds to remove the devices. Of the 12 recovered devices two were removed by the kea within the first hour following deployment – these units were operating normally, but due to their short deployment periods they were excluded from further analysis. One of the two birds for which the GPS loggers were not recovered was seen several times after deployment but proved

too difficult to recapture; the second was never observed again. In 5 of the 14 loggers small amounts of moisture had condensed in the outer layers of the shrink wrap; however, when recovered all of these units were in working order and had successfully recorded locations. Eight of the harnesses appeared to have been chewed on, but the damage was superficial and did not weaken the integrity of the attachment.

2.3.3 Performance of GPS loggers

Operational periods of the GPS loggers during the field trials ranged between 118.7 and 186.0 h and the number of position fixes recorded by the devices varied between 1384 and 3622 ($n = 10$; Table 2.1). Fix-success rates ranged between 58% and 102% (mean = $74\% \pm 8\%$). The higher-than-expected FSR of 102% recorded for one logger most likely was due to water damage to the internal clock, which was evident when the device was recovered; therefore it was excluded from the calculation of FSR. Removal of gaps (3 or more successive fixes between sunset and sunrise) in the time series of GPS observations, when presumably the kea were roosting in rock cavities or other areas where fixes could not be obtained, increased the mean FSR to $84\% \pm 9\%$. The median locational error of one logger ($n = 400$ observations) at a fixed location under open sky was 5.7 m.

Table 2.1: Performance characteristics of archival GPS dataloggers recovered from 10 wild kea (adults) following field trials at Arthur’s Pass National Park. ‘FSR’ refers to fix success rate, the ratio of the number of location estimates actually recorded to the number expected during the observed operational periods given the nominal sampling interval. ‘*’ denotes a logger that collected more position fixes than was expected, due a malfunction of the internal clock.

ID	Date deployed	Observational period (h)	Number of fixes	FSR
V-1694	September 3, 2012	148.3	2302	77.6
V-0755	September 4, 2012	118.7	1384	58.3
V-0303	September 5, 2012	147.9	2090	70.7
V-1021	November 11,2012	165.3	2306	69.7
V-0026	November 27,2012	177.0	3622	102*
V-0669	November 27, 2012	173.6	2632	75.8
V-0754	January 10, 2013	184.1	3112	84.5
V2353	November 10, 2013	186.0	2996	80.5
V-0601	November 27, 2013	174.9	2452	70.1
V-0032	December 11, 2013	145.1	2195	75.6
Mean \pm 1 SD		162.1 \pm 21.5	2509 \pm 622	73.7 \pm 7.6

Data recorded by one of the birds’ GPS logger are shown in Figure 2.3. From variation in patterns of movement distinct bouts of flight (location 1 in the figure), walking (location 2), and area-restricted behaviours suggestive of foraging or rest (location 3) can be identified. Probable night-roost areas (locations, 4, 5, and 6) can be inferred through consideration of the timing of prolonged periods of stasis. During 4 of the 6 days of the field trial the kea repeatedly visited a popular scenic lookout (‘Death’s

Corner'; location 7) mostly during the middle of the day during which it was observed begging tourists for food and 'playing' with motor vehicles. From the GPS data it was possible to accurately quantify how long the bird remained at the site (~2 hrs per day) where it regularly interacted with humans. One location (#8) was visited daily, perhaps because it was a favored foraging area but more probably because the bird was provisioning a nest. Periods of stasis and active movement can be easily differentiated: during day 6 there was a brief bout of flight over a distance of >1 km beginning well after midnight (location 9), somewhat unusual for kea because they are considered to be strongly diurnal (Diamond & Bond 1999).

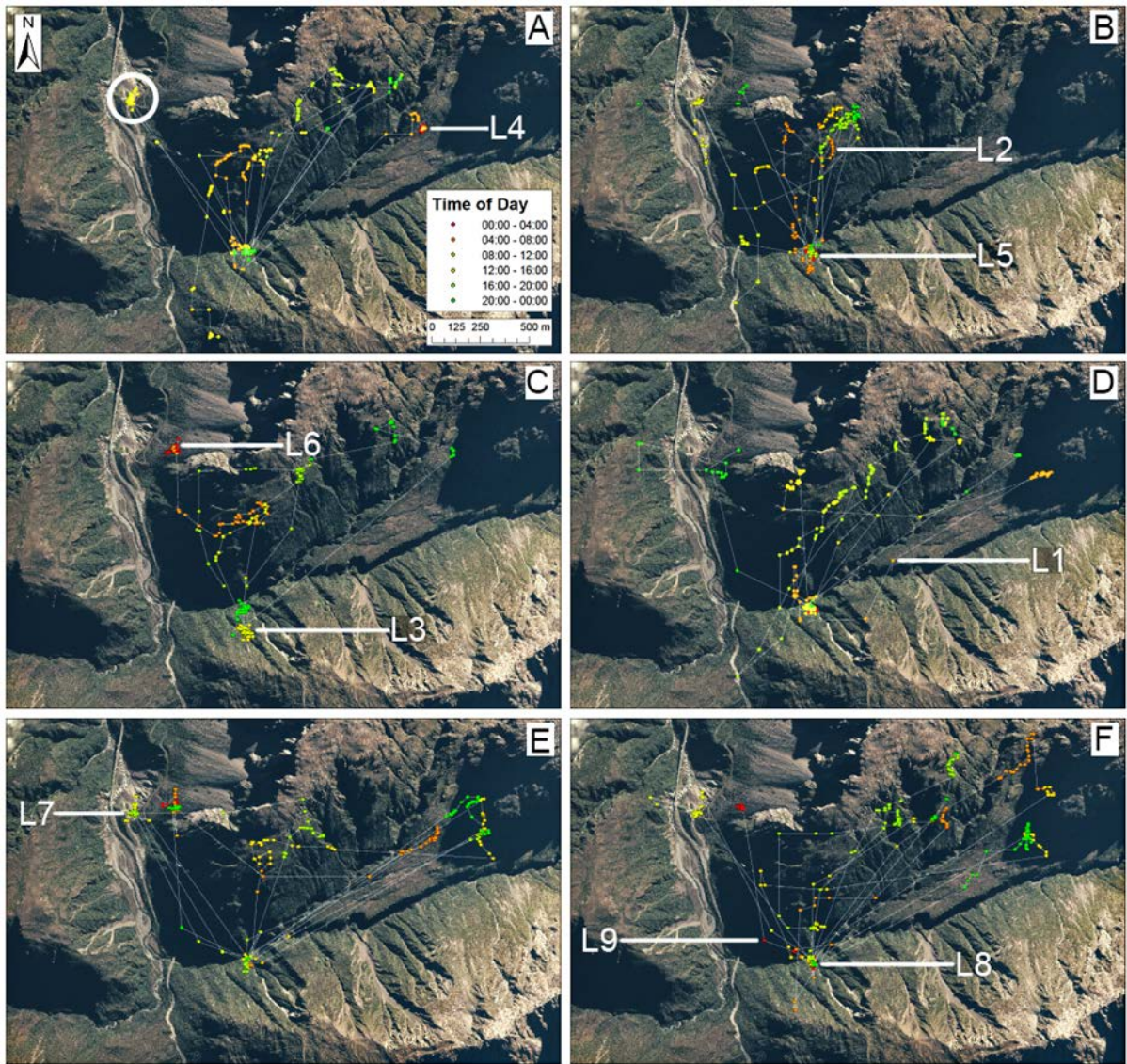


Figure 2.3: Consecutive daily GPS locations of an adult male kea (*Nestor notabilis*) in Arthur's Pass National Park, New Zealand, November 28 – December 3, 2012. Letters in upper right-hand corner represent the sequence of days over which the data were collected (e.g., (A) = day 1; (B) = day 2, etc.). Colored points indicate individual location estimates (nominal sampling interval = 3 min) and light-grey lines link sequential observations. The white circle in (A) denotes the capture location. Numbered locations refer to comments in the main text.

2.4 Discussion

I assessed whether GPS telemetry is a viable means of tracking the movement patterns of wild, free-ranging kea. Three main results emerged from my field trials: (1) the retention rate of GPS loggers attached by backpack harnesses was sufficiently high (6 – 270 days) to justify confidence in obtaining acceptable results in future studies; (2) the logger housing was robust enough to endure water and bite damage such that operation was not impaired; (3) the inexpensive and simple-to-construct loggers that were evaluated in my study performed similarly to comparable devices deployed on other animal species.

2.4.1 Effect on behaviour and physical condition

During the field trials most of the kea initially would chew on or attempt to remove the harnesses and loggers, but when later re-sighted the devices appeared to be well preened into the body feathers, reducing the likelihood of snagging on vegetation or other materials. Similar to Le Soeuf *et al.* (2013), who investigated the effects of attachment methods of tracking devices on several species of captive Black Cockatoos (*Calyptorhynchus spp.*), I observed no damage to skin or feathers where the tracking devices were fitted to the kea. Finally, during the field trials I observed no discernable differences in flight behaviour between tagged and untagged birds, which I attribute to the comparatively low proportional weight (1.9% to 2.6%) and cross-sectional area of the loggers ($\sim 3.2 \text{ cm}^2$, only around half of which protruded above the body feathers).

2.4.2 Damage of tracking gear

Two of the kea removed their loggers during the field trials; in both cases this occurred within one hour of deployment, suggestive of a 'critical' period after which the probability of loss was reduced. Direct observations of the study birds during the field trials and inspection of the discarded loggers indicate that both kea had chewed through the weak links on the harnesses to remove the devices. Careful re-design of the weak links so that they are inaccessible to the birds and use of stronger materials may mitigate this problem. The external housing of the GPS units proved to be sufficiently durable to successfully dissipate the keas' bite forces, most likely because it was difficult for birds to tightly grasp the housing's rounded and smooth surface. Species-specific differences in bite strength should be contemplated when evaluating the potential of GPS telemetry for other Psittaciforms, especially for large species. For such species a number of other materials are available from which to construct external housings that may be suitable, including carbon fiber, epoxy/microballon composites, and various vacuum-molded plastics.

2.4.3 Operational performance of the GPS loggers

The marked variation in FSRs among the individual GPS loggers (ranging between 58– 85%, excluding the one unit that malfunctioned) may have been due to a number of factors, including: the amount of 'available sky', which depends on the composition and density of local vegetation and topography; and individual differences in patterns of activity and behaviour, which can affect the orientation and, therefore, the reception probability of GPS antennae (Frair *et al.* 2010; Mattisson *et al.* 2010). Inspection of the keas' movement trajectories in geographic-information-system ('GIS') software

revealed that large gaps in the time series of GPS locations occurred mostly at night, during assumed rest periods. Kea commonly roost in natural rock crevices, but also in hollow logs, tree cavities, or among the roots of trees (McCaskill 1954; Jackson 1963; Temple 1996). Acquisition of GPS position fixes in such places often is unsuccessful, as dense wood, earth, and rock occlude reception of satellite signals (Cain *et al.* 2005; Bourgoin *et al.* 2009;). Nevertheless, the FSRs of the loggers in my study compare favorably with those of other field deployments of GPS receivers. Cain *et al.* (2005), who reviewed 35 published studies using GPS devices to track a variety of animal species, reported a mean FSR of 69% – marginally below the 74% observed in my study.

The operational performance of the GPS loggers I evaluated compares well to that of tracking technologies. The large volume (~2500 fixes; 367 ± 55 per bird per day) of data collected during my field trials (at a cost of ~2c per fix, excluding labor) would be difficult to replicate with methods other than GPS telemetry. A review of 20 studies that used radio-telemetry to track 11 different parrot species showed that almost half employed radio-telemetry simply to relocate animals, primarily for quantification of mortality rates (e.g. Meyers *et al.* 1996; Collazo *et al.* 2003; White *et al.* 2005). These studies collected far less data per unit time than is possible with GPS telemetry and also incurred higher logistical costs because of the increased need for involvement of field staff. For example, one radio-tracking study of Ground Parrots (*Pezoporus wallicus*) in Australia obtained only 28 – 70 fixes per bird over a period equivalent to my trial duration of ~7 days (McFarland 1991).

2.4.4 Future directions

Although the loggers I developed and evaluated in this study performed well, a number of technological innovations will greatly extend the applicability of GPS telemetry for the study of parrots. Among the most important developments is the ongoing reduction in the size of GPS receivers; 1-g devices are now commercially available, so species weighing as little as 30-g are sufficiently large to be tracked. A second innovation is the increasing access to radio technologies that enable two-way communication with tracking units. Such technology permits remote download of data, precluding the need to recapture tagged animals (Thomas *et al.* 2011), and allows researchers to define geographic areas where alerts can be communicated via SMS text or email when study animals enter or exit ('geofencing'; Wall *et al.* 2014), as well as enabling remote re-configuration of the sampling regimen of tracking devices. Recent advances in the efficiency of batteries and photovoltaic cells will greatly increase the operational lifetimes of tracking devices (Tarascon 2010; Jung *et al.* 2011). Remote drop-off harnesses, especially those operated by user command, will aid in recovery of archival data and tracking devices from birds that may be difficult to recapture. Collectively, these technologies herald a new era in which GPS telemetry can provide information about the movement- and space-use patterns of free-ranging parrots (and other birds) that is critical for development of effective conservation and management strategies.

3

A SPATIALLY EXPLICIT APPROACH FOR ASSESSING HUMAN-

WILDLIFE INTERACTIONS AND CONFLICT IN THE KEA (*Nestor notabilis*)

3.1 Introduction

Globally, human-wildlife conflict (HWC) is an issue of growing concern to conservation biologists (Messmer 2000; Dickman 2010; Manfredo 2015). HWC occurs where the activities and requirements of humans and wildlife overlap, resulting in direct and indirect negative impacts to one or both sides (ICUN 2003). Human population growth and the accompanying decline in 'wild spaces', combined with the restoration of some wildlife populations, has led to an increase in the frequency and severity of HWC; a trend that will likely continue to escalate (Madden 2004; Thirgood & Redpath 2008; Dickman 2010). From a conservation perspective, conflicts between humans and wildlife are of particular concern when and where they lead to the harm or death of individuals of threatened or protected species. Taxa subjected to persistent conflict(s) with humans are more vulnerable to population decreases, which ultimately may lead to their (local) extinction (Messmer 2000; Ogada *et al.* 2003). Increases in mortality as a direct or indirect consequence of human activity not only affect the population viability of endangered species, but also have broader environmental impacts on ecosystem dynamics and the preservation of biodiversity (Woodroffe *et al.* 2005).

Quantifying the extent of interactions between humans and conflict-prone wildlife is essential for predicting and mitigating future negative encounters (Graham *et al.* 2009; Gubbi 2012). The type and duration of human-wildlife interactions can vary markedly in space and time because such interactions are the outcome of dynamic abiotic and biotic processes. In Nepal, habitat fragmentation has pushed tigers into close proximity to human areas where they alter their natural activity patterns to avoid periods of high human activity (Carter *et al.* 2012). One example of how biotic factors influence the likelihood of HWC is reproductive state: during musth, male elephants have heightened aggression levels, which can induce them to attack humans (Das & Chattopadhyay 2011). Effective management of HWC requires understanding how animal populations respond differentially to human presence (e.g., neutral, repulsed, or attracted). The response-continuum to humans is both contextual and scale-dependent, varying among individuals based on their experience and innate tendencies (Dall *et al.* 2004). Some animals, for example, are strongly attracted to human areas, and this behaviour elevates their susceptibility to conflict with humans (Jäggi 2008). Despite the importance of understanding how animals and humans interact, little is known about the spatio-temporal patterns of these interactions, primarily due to the considerable logistical challenge of quantifying them.

A spatially explicit approach, in which animal locations are used to characterise patterns of movement in human-modified landscapes, has great potential to improve our understanding of the dynamics of wildlife interactions with people. Animal locations provide the basic unit of movement paths and can identify areas where individuals interact with habitats co-used by humans (Cagnacci *et al.* 2010). For example, information about the movement patterns of tigers provides knowledge of the

probability of tiger-human interactions in multiple-use landscapes, which is vital for providing guidance on how to balance competing land-uses (Ahearn *et al.* 2001).

Additionally, location fixes of African elephants provides information about patterns of spatio-temporal overlap with people and provide insight into how elephant movement behaviour influences incidences of crop raiding (Jackson *et al.* 2008). At present, the most efficient means for obtaining location data from a variety of animal species is through the use of animal-borne tracking technologies.

Animal-borne tracking technologies, such as the Global Positioning System (GPS), can be used with high accuracy to pinpoint the locations of animals. A range of technologies have been used to track wildlife; e.g., radio-telemetry (Millspaugh & Marzluff 2001), geolocators (Egevang *et al.* 2010), ARGOS satellite tags (Costa *et al.* 2010), GPS/GSM loggers (Weber *et al.* 2015), and video-tracking (Moll *et al.* 2007). These devices have been used to study patterns of animal habitat use and resource selection (Kertson *et al.* 2011; Nelson *et al.* 2012), activity patterns (Owen-Smith & Goodall 2014), identification of areas important for conservation (Schofield *et al.* 2013), and response to anthropogenic disturbances (Panzacchi *et al.* 2013). The resultant data sets allow researchers to perform a range of analyses that can yield insights into the mechanisms underlying patterns of movement (Wells *et al.* 2014; Bestley *et al.* 2015; Gurarie *et al.* 2015). For example, GPS location fixes can be used to infer behavioural states from fine-grain movement data, which provides a new approach for quantifying animal movement behaviour in human-dominated landscapes (Jonsen *et al.* 2005; Wall *et al.* 2014; Zhang *et al.* 2015). Tracking technology and the associated analytical techniques it facilitates have the potential to provide a detailed picture of how wildlife interacts with humans and human-associated areas.

Here, I describe the approach of adopting a spatially explicit perspective to assess human-wildlife interactions as a proxy of HWC. I used location data obtained with GPS telemetry to quantify the locations and magnitude of interactions between wild kea (*Nestor notabilis*), and centres of human activity in New Zealand. My aims were to: (1) characterise the spatial distribution of GPS fixes collected, and ascertain whether kea are selecting human areas as preferred habitat; (2) determine how distance to human areas, and therefore conflict probability, varies through time; (3) assess individual-level differences in the locations and magnitude of interactions; and (4) quantify how behavioural patterns differ as a function of increasing distance from human areas. Finally, I discuss the general issues related to using a spatial approach to quantify HWC and the implications for the management of conflict-prone species.

3.2 Methods

3.2.1 Study species

The kea is a large, omnivorous parrot (family Strigopidae) found mostly in high-altitude Southern Beech (*Nothofagaceae*) forest, sub-alpine shrublands, and high-alpine basins and ridges in the South Island of New Zealand. Recently, kea were classified as 'Nationally Endangered' by the New Zealand Department of Conservation ('DoC') (Robertson *et al.* 2013) and the species' current IUCN classification is 'Vulnerable', CITES Appendix II (IUCN 2014). Kea populations are believed to be declining and this downward trend is attributed in large part to increasing conflicts with humans (Temple 1996; Edwards & O'Connor 2014). Kea are opportunistic scavengers that often exploit anthropogenic resources in their habitats, potentially causing property damage, stock deaths, economic losses, and disturbance of worksites and businesses (Brejarrrt 1994;

Reid, McLelland & Gartnell 2011). Conflict between kea and humans can result in intentional (e.g., shooting, poisoning) or accidental (e.g., road accidents, electrocution) mortality events (Orr-Walker & Roberts 2009). Successful mitigation of kea-human conflict will require a thorough knowledge of interactions between the two species.

3.2.2 Study area

My study was undertaken at Arthur's Pass National Park (42.93°S, 171.56°E) in the Southern Alps, near Mounts Rolleston, Temple, and Cassidy (Figure 3.1). Topographic features at the study site include deeply incised glacial valleys, high alpine peaks, and steep scree slopes; elevations range from 300 – 1720 m above mean sea level. In the study site there is a small area of human settlement centered on Arthur's Pass village (0.6 km², Dundas 2008) consisting of a small resident population of c. 50 people (Brown 2007) and a large annual influx of tourists (c. 250,000 p.a.; Dundas 2008). There are approximately 70 – 100 resident kea in the study area (DoC).

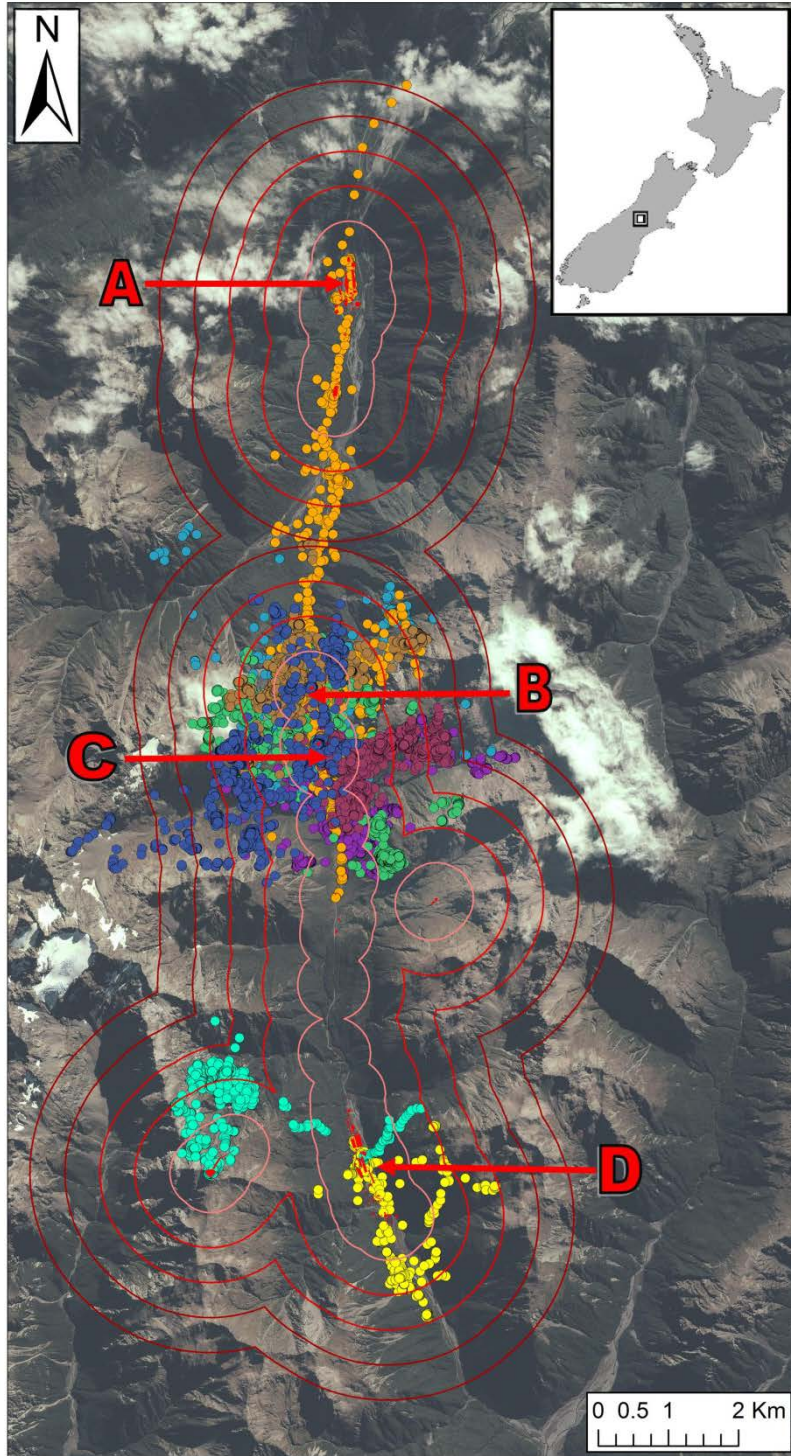


Figure 3.1: Arthur's Pass National Park, New Zealand, showing GPS fixes from all study birds. Each individual's locations are indicated by a different colour. Contour lines represent distances from human areas at 500-m intervals with lightest red colour denoting the nearest distance. Letters have been used to highlight the main centres of human activity (A= Otira Village; B= Candy's Bend Lookout; C= Death's Corner Lookout; D= Arthur's Pass Village).

3.2.3 Tracking devices

The GPS loggers used in my study were commercially available 20-channel receivers (Mobile Action Technology; Xindian District, New Taipei City, Taiwan) with integrated data storage and passive ceramic aerial, powered by a 380 mAh 3.7V lithium-polymer rechargeable battery. The receivers were removed from their original plastic housing and sealed in two layers of c. 0.9 mm polyolefin heat-shrink wrap (RNF-100-1, Raychem; Menlo Park/Redwood City, California, USA). Plastic tubes (6 and 4 mm external and internal diameters, respectively) for attachment of harnesses were fixed to the loggers with superglue, before a third layer of shrink wrap was added and sealed. Completed devices weighed approximately 19 g and were c. 60 mm × 27 mm × 12 mm in dimension. I configured the loggers to continuously record position fixes over a 24 h period at a nominal sampling interval of one fix every 3 min; this sampling regime permitted collection of sufficient data to describe, in detail, the birds' daily patterns of movement and behaviour.

3.2.4 Capture and handling

GPS data-loggers were deployed on 10 adult male kea intermittently between 03 September, 2012 and 08 January, 2014. Locations where kea were captured had a strong human presence. I selected these sites as 'urban' birds are the most likely to be interacting with humans, which are the data I required for this study.

Kea are a protected species and I was only granted legal permission to catch a limited number of adult males. In addition, these birds must have been spotted previously around the study site at least three times to give an increased probability of successful recapture. To assess the age of my study birds, I used the DoC database, which provides

records of resident birds. Kea were captured either using a leg noose mounted on a 1-m pole, noose lines, (see Bub 2012), or with a net gun that used a 0.32-calibre blank pistol cartridge to propel a 4-m weighted net over the target. GPS loggers were attached to the birds (generally in <15 min) between the wings and above the center of gravity using backpack harnesses (2 g) constructed of 2-mm nylon cord that incorporated a cotton weak link positioned over the keel (Karl & Clout 1987). GPS devices and harnesses ranged in weight between 1.9% and 2.6% of the study birds' body mass (810 g – 1079 g). Loggers were retrieved by re-capturing the study birds (using the methods described above) after a minimum of seven days – the approximate operational life of the batteries at the scheduled sampling interval. Data recorded in the on-board memory of the loggers then were downloaded to a laptop computer for subsequent analysis. Methods of capture, attachment, and recapture are described in more detail in Kennedy *et al.* (2015).

3.2.5 Data analysis

Error screening. – The latitude and longitude locations downloaded from the GPS loggers (World Geodetic Survey 1984) were converted to planar eastings and northings in New Zealand Transverse Mercator (NZTM) coordinates using the PROJECT tool in ArcMap v. 10.1 (ESRI 2012). To remove large locational errors, I applied a running median-median smoothing filter (Tukey 1977) to the eastings and northings of each individual's movement trajectory. Median filters reduce possible signal noise and are considered to be the 'ideal' smoothers of spikey time-series data (Evans 1982). Similar to Tukey (1977), my process employed a sampling window of $n = 3$ sequential observations using the 'moving' function in MATLAB v. R2012b (The MathWorks,

Natick, MA, USA). A sampling window of three locations is optimal as it excludes single outliers and negates the 'staircase' effect that is common in median smoothing (Lind *et al.* 2005).

Spatial distribution of GPS fixes. – I digitised a 0.4 m resolution aerial photograph of the study site (Land Information New Zealand) to develop a feature class map in ArcMap v. 10.1 (ESRI 2012) and identified the following human infrastructure: buildings, backyards, parks, camping sites, car parks, and tourist lookouts. Roads were not included as human infrastructure as they follow the natural major orientation of the valley (a natural landscape feature) and hence may be misleading when interpreting movement trajectories. To determine the spatial distribution of GPS fixes in relation to the distance to human infrastructure, I calculated the horizontal distance of each GPS fix to the nearest digitised human feature using the Point Distance tool in ArcMap v. 10.1 (ESRI 2012).

Habitat Selection. – Jacobs Index (Jacobs 1974; Eq. 3.1), as calculated in Ranges7v0.81 software (South *et al.* 2005), was used to assess whether individuals preferentially selected areas of human infrastructure within their 99% kernel density estimate of space use ('third-order' selection; Johnson 1980).

Equation 3.1

$$D = \frac{(r - p)}{r + p - 2rp}$$

Where r is the proportion of habitat type used and p is the proportion of that habitat available. A value of +1 indicates maximum selection, -1 indicates maximum avoidance,

and 0 is neutral selection (i.e., selection is proportional to availability). In this evaluation, individuals were considered to be the sample unit, and human infrastructure was determined to be significantly preferred or avoided if the mean value of Jacob's index was significantly different from zero (Palomeres *et al.* 2000). The evaluation was accomplished by calculating 95% confidence intervals for all individuals' D-indices to assess whether zero was inside or outside the interval, as in (Kauhala & Auttila 2010).

Inferring behavioural states. - Models of multiple correlated random walks were fitted to each kea's movement trajectory using a switching Monte-Carlo Markov-Chain (MCMC) algorithm (as in Morales *et al.*, 2004). MCMCs provide a means to assign a distinct behavioural state to each individual GPS location fix; these are dependent on distributions of step lengths and the absolute values of relative turning angles. This method is commonly used to infer modes of behaviour from movement trajectories (e.g., Patterson *et al.* 2009; Postlethwaite & Dennis 2013), and it is well suited for analysis of remote animal-tracking data, in which consecutive data points are typically nondependent (Dean *et al.* 2012). First, I ascertained the number of distinct behavioural states within each kea movement trajectory using a maximum likelihood method, as in (Dean *et al.* 2012). WinBUGS 1.4 (Spiegelhalter *et al.* 1999) was used to run the MCMC; parameters were first initialised using *k*-means clustering (Leggetter & Woodland 1995) and then optimised through unsupervised training using the Baum-Welch algorithm (Rabiner 1989). For detailed descriptions of the MCMC technique as applied to animal-movement data see Morales *et al.* (2004) and Postlethwaite & Dennis (2013).

Behavioural bouts. - By assigning states of behaviour as inferred from the MCMC model to GPS fixes, I plotted the sequence of behaviour over an individual's entire movement trajectory, showing where, when, and for how long each kea engaged in different states of behaviour. Behavioural bouts were defined as sub-segments of movement trajectories in which behavioural states for sequential observations were the same (a minimum of two observations were considered sufficient to constitute a bout). The duration of each behavioural bout was calculated by subtracting the time of the first fix from the end time of the last fix of the bout. I used a two-tailed paired *t*-test to test for differences in the mean bout duration of different behavioural states inferred by the model. As most interactions occur during the day, only behavioural bouts from the time between sunrise and sunset were used.

Temporal and spatial variation in behaviour. - I calculated how distance to human features and total distance travelled varied for the behavioural states over a 24 h period by using each individual's mean distance to the nearest human feature and distance travelled per hour (sum of distances between locations) over the duration of the tracking period. Here I presented two representative examples of segments of one individual's (B) movement trajectory to evaluate how behaviour is dependent on distance to Arthurs Pass Village ('APV'). To evaluate whether there was a correlation between proximity to humans and duration of 'State 1' behaviours in each segment, I used linear regression.

3.3 Results

3.3.1 Spatial distribution of GPS fixes

Data obtained from the GPS loggers demonstrate the degree of association of the kea's locations to areas of human settlement. Six of the ten study birds regularly visited two tourist areas beside a primary road (Death's Corner and Candy's Bend), while areas of activity for the four remaining birds were concentrated near APV (Figure 3.1). One individual (D) repeatedly travelled between the two tourist areas and a nearby village (Otira) c. 6 km distance, where he recurrently visited several residences. Recorded distances of kea locations from the nearest centres of human activity varied between 0 and 3749 m, with a mean of 676 ± 3 m (Figure 3.2). More than 50% of all GPS fixes were recorded within 700 m of human infrastructure for eight of the kea, and within 1055 m for all birds (Figure 3.2). All kea clearly preferentially selected human areas. Jacob's Index values were all positive, ranging from 0.33 to 0.98 ($= 0.81 \pm 0.15$, 95% confidence intervals; Table 3.1), demonstrating that habitat use of human areas was disproportionately higher than expected on the basis of availability.

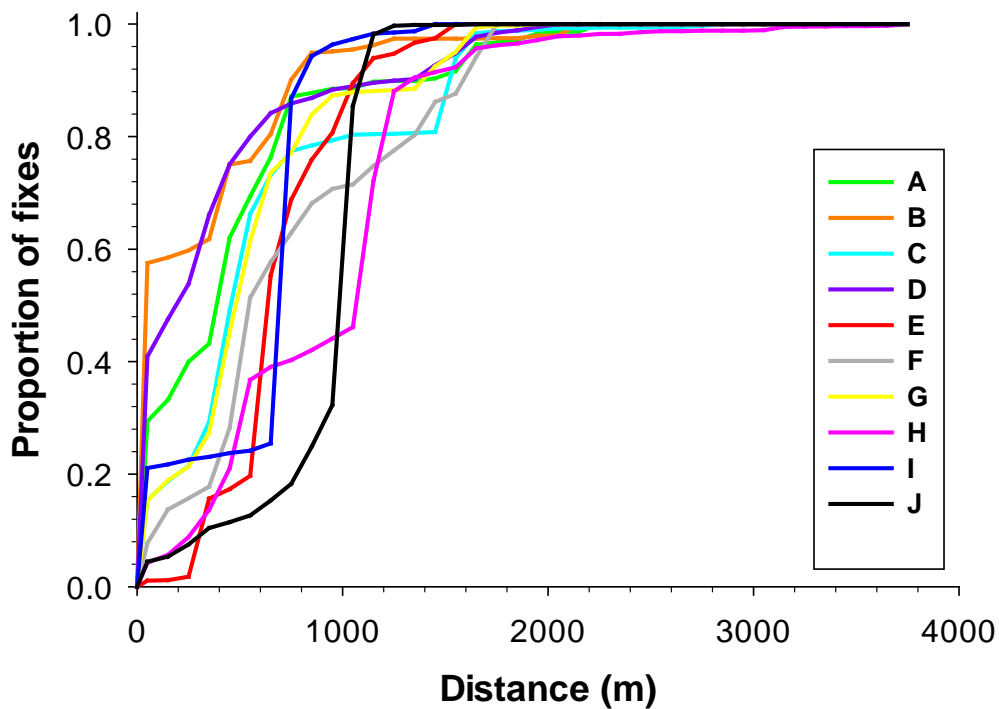


Figure 3.2: Cumulative proportion of GPS fixes from ten GPS-tracked kea in relation to distance from human areas.

Table 3.1: Jacob's Index values showing selection of areas of human activity within 99% kernel-density estimates (KDE) of space use. Positive values indicate preference; i.e., more location fixes were recorded in human areas than expected based on habitat availability alone, whereas negative values indicate avoidance. 'N' represents number of GPS locations.

Individual	99% KDE (ha)	Human area (%)	N	Locations in human areas (%)	Jacobs Index
A	349.3	0.1	1971	13.4	0.98
B	188.9	3.5	1194	40.6	0.90
C	401.8	0.1	1832	8.6	0.98
D	725.2	0.7	2036	23.0	0.95
E	568.6	0.1	3186	0.7	0.69
F	151.5	0.3	2321	5.2	0.91
G	226.0	0.1	2573	8.2	0.97
H	572.8	0.1	2506	2.5	0.91
I	56.0	7.3	2083	13.5	0.33
J	164.5	1.1	2191	2.7	0.43
Mean ($\pm 95\%$ CI)	340.5 (± 137.3)	1.3 (± 1.5)	2189 (± 324)	11.9 (± 7.5)	0.81 (± 0.15)

3.3.2 Behavioural model

All of the kea exhibited two distinct modes of behaviour in their movement trajectories. 'State one' behaviour as inferred by the MCMC model is characterised by low movement rates (6.6 ± 0.7 m/min; mean + 1 SEM) and high relative turning angles ($81.8 \pm 2.1^\circ$), while 'State 2' behaviours exhibited the reverse pattern (42.8 ± 5.3 m/min and $54.5 \pm 1.7^\circ$). Visual inspection of the movement trajectory of kea A (Figure 3.3) indicates that location observations classified as 'State 1' are representative of 'ground-based' behaviours such as resting (example 1a) and walking (example 1b), whereas location observations classified as 'State 2' behaviour are representative of flight, including shorter-distance 'hop' flights around single focal areas (example 2a) and longer-distance commuting trips between focal areas (example 2b).

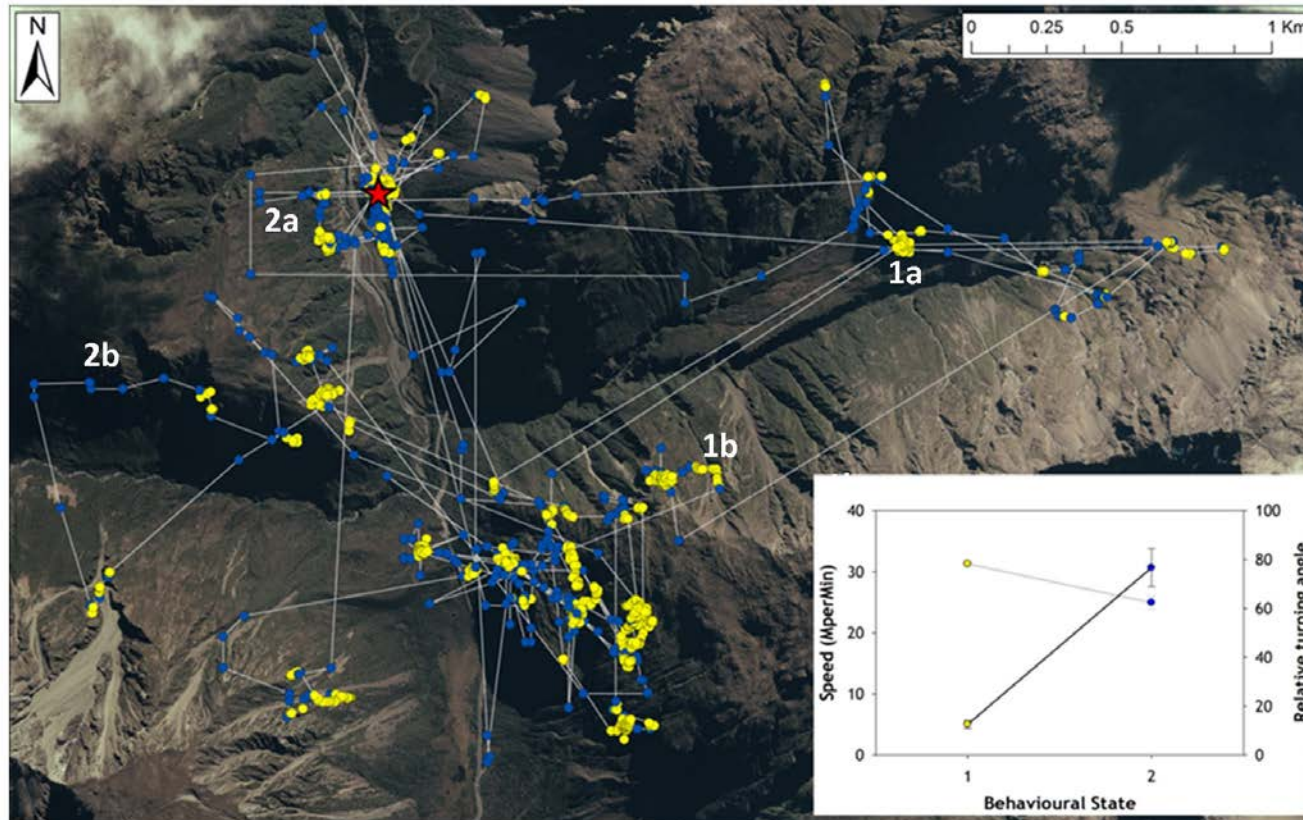


Figure 3.3: Consecutive daily GPS locations of kea A over a 7-d period in Arthur's Pass National Park, New Zealand. The nominal sampling interval of the loggers was 1 fix every 3 minutes. Coloured points indicate different states of behaviour inferred by a MCMC model of animal movement. Yellow = 'State 1' (area-restricted behaviour such as resting, e.g., '1a' and walking, e.g., '1b') and blue = 'State 2' (flight, '2a' and '2b'). The red star denotes the capture location for kea A. Inset shows classification of behaviour via inter-fix speed (black line) and relative turning angles (grey line), and the vertical bars represent one standard error.

The proportion of fixes and the mean duration of bouts in each of the two inferred behaviours are summarised in Table 3.2. ‘State 1’ behaviours accounted for a proportion of between 0.55 – 0.82 of all observations ($\bar{x} = 0.71 \pm 0.03$). Mean durations of behavioural bouts of all ten study birds ranged from 29.6 – 52.6 min for ‘State 1’ and 13.2 – 50.5 min for ‘State 2’. Mean bout durations of ‘State 1’ behaviours (= 43.3 ± 13 min) were 62.8% longer than those of ‘State 2’ behaviours (= 26.6 ± 4.2 min) and the bout durations differed significantly (paired *t*-test, $n = 10$; $t = 0.002$; $p = 0.005$).

Table 3.2: Means and standard errors of the number, proportion, and duration of bouts of different behavioural states for the observational periods of ten kea ranging from 145 – 186 hours. ‘N’ represents number of GPS locations.

Individual	State 1			State 2		
	Proportion	N	Duration (min)	Proportion	N	Duration (Min)
A	0.78	94	47.4	0.22	88	18.63
B	0.74	45	41.6	0.26	42	29.2
C	0.65	55	50.0	0.35	53	50.5
D	0.55	129	45.32.71	0.45	126	30.0
E	0.82	138	39.850.0	0.18	129	13.2
F	0.77	148	44.545.1	0.23	142	15.1
G	0.69	148	52.639.8	0.31	148	19.5
H	0.67	112	29.644.5	0.33	105	31.8
I	0.66	84	52.6	0.34	80	45.7
J	0.76	166	29.6	0.24	162	12.5
Mean (± 1 SEM)	0.71 (± 0.03)	112 (± 13)	43.3 (± 2.4)	0.29 (± 0.03)	108 (± 13)	26.6 (± 4.2)

3.3.3 Temporal variation in behaviour

The mean distances of kea from human areas consistently varied with time of day over multiple tracking days for each kea (Figure 3.4). Generally, birds were closer to human sites between the hours of 08:00 and 18:00, although birds A, B, and C were also sometimes observed in close proximity of human areas during night-time hours. Over a 24-h period, individual kea tended to 'visit' centres of human activity on 1 – 3 separate occasions for between 1 and 8 hours per occasion. Maximum rates of movement were generally highest at sunrise and sunset, although six of the birds showed some degree of night-time activity.

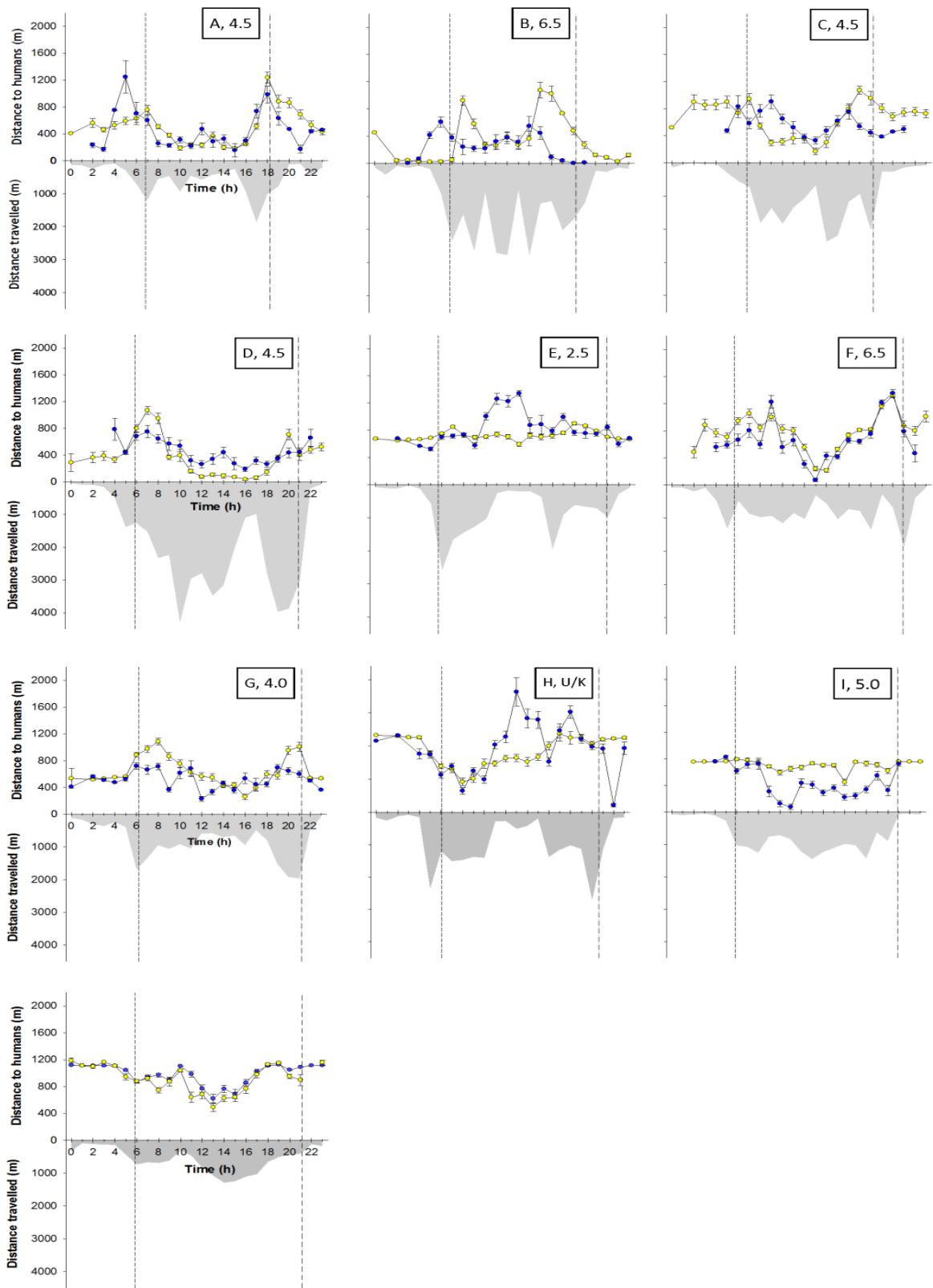


Figure 3.4: Mean distances of kea to the nearest human area, differentiated by behavioural state (yellow= 'State 1' and blue= 'State 2') in relation to time of day. Sunrise and sunset are indicated by horizontal dashed and dot-dashed lines, respectively. Inverted grey-filled areas represent

mean distances travelled per hour. Each panel (A-J) represents a different kea (all adult males), with numbers beside identification letters corresponding to the individual's age in years. Age of kea **H** is unknown.

3.3.4 Individual differences in behaviour

Individuals show differences in movement behaviour, and these may be partly related to the individual's ages. Kea A, C, D, and G (4 – 4.5 years old) all showed similar patterns of association with human areas throughout the day, particularly in prolonged visits during midday (5 – 8 hours; Figure 3.4). Birds F and I, aged 6.5 and 5 years respectively, also were near human areas around mid-day, but for a much shorter duration (1 – 2 hours). Kea B was the only bird to visit human areas consistently during the night. The youngest and oldest birds, 2.5 and 8 years respectively, commonly were further from human sites during the study period. Overall distance travelled per hour also varied among the kea; bird D travelled extensively (maximum distance travelled over an hour ranged from 1289 – 4308 m) while A, F, and J showed more limited movements. Individual birds also showed marked differences in the total distances they travelled during the day.

3.3.5 Spatial variation in behaviour

Movement patterns of kea were influenced to some extent by distance from human areas. Kea showed some steep increases in cumulative distance travelled; when considered alongside the inferred behavioural states, these peaks were associated both with directed behaviour (e.g., commuting to and from human areas) and also area-restricted behaviours (e.g., foraging, playing, or resting) within close proximity to centres of human activity (Figure 3.4). Typically, individual kea showed a roughly equal

mix of 'State 1' and 'State 2' behaviours when near human sites, although individuals H and I demonstrated predominantly 'State 2' behaviours.

I present detailed results of the relationship between distance from human areas and duration of 'State 1' behaviours for one individual (individual B: Figure 3.5). For this individual the duration of 'State 1' behaviour was predicted by distance from the APV for both segments of its movement path (segment 1: $r^2 = 0.91$ $p = 0.048$ segment 2: $r^2 = 0.97$ $p = 0.002$). B had a higher number of bouts of 'State 1' behaviour within the village than those that occurred further from the village, but bout durations were much shorter (range = 9 – 37 min) than further distances (range = 99 – 143 min). Visual inspection of individual bouts of behaviour revealed a higher occurrence of 'area-restricted' behaviour in the APV and comparatively more walking behaviour within the forest habitat outside the APV.



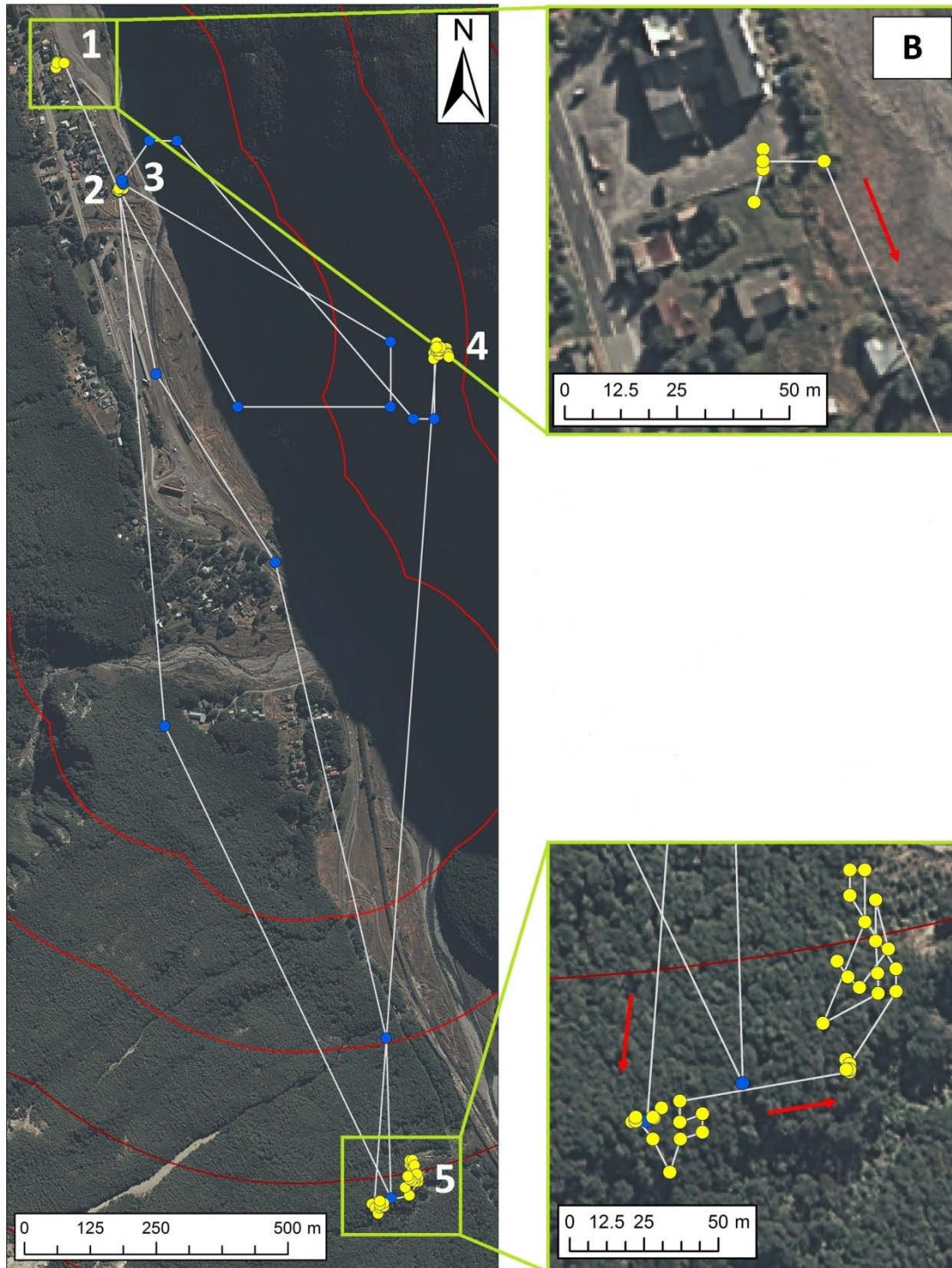


Figure 3.5: Two examples (panels A and B) of sequences of consecutive behavioural bouts of kea **B** in Arthur's Pass Village. White numbers denote individual bouts of state 1 behaviour (yellow GPS locations= state 1 and blue GPS locations = state 2). On both panels (A and B) there are two close-ups of behavioural bouts with green double lines and boxes arrows indicating which bout is shown. Red arrows depict direction of movement. Contour lines represent distances from human areas at 500-m intervals with lightest red colour denoting the nearest distance.

3.4 Discussion

My study demonstrates how a spatial approach is an effective means of characterising and quantifying interactions between a conflict-prone species and centres of human activity. Specifically, I found that kea: (1) were often in close proximity to human areas and were strongly selecting this as preferred habitat; (2) spent significantly more time on ground-based activities than flight, where they are more likely to interact with humans, potentially leading to conflict; (3) demonstrated strong temporal variation in proximity to human areas, being closer to these areas during periods when human activity was high; (4) showed clear individual differences in movement patterns that may have been influenced by age/reproductive state or specialisation; and (5) for some individuals, area-restricted behaviours were related to proximity to human areas.

3.4.1 Proximity and habitat selection

The high proportion of GPS fixes recorded near human areas and the strength of habitat preference as measured by Jacob's Index revealed that the kea in my study were strongly attracted to human areas. Many conflict-prone animal species have been forced into human areas by habitat fragmentation (Carter *et al.* 2012). Conversely, kea are highly mobile, and individuals can travel long distances to favoured locations. Some individual kea have been shown to travel at least 98 km between areas of interest (Marchant & Higgens 1990), and appear to actively select human areas. Kea near Arthur's Pass have access to an abundance of native habitat and only a small amount of human infrastructure. My results suggest kea are 'urban adapters'; that is, populations which actively use anthropogenic resources, as well as natural ones (as defined by Blair,

2001). Urban-adaptors typically consist of animals that are ‘edge species’ (Whitcombe *et al.* 1981), omnivores/generalists (Sanz & Caula 2015), display behavioural plasticity (Wong & Candolin 2015), exploit human-provided resources for food and shelter (Lowry *et al.* 2012), and tend to thrive in human areas, often reaching greater abundance than in areas that are not associated with persistent human activity (McKinney 2002). While human areas present many short-term benefits to urban-adaptors such as kea by providing consistent sources of food, shelter, and play objects, sustained proximity to human areas in the long-term likely increases the probability of interactions with humans that result in injury or mortality.

3.4.2 Occurrence of behaviour

Most of the kea in my study demonstrated a higher proportion of GPS fixes and also a longer mean time in bouts of ground-based behaviours than in flight, potentially increasing the risk of HWC. When examining kea movement trajectories it becomes apparent that these individuals typically ‘commute’ by flying between focal areas of interest, and once in these focal areas, tend to use more ‘area-restricted’ behaviours and short flight ‘hops’. Spending a large amount of time on the ground is common for many bird species (Weathers & Sullivan 1993; Hinsley & Ferns 1994) and urban-adapted species often show shorter flight distances within human-associated landscapes than in natural habitats (Evans *et al.* 2009). Ground-based behaviours near human areas put individuals at risk of a suite of indirect potential human hazards (e.g., motor vehicles, illness from human food items). Moreover, kea are highly neophilic and this curiosity leads to them to damage property (e.g., pulling off fittings), disrupt work sites (e.g., climbing on equipment and throwing around objects), and stealing food (Diamond &

Bond 1999). These behaviours have resulted in ongoing direct persecution (e.g., shooting, poisoning, and trapping; Orr-Walker & Roberts 2009). In any habitat that kea occupy there are specific locations where the probability of mortality through direct persecution is elevated (i.e., 'hot-spots' of conflict), whereas the probability of mortality through indirect means is likely more spatially homogenous (and therefore harder to predict when and where it may occur). Understanding the dynamics of 'urban adapter' behaviour in human areas is key to understanding the nature of potential conflict and ranking the hazards for prioritization of management objectives.

3.4.3 Temporal patterns

Diamond and Bond (1999) indicate that kea interact with humans to gain food resources (being actively fed and stealing food) and it may be that they are attracted to, and even become reliant on, these food sources. Most of the ten kea exhibited clear temporal patterns of proximity to human areas and appeared to seek encounters with people that were in possession of food or interesting objects (unpubl. pers. obs.). My results suggest that kea timed their movements so they were closest to human areas during periods when human activity was most intense. While APV only has a small amount of human infrastructure, there is a large and consistent influx of people using Arthur's Pass to travel between the West and East Coasts of the South Island. Because there are only a limited number of areas in APV at which to stop and purchase food, petrol and so on, peaks in human activity are predictable in time and space. Kea activity peaks during the hours of daylight, and so overlaps with times of human activity. However, even when kea are active after sunrise and before sunset, they typically do not visit human areas when tourist activity in Arthur's Pass is at its lowest. Also, kea

numbers increase with number of humans and motor vehicles present (pers. obs.), which suggests that kea have identified the hotspots and peaks of tourist activity. In summary, there are specific time periods when negative interactions between kea and humans are far more likely to occur.

Other studies have shown that human food supplementation causes behavioural shifts for species in an anthropogenic landscape (Ryan & Larson 1976; Saggese *et al.* 2011; Galbraith *et al.* 2015). Carnivores such as dingoes, coyotes, and black bears in urban settings show behavioural plasticity and this allows populations to exploit environments modified by humans (reviewed in Bateman & Fleming 2012). For example, red foxes in Zurich are gaining c. 50% of their food from human sources, most often purposely provided by people (Contesse *et al.* 2004). However, there are many dangers to both humans and wildlife associated with feeding; e.g., wildlife fed by humans often become aggressive towards humans, leading to attacks (Orams 2002), and animals fed near roads often become habituated to vehicles, increasing the probability of injury or death through vehicle strike (Silva, Johnson & Opps 2009). Using a spatio-temporal approach to characterise interactions provides a way to identify periods with a high risk of conflict to inform the development of planning interventions.

3.4.4 Individual variation

The resolution of my tracking data was sufficient to quantify inter-individual variation among kea, and individuals displayed clear differences in their patterns of movement behaviour. There are two plausible explanations for these differences. First, it is possible that reproductive state affected kea interactions with human areas. Sexually immature birds (juvenile birds under the age of 5) spent considerably more

time closer to human areas than did sexually mature males. Older, sexually mature males are more likely to spend much of the day provisioning a mate and offspring (Diamond and Bond, 1999), and typically visit human areas for limited periods around midday when there is a higher chance of gaining human-provided food. Second, some individuals appeared to specialise in use of human areas. For example, one individual (**B**) was often active at night in the illuminated village area, where he visited residential sites, possibly trying to scavenge food (e.g., in rubbish bins) without disruption. Other potential causes of intraspecific variation in patterns of movement behaviour include sex (Smith *et al.* 2015), physical condition (Saïd *et al.* 2009), age (Cederlund & Sand 1994), differences in experience (Dall *et al.* 2004), and habitat variability (Kilpatrick & Stober 2002).

Irrespective of the underlying mechanisms, pre-reproductive males appear more at risk of conflict with humans than do males with nests. Therefore, HWC mitigation strategies must account for the variation in risk for different subsets of the population. Recognising and quantifying inter-individual variation is essential for informing conservation measures; for example, designing a management plan based on the central tendency of a population may do more harm than good as individuals may vary widely in their movement behaviour (Bolnick *et al.* 2003; Ascensao *et al.* 2014). I advocate that both collective and inter-individual results should be considered when assessing HWC.

3.4.5 Influence of proximity to human areas

Kea movement behaviour varied as a function of proximity to human areas. A detailed examination for the movement behaviour of an individual bird captured in APV showed that he switched behaviours more rapidly when in the village, with time spent

in behavioural 'State 1' (ground-based behaviours) increasing proportionally with distance from the APV. These results, plus a strong personal observational confirmation, suggest that the environment in the village was more temporally variable than his natural habitat. Urban areas consist of a range of dynamic sensory stimuli (e.g., approach of people, domestic pets, motor vehicles, bicycles) that vary in space and time. Often anthropogenic stimuli will impact animal behaviour either by acting as an attractant or a disturbance and so inducing displacement. Birds that are 'urban-adapters/exploiters' will fly significantly shorter displacement distances from human disturbances than non-urban species and are more likely to return quickly to the area if an attractant is present (Geffroy *et al.* 2015; Møller *et al.* 2015), a pattern which is reflected in the patterns of movement in kea at Arthur's Pass. The movement patterns created by the combination of a dynamic environment and habituation to human stimuli create a situation where the probability of conflict events is high. Quantifying the effect of human stimuli on conflict-species movement behaviour can help identify and rank threats and help to inform mitigation strategies.

3.4.6 Limitations and future directions

While my preliminary research demonstrates that considerable and useful behavioural information can be obtained from applying a spatially explicit approach to assessing interaction between wildlife and centres of human activity, I also identified areas that could be improved in future research. GPS loggers have a limited battery life which constrains sampling duration and frequency; a shorter sampling interval over a longer time period would likely have revealed more and different behavioural information about kea. Recent technological innovations will greatly extend the

applicability of this spatial approach to study HWC across a variety of taxa. Among the most important developments is the ongoing reduction in the size of GPS receivers and advances in the efficiency of batteries and photovoltaic cells, which will greatly increase the operational lifetimes of tracking devices used to quantify HWC (Tarascon 2010; Jung et al. 2011). With technological advancements such as solar batteries, remote download, geofencing, sensor networks, and real-time tracking, improved management of conflict species will be possible. For example, short-term mitigation of conflict for a highly endangered species (e.g., tigers, rhinos, elephants) could include use of a two-way satellite/GSM network server so that if a tracked individual comes within a certain proximity of human areas the system will set off deterrents (e.g., electric shock from collar, sirens or lights). In the long-term, adopting a spatial approach could help inform future development of human infrastructure (e.g. wind farms) as humans continue to spread farther into wildlife areas.

3.4.7 Summary

The spatial approach adopted here is an effective means of describing fundamental aspects of HWC. By tracking kea using GPS loggers, I was able to describe the movement patterns of individual kea in relation to humans and their centres of activity. The patterns revealed allowed me to identify the behaviours and characteristics that potentially presented kea with the greatest risk of conflict with humans, as well as allow me to predict when and where conflicts are most likely to occur. The ability to predict conflict events is essential to improving management of species that co-occur with humans. As technology and the associated analytical toolkit continue to improve, the

use of GPS telemetry to characterise wildlife-human interactions will prove to be a useful tool for exploring and mitigating HWC in a range of species.

4

USING A POPULATION VIABILITY ANALYSIS TO EXPLORE

HOW HUMAN-WILDLIFE CONFLICT INFLUENCES POPULATION DYNAMICS: A CASE STUDY WITH THE KEA (*Nestor notabilis*)

4.1 Introduction

Population viability analysis (PVA) is an effective means of quantifying population dynamics, and can provide essential information for management of threatened and endangered species (Boyce 1992; Morris & Doak 2002). PVAs are quantitative models informed by demographic data, which allow researchers to evaluate and predict how different biotic and abiotic factors will affect population growth or decline over time (Beissinger & Westphal 1998; Mills & Lindberg 2002). Historically, PVAs have been used primarily as predictive tools, e.g. to calculate minimum viable populations and to predict absolute values of future populations (Allee 1931; Ginzburg *et al.* 1982; Boyce 1992). However, models are simplifications of the systems and phenomena they seek to represent; hence there is always some uncertainty associated with their predictions (Coulson *et al.* 2001; Ellner *et al.* 2002). More recently, researchers have been using PVAs to explore the qualitative differences in systems rather than making predictions based on outputs (Simpkins *et al.* 2015). Understanding how different threats will influence population dynamics (i.e., the putative factors causing decline), the relative importance of these factors, and how their influence will vary over time and space is essential for guiding future data collection efforts and allocating resources for effective management strategies. In addition, PVAs can be used to help find links between factors: if one threat is removed, it may have an unforeseen influence on another factor

that, in turn, has a more deleterious effect on the population (e.g. the meso-predator release effect; Crooks & Soule 1999).

Humans are rapidly expanding into wildlife areas, causing an increase in human-induced mortality (HIM). Human-wildlife conflict (HWC) is widely reported because it affects humans as well as the wildlife populations themselves (e.g., wildlife attacks on humans, crop raiding; Woodroffe *et al.* 2005). A number of conflict-prone species are endangered or threatened animals (e.g., African elephants, Sumatran tigers, Asian lions) and it is assumed that HIM plays a large role in causing and/or maintaining population decline (Thouless 1994; Landa *et al.* 1999). However, it is important that managers ascertain the magnitude of the impact of HIM on a specific population, as well as considering the degree of influence of HIM relative to other potentially deleterious factors. Managers often have limited resources (e.g. money, time, and equipment) and need detailed information about whether it might be more practical to focus on mitigating all threats equally, or, alternatively, focus more intensively on a smaller suite of particular threats/limiting factors. LaFever *et al.* (2008) used a stage-based PVA to evaluate the human-induced impacts on the Lower Keys marsh rabbit, and Goswami *et al.* (2014) assessed the importance of conflict-induced mortality on elephant populations; however, the explicit use of PVAs to explore HWC is somewhat limited. This shortfall may be due to many conflict scenarios being relatively new (and constantly changing), so demographic data capturing the effects of human-wildlife conflict are scarce.

Kea are one of New Zealand's best examples of a species that encounters HWC. They are the world's only mountain- and rainforest-dwelling parrot (Greer *et al.* 2015) and have an innate intelligence and curiosity that stems from the need to source a wide

variety of food (Diamond & Bond 1999; Auersperg *et al.* 2011). Historically, this curiosity led to conflict after high-country farmers reported incidences of kea attacking sheep to eat fat from around the kidneys, often leading to death of the sheep from sepsis (Orr-Walker & Roberts 2009; Reid, pers. comm.). Consequently a bounty was instituted by the government to cull kea, leading to c. 150,000 individuals being killed over a 100-year period (Temple 1996), before the species was afforded full protection under the Wildlife Act in 1986 (Seal *et al.* 1991). Kea damage human property, and there are still reports of kea strike on sheep, resulting in both direct persecution and indirect human-induced mortality (Seal *et al.* 1991; Department of Conservation kea database; Reid, pers. comm.). Even attempts to protect the kea have created unexpected HIM; 1080 (sodium fluoroacetate), which has been used as a poisoning agent to control predators, has also been found to cause the accidental death of some adult kea through ingestion of the bait (Orr-Walker *et al.* 2012). In such situations, there is a pressing need to evaluate the relative benefits of different management intervention strategies.

Recently, kea were classified as 'Nationally Endangered' by the New Zealand Department of Conservation (Robertson *et al.* 2013) and currently the IUCN classification is 'Vulnerable', CITES Appendix II (IUCN, 2014). Nevertheless, populations still appear to be in decline due to predation by introduced mammals, and, to an unknown extent, direct or indirect conflicts with humans (Elliot & Kemp 2004; Gartrell & Reid 2007). Despite the kea's conservation status, little is known about the influence of HIM on kea population dynamics, or the effect of HIM relative to mortality by exotic mammalian predators. Seal *et al.* (1991) did undertake a kea population and habitat viability assessment; however, their focus was not on exploring the impacts of HIM but was rather on the general/overall population dynamics.

I developed an age-structured, density-dependent model of kea population dynamics in a stochastic environment. I used this model to investigate questions relevant to the management of a HWC species. My objectives were to develop a PVA model for kea and use it to: 1.) Assess what affect HIM has on kea population dynamics; 2.) Determine the relative impacts of HIM and predation on population size; and 3.) Evaluate whether the use of 1080 for predator control is detrimental to kea populations due to accidental by-kill.

4.2 Methods

4.2.1 Study species

The kea is a large, omnivorous parrot (family Strigopidae) restricted to the South Island of New Zealand (Figure 4.1). Kea habitat varies from coastal dunes to high alpine peaks but kea are most common in high-altitude southern beech (Nothofagaceae) forest, sub-alpine shrublands, and high-alpine basins and ridges (Higgins 1999; Robertson *et al.* 2007). The current kea population size is uncertain, but the most recent estimate of overall population size gives numbers of between 1000-5000 wild birds (Anderson 1986). It is difficult to precisely estimate kea numbers due to their extensive range (largely in rugged terrain), low density, and the cryptic behaviour of adults (Orr-Walker & Roberts 2009).

The maximum life span of kea in the wild is thought to be c. 25 years (Seal *et al.* 1991), but birds in captivity have been shown to live more than 47 years (Brouwer *et al.* 2000). Kea are non-territorial, and form monogamous long-term pairs (Bond *et al.* 1991). They nest on the ground in crevices, usually below the treeline (McCaskill 1954).

Females generally become sexually mature at 4 years; although in some cases they breed at 3 years (Jackson 1963). Individuals nest between July and January, with between 1 and 5 eggs being produced (Seal *et al.* 1991). Incubation takes 22-24 days, and chicks fledge in approximately 90 days (Pullar 1996). Kea chicks have a long juvenile period and are dependent on their parents for 4-5 months after hatching (Orr-Walker 2010).



Figure 4.1: The kea's current range (red) in the South Island of New Zealand.

4.2.2 Model structure

I assessed the influence of HIM on kea by exploring a range of scenarios with a stochastic simulation model which represented the population dynamics of kea. The model incorporated information about three age classes comprised of juveniles (0-1 year), sub-adults (1-3 years), and adults (3+ years) to match the life-history of kea (Seal

et al. 1991). The model comprised two sub-models. The first represented the transitions between age classes, and incorporated parameters relating to breeding biology (Figure 4.2A), and the second sub-model incorporated information about mortality rates as a function of predation (which also encompassed baseline mortality) and HIM rates (Figure 4.2B). The overall mortality rates for each age-class were fed into the population growth sub-model ('A' in Figure 4.2).

I only represented females in the model as the kea's monogamous reproductive status suggests that unpaired males will rarely contribute to population growth rate (Bond *et al.* 1991; Ferson & Burgman 1995). Previous research suggests that the sex-ratio in kea is skewed towards males, (Bond *et al.* 1991; Seal *et al.* 1991), and therefore it is likely that all females form pair-bonds. Due to lack of information, I assumed that the statistical associations between demographic parameters included in the model were perfectly correlated (Ellner *et al.* 2002); although such strong correlation in vital rates is unlikely, it provides a more conservative approach to assessing population viability (Ferson & Burgman 1995).

The model was constructed using Vensim PLE Plus software (Ventana Systems), with each time step consisting of one year, and model runs typically spanning 250 years (approximately ten generations given a 25-year lifespan in the wild). This period was chosen because it was long enough to detect trends that may otherwise been missed in a long-lived species, but short enough to still be relevant from a management perspective.

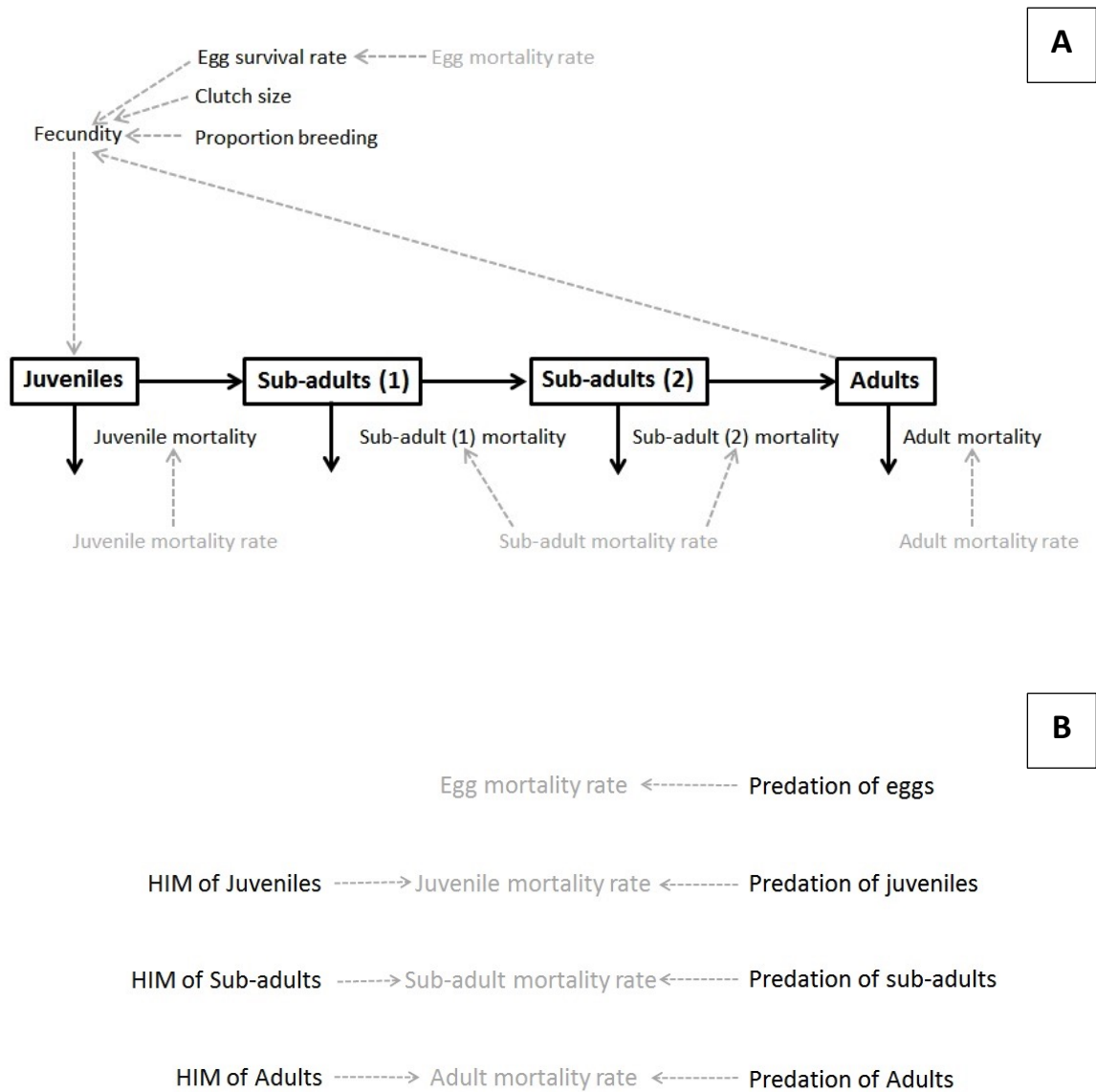


Figure 4.2: Schematic representation of the age-class sub-model of kea population dynamics (**A**) and the mortality rates (**B**) that feed into sub-model (**A**). Solid arrows denote flow of individuals between age-classes, dashed lines show how model parameters affect each other, and grey text indicates variables that connect sub-model **B** to sub-model **A**.

4.2.3 Model parameters

Population parameters. – The initial population size of kea was based on the lowest published estimate of 500 females (Pullar 1996). I used this lowest value because there is considerable uncertainty in the population estimates (Orr-Walker & Roberts 2009) and I wanted to consider the worst-case scenario presented. I assumed a stable age-distribution.

Reproduction. – Kea have a monogamous breeding system (Bond *et al.* 1991) and are reported to begin breeding as early as age three, although age four is more typical (Jackson 1963). Fecundity (Figure 4.2) was defined as the product of the number of adult females, clutch size, and egg and nest survival. I set the proportion of breeding adults at 0.4 as not all females breed every year (Bond *et al.* 1991). Clutch size for kea is known to be 1-5 eggs per year (Seal *et al.* 1991). Thus, I assumed that two female eggs are produced each year on average – this favours kea and so is conservative with respect to extinction estimates. The number of eggs produced each followed an un-truncated Poisson distribution with rate (λ) = 2.

Mortality. – Annual mortality rates were age-specific (Table 4.1) Mortality-rate probabilities were composed of mortality due to predation, HIM, and all other types of mortality (i.e., background mortality).

Current baseline mortality and predation rates were based on those provided by Seal *et al.* (1991) in their population and habitat viability analysis. In addition, approximately every four years a beech mast (i.e., massive seed production) occurs (Ogden *et al.* 1996), potentially triggering irruptions of species that predate kea, leading to an increase in predation mortality (Elliott 1996; Choquenot 2006). I accounted for this dynamic by adding a mast frequency parameterised at a rate of 0.25 and, when a mast year occurred, I assumed that there was a 10% increase in predation rate across all age classes. I assumed that there was no temporal structure in the pattern of masting and so mast events could occur in successive years. I then systematically adjusted the values I had adapted from Seal *et al.* (1991) until the model produced a slightly declining population trend under current levels of HIM. I targeted this trends because it is believed to be occurring in many kea populations (values used can be seen in Table 4.1). Stochasticity was added to all background and predation mortality rates by multiplying them by values from a random uniform distribution ($U \sim [0.9, 1.1]$).

Department of Conservation's database was used to determine how many kea deaths can be attributed to HIM; I counted intentional causes (e.g. shooting, trapping) and accidental causes (e.g. vehicle strike, food poisoning) but not predation by introduced mammals (an indirect effect of HWC). I represented HIM estimates as a rate (Table 4.1) based on the proportion of kea in the population that die because of HIM per year. Human-induced mortality rates were constant over all age-classes. I did not assign any HIM to eggs, as kea nests are cryptic and generally in dense forest so there is a minimal chance of people encountering them. For current management conditions stochasticity was added by drawing values from a Gaussian distribution; $\mu = 0.015$ and $SD = 0.0025$.

ADD mean

To represent potential increases in HIM rates over time I evaluated linear, exponential, and logistic growth in HIM. Exponential growth was represented by:

Equation 4.1

$$Mort_t = Mort_t(1+C)^t$$

Where: t is time (years) and C is rate of change in population.

Logistic growth was represented by:

Equation 4.2

$$Mort_t = CMort_t \left(\frac{1 - Mort_t}{1} \right)$$

Where: t is time (years) and C is the rate of change in HIM.

Table 4.1: The baseline demographic parameters used in the PVA model. N represents the initial number of individuals. Rates are all expressed per year.

Age class	N	No predation (baseline mortality rate)	Low predation rate	Medium/current predation rate	High predation rate	Mast year mortality rate	Current HIM rate
Egg	-	0.1	0.2	0.4	0.8	0.1	0.015
Juvenile	125	0.005	0.1	0.2	0.4	0.1	0.015
Sub-adult	250	0.0125	0.025	0.05	0.1	0.1	0.015
Adult	125	0.025	0.05	0.1	0.2	0.1	0.015

4.2.4 Model scenarios

I evaluated 12 different scenarios representing the effect of different predation and HIM rates (all scenarios and corresponding parameters are summarised in table 4.2).

Table 4.2: Range of scenarios tested with the PVA; showing specific parameter values. Rates are all expressed per year. HIMR= human-induced mortality rate; PR= predation rate; ME = mast effect; C = growth rate in the relevant equation. The predation rates for each age class were expressed as egg/juvenile/sub-adult/adult rates. Stochasticity was added to all background and predation mortality rates by multiplying them by values from a random uniform distribution ($U \sim [0.9, 1.1]$). For current management values of HIMR, stochasticity was added by drawing values from a Gaussian distribution; $\mu = 0.015$ SD= 0.0025).

Scenario	Parameterisation	Explanation
I	HIMR= 0.015 (0.0025) PR=0.4/0.2/0.05/0.1 ME=0.1	The most accurate representation of the population dynamics under current management (e.g. baseline rates)
II	HIMR= 0 PR=0.4/0.2/0.05/0.1 ME=0.1	A system with effective mitigation of HIM
III	HIMR= 0.015 PR=0.4/0.2/0.05/0.1 ME=0.1	Current management of HIM but keeps the HIM rate static (i.e., no stochasticity)
IV	HIMR= 0.015 C= 0.005 PR=0.4/0.2/0.05/0.1 ME=0.1	HIM increases at a slow linear rate to represent the potential effect of rising population and tourism numbers on HIM
V	HIMR= 0.015 C= 0.01 PR=0.4/0.2/0.05/0.1 ME=0.1	HIM increases at a fast linear rate to represent the potential effect of rising population and tourism numbers on HIM
VI	HIMR= 0.015 C= 0.01 PR=0.4/0.2/0.05/0.1 ME=0.1	HIM increases at a slow exponential rate (Eq. 4.1) to represent the potential effect of rising population and tourism numbers on HIM
VII	HIMR= 0.015 C= 0.02 PR=0.4/0.2/0.05/0.1 ME=0.1	HIM increases at a fast exponential rate (Eq. 4.1) to represent the potential effect of rising population and tourism numbers on HIM
VIII	HIMR= 0.015 C= 0.005 PR=0.4/0.2/0.05/0.1 ME=0.1	HIM increases at a logistic rate (Eq. 4.2) to represent the potential effect of rising population and tourism numbers on HIM
IX	HIMR= 0.015 (0.0025) PR=0.1/0.005/0.0125/0.025 ME=0	A system where pest management efforts in New Zealand are successful in removing all introduced predator species from the country
X	HIMR= 0.015 (0.0025) PR=0.2/0.1/0.025/0.05 ME=0.1	A system where an increase in the effectiveness of pest control resulting in the reduction of predator numbers and density
XI	HIMR= 0.015 (0.0025) PR=0.8/0.4/0.1/0.2 ME=0.1	A system with the complete absence of predator management, leading to higher numbers of predators
XII	HIMR= 0.015 (0.0025) Adult HIMR= 0.065 PR=0.4/0.2/0.05/0.1 ME=0.1	Describes the effects of increased adult mortality (by 5%) as a result of 1080 by-kill. It is important to note that current management involves the use of 1080 to maintain predators numbers at their present level (i.e., medium predation) and the predation rates for scenario I reflect this management strategy. However, I did not include the by-kill of adult kea in scenario I HIM rates as I wanted to test the effect of adult by-kill explicitly as a scenario.

4.2.5 Model execution and analysis

Each scenario was evaluated by running 200 simulations each of 250 time-steps (years). Rather than using absolute extinction (i.e., $N_t = 0$), I used a critical population size as a ‘quasi-extinction’ threshold (Morris & Doak 2002), as is often used in conservation policy (Mace & Lande 1991; DeMaster *et al.* 2004). I defined the quasi-extinction threshold as being a population abundance of 50 individuals (Otway *et al.* 2004). Time until extinction was determined by calculating the year at which an extinction event occurred. The extinction risk for each scenario was estimated by the fraction of the 250 replicates that ended in population extinction (i.e., $N < 50$).

Additionally, I produced extinction curves by dividing the number of simulations that had dropped below 50 (quasi-extinction), 100, or 200 individuals. Population growth rates for each simulation were determined using the mean geometric growth:

Equation 4.3

$$\lambda = \left(\frac{N_t}{N_0} \right)^{\frac{1}{t}}$$

where: λ is growth rate, N_t is the number of kea at time t , and N_0 is the number of kea at time zero.

4.2.6 Sensitivity analysis

I conducted a univariate sensitivity analysis for clutch size, proportion of adults breeding, and the relative importance of predation on each of the four age classes. The model was run using the same baseline parameterisation as Scenario I (current conditions). Sensitivity analyses were performed by individually varying each parameter of interest $\pm 10\%$ of their baseline values over 200 iterations of 250 time-

steps each. Parameter sensitivities were determined using the index described by Hamby (1994):

Equation 4.4

$$S_{y,x} = \frac{(\Delta y / y_b)}{(\Delta x / x_b)}$$

where S_{yx} is the sensitivity of the state variable y to a change in parameter x (i.e., the ratio of the relative change in state variable y to a relative change in parameter x), Δy is the change in state variable y , y_b is the baseline output, Δx is the change in parameter x , and x_b is the baseline parameter value. The population size of kea was used as the state variable of interest and a parameter was considered to be 'sensitive' if the index (Eq. 4.5) resulted in a value > 1 .

4.3 Results

4.3.1 Effect of HIM rate on kea population size and growth rate

Scenarios I – XII showed the effects of varying levels of HIM rates on population size (summarised in table 4.2.) Scenario I was the closest to current conditions that kea encounter and produced a slightly declining population (Figure 4.3) resulting in a population of 266-**358**-473 (5th percentile-**median**-95th percentile) and mean growth rate of 0.999 ± 0.001 (± 1 SD). By comparison, scenario II, which had no HIM, produced a stable population dynamic ($\lambda = 1.000 \pm 0.001$), with a population size of 310-**416**-549, which was 16% higher than under scenario I.

Scenarios IV – XII represented population dynamics under increased rates of HIM. The rapid linear increase in HIM (scenario V) had the most negative effect on population

size **8-10-13**, and mean growth rate ($\lambda = 0.823 \pm 0.020$). In this scenario extinction occurred after 11 years on average. Logistic growth in HIM rates (scenario XII) had the least effect of the scenarios assessed, with a mean final population size of 222-**303**-404 and a mean population growth rate of 0.996 ± 0.001 .

4.3.2 Effect of predation rate on kea population size and growth rate

The total removal of mammalian predation (scenario XI) resulted in the largest population (676 ± 157 individuals), which was 86% higher than that under scenario III (current conditions). High (twofold increase) predation rates always resulted in population extinction, the lowest population size **6-7-8** and the lowest population growth rate (0.820 ± 0.024).

4.3.3 Effect of 1080 pest control on kea population size and growth rate

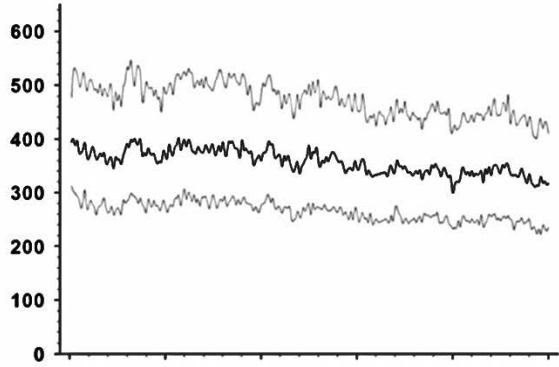
When adult HIM was increased to simulate the effect of 1080 pest control (Scenario XII) it resulted in a 10% decrease in population size from current conditions (266-**358**-473 vs. 240-**323**-425). However, Figure 4.4 shows that the population trend of scenario III does not differ markedly from scenario XII.

Table 4.3: Summary of results for Scenarios I-XII over 250 years and 200 simulations. Population size is expressed as the mean of 5th-**median**-95th. Standard deviations are shown in parentheses. If a scenario never resulted in extinction (i.e., probability of extinction was 0.00) then that model had an undefined mean time to extinction. Scenarios in bold have a mean $\lambda < 1.0$ and so indicate population decline.

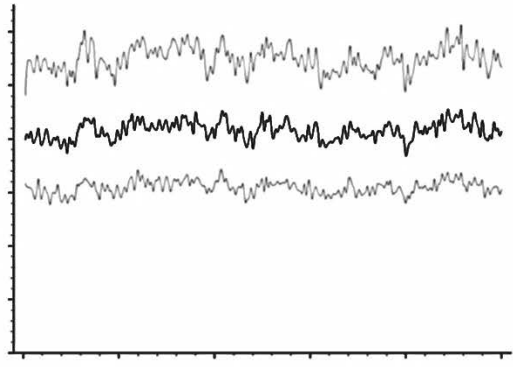
Scenario	Mean Population size	Mean time to extinction (years)	Probability of extinction	Mean population growth rate
I	266- 358 -473		0.00	0.999 (0.001)
II	310- 416 -549		0.00	1.000 (0.001)
III	287- 385 -508		0.00	1.000 (0.001)
IV	30- 41 -56	47.3 (3.1)	1.00	0.958 (0.004)
V	8- 10 -13	11.4 (1.1)	1.00	0.823 (0.020)
VI	211- 288 -384	247.5 (3.2)	0.04	0.998 (0.005)
VII	114- 155 -207	140.3 (3.8)	1.00	0.986 (0.001)
VIII	223- 303 -404		0.00	0.996 (0.001)
IX	447- 669 -940		0.00	1.001 (0.000)
X	353- 489 -661		0.00	1.000 (0.001)
XI	6-7-8	9.3 (1.2)	1.00	0.820 (0.024)
XII	240- 323 -425		0.00	0.999 (0.001)

A

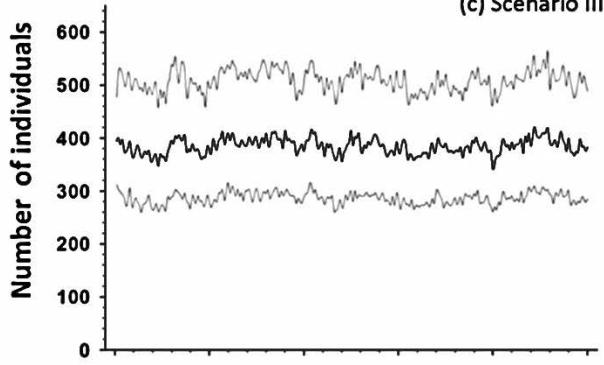
(a) Scenario I



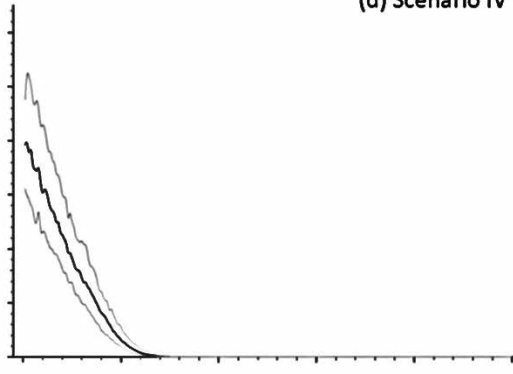
(b) Scenario II



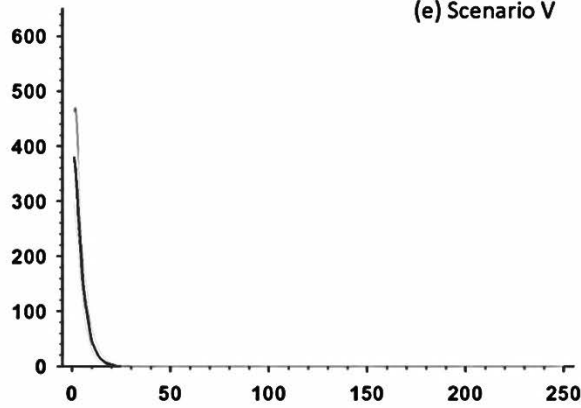
(c) Scenario III



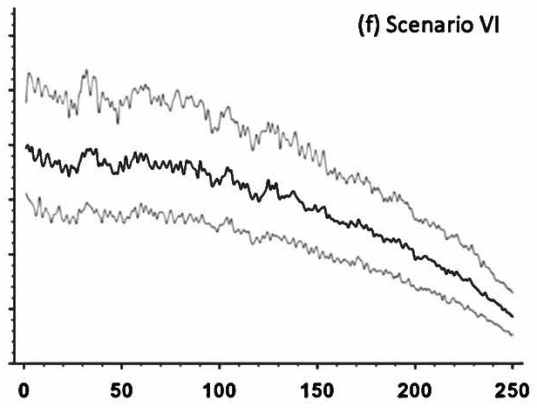
(d) Scenario IV



(e) Scenario V



(f) Scenario VI



Time (years)

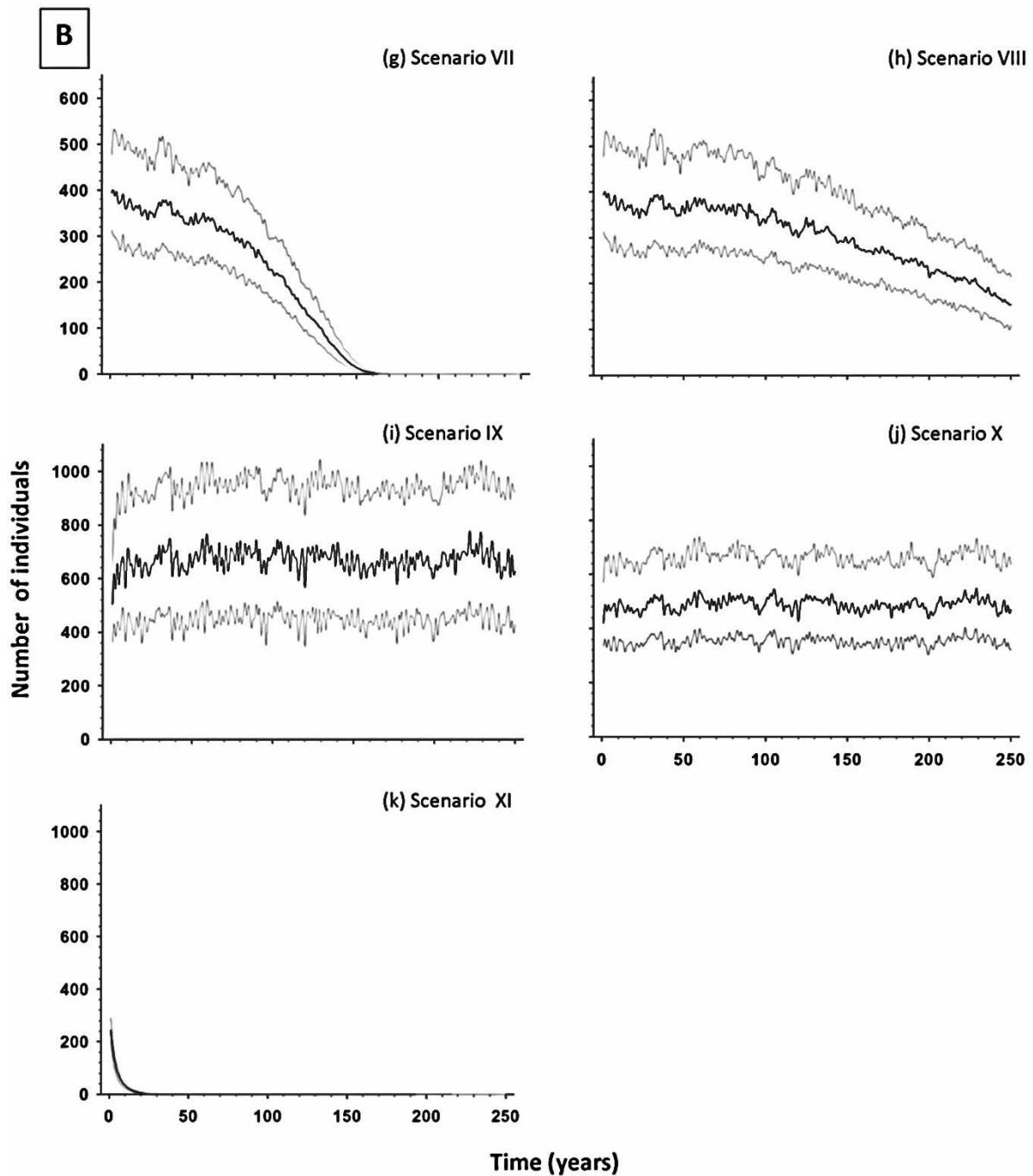


Figure 4.3: Model outputs across the 12 kea population scenarios assessed, based on 200 simulations over 250 simulation years duration, with the medians represented by the black lines and the 5th and 95th percentiles denoted by the grey lines. Scenarios I-VI in A and VII-XII in B; for Scenario details see Table 4.2.

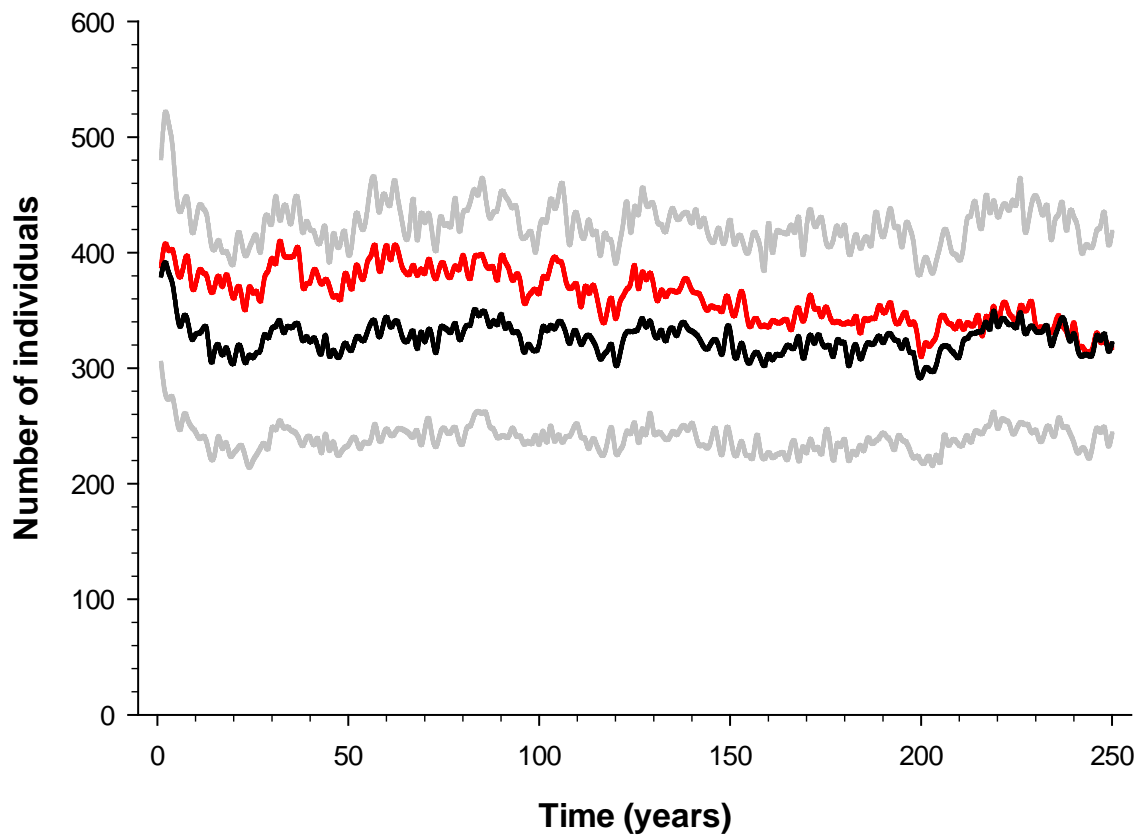


Figure 4.4: Population dynamics under Scenario XII showing the effect of increased adult mortality due to 1080 pest control. The median is represented by the black line, the 5th and 95th percentiles are shown by the grey lines. The red line shows the median number of individuals of Scenario III, which is the closest representation of current mortality rates. Note that in the long-term, the two scenarios do not differ.

4.3.4 Effect of HIM on extinction risk

Of the 12 scenarios evaluated, only scenarios IV – VII resulted in populations that dropped below 50 individuals (i.e., below the quasi-extinction threshold) as shown in Table 4.2. Under scenarios IV, V, and VII extinction always eventuated, and this was most rapid in scenario V with a mean time to extinction of 11.43 ± 1.06 years (Figure 4.5). In comparison, scenario VI (slow exponential increase in HIM rates) had a 0.04 probability of extinction, with a mean time to extinction of 247.5 ± 3.2 years. No simulations of scenario VIII (slow, logistic increase in HIM rates) ever fell under 50 individuals; however, in this scenario population size did drop below 200 individuals at approximately 105 years and below 100 at approximately 240 years suggesting that ultimately extinction would be likely to occur.

4.3.5 Effect of predation on extinction risk

High rates of mammalian predation resulted in the highest extinction risk, with kea population size falling to fewer than 200 individuals in just a handful of years and a mean time to extinction of just 9.3 ± 1.2 years. This result is, perhaps, unlikely in the real system in terms of its rapidity, but illustrates the sensitivity of the population to predation. Reducing predation levels to low rates, or removing predation mortality altogether, led to populations that had no risk of extinction.

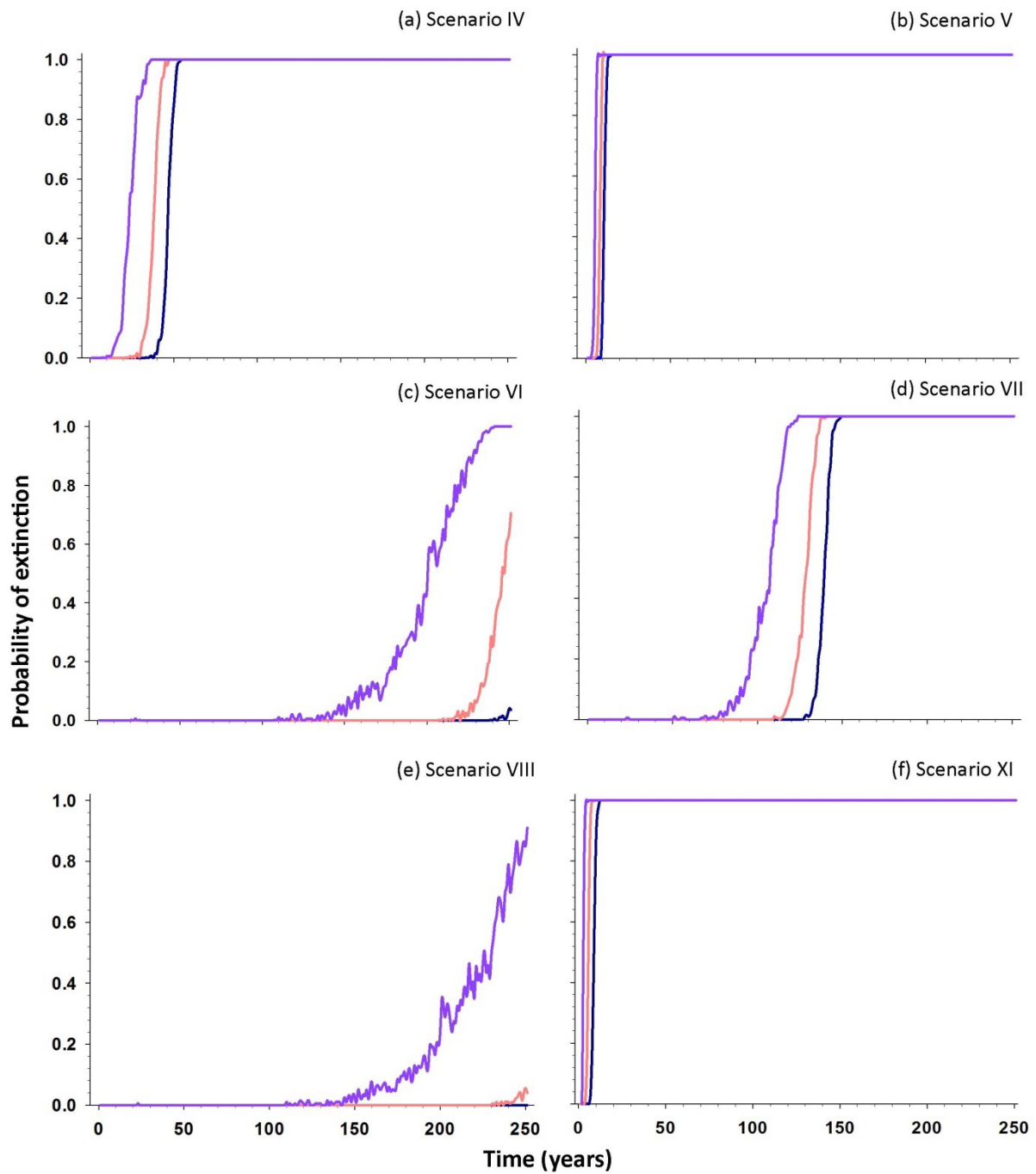


Figure 4.5: Extinction curves for scenarios IV, V, VI, VII, VIII, and XI; for scenario details see Table 4.2. The proportion of simulations that go below 200 (purple line), 100 (orange line), and 50 (dark blue line) individuals at each time step are shown.

4.3.6 Sensitivity analysis

Sensitivity analyses (table 4.4) showed that sensitivity ranged from 0.000-0.028, all well below one, demonstrating that kea populations (as modelled) were not sensitive to any of the parameters tested. Of the parameters tested, clutch size, proportion breeding, and adult predation rate comparatively had the most effect on population size (0.028, 0.013 and 0.011 respectively). The low sensitivity values for predation rates are rather surprising considering the large impact of high predation (scenario XI) on population numbers. However, my analyses were local and therefore only assess sensitivity in a small portion of the entire range of a parameter's plausible values; this is a common problem with local sensitivity analyses (Drechsler 1998).

Table 4.4: Sensitivity values for nine model parameters. Baseline input values were based on scenario III which is closest to current conditions. Model parameter means were varied by $\pm 10\%$. Parameters ordered in descending sensitivity.

Parameter	Baseline input value	Input range	Sensitivity
Clutch size (mean)	2.000	1.800 – 2.200	0.028
Proportion breeding	0.600	0.540 – 0.660	0.013
Adult predation rate	0.100	0.090 – 0.110	0.011
Egg predation rate	0.400	0.360 – 0.440	0.003
Juvenile predation rate	0.200	0.180 – 0.220	0.002
Sub-adult predation rate	0.050	0.045 – 0.055	0.001
Adult HIM rate	0.015	0.149 – 0.152	0.001
Juvenile HIM rate	0.015	0.149 – 0.152	0.000
Sub-adult HIM rate	0.015	0.149 – 0.152	0.000

4.4 Discussion

My study demonstrates how the population dynamics of a human-conflict prone species can be explored using PVA. I found that: (1) HIM currently does not have a marked effect on kea populations, but if HIM rates were to increase they could threaten kea persistence; (2) predation rate had a larger influence on kea population dynamics than HIM rate; and (3) the use of 1080 for predator control was beneficial for kea populations, despite the unintentional mortality of some adult kea.

4.4.1 Effect of current HIM rates on kea population dynamics

The outcomes of my PVA suggest that current levels of HIM have little effect on kea population dynamics. Under current conditions (Scenario I), the outputs indicate that the kea population will decline slightly over the 250 year simulation period. I found that in the absence of HIM events there is a 16% increase in population size and both scenarios have zero probability of kea going extinct. Other research in different conflict species has shown contrasting results. Chase *et al.* (2016) showed that the African elephant's annual 8% decrease in population numbers is predominantly due to poaching. It is likely that HIM has a variable effect on the population dynamics of different conflict species depending on the nature of the conflict scenario and other aspects of the species ecology. For example, two species encountering the same conflict scenario can have different conservation statuses. In Zimbabwe both baboons and lions kill local livestock, leading to persecution from farmers; yet lions are classified as vulnerable, and baboons are of least concern (Butler 2000).

4.4.2 Influence of HIM rates increasing over time

When rates of HIM-induced mortality increased over time (scenarios IV to VIII), it had a more marked influence on kea population dynamics, with three out of the five scenarios resulting in 100% chance of extinction (in the most extreme case extinction occurred within 12 years). Statistics New Zealand has reported that the resident and visiting human population, is growing; with a 1.9% and 11% increase respectively, in 2015. Therefore, while HIM may not be currently be the most pressing threat for kea, it is likely to become a more significant problem in the near future. Research suggests that as human populations grow there is a subsequent rise in HWC (Thirgood *et al.* 2005). For example, monitoring carried out by the Ministry of Water, Land, and Air Protection in British Columbia (2003) has shown that human population growth is correlated with the number of encounters and serious incidences with cougar, black bears, and grizzly bears. With a rise in conflict between wildlife and humans, an increase in HIM can be expected.

4.4.3 Relative influence of predation rate and HIM rate on kea population dynamics

The PVA outputs suggested that rate of predation had the largest effect on kea population abundance. My model results predicted that scenario XI, where current predation levels were doubled, would result in the most rapid extinction dynamics. Overall, removing predation from kea populations (IX) was much more beneficial than removing HIM (II); resulting in an 86% increase in population size compared to the 16% increase in Scenario II. Other studies using PVAs for threatened bird species have had varied results; isolated predation was identified as the main threat to Mohua

(passerine bird; Elliott 1996), and the swift parrot (Heinsohn *et al.* 2015). In contrast, Weller *et al.* (2014) showed that predation was not the main contributing factor to African penguin decline.

4.4.4 Use of 1080 for predator control

My PVA suggested that the benefits of using 1080 to control introduced predators outweigh any incidental losses of adult kea. The outputs revealed that the additional losses of adult kea after a 1080 poison drop would not result in population abundance markedly different to that under current conditions. However, without the use of 1080 to suppress predator populations, predation rates would increase, which was shown to have the greatest negative effect on kea populations. Some demographic models have shown that long-lived avian species tend to be most sensitive to adult mortality (Boyce 1992). My sensitivity analysis showed that adults were comparatively only slightly more sensitive to predation and HIM rate than the other age classes. Therefore I conclude that the slight 1080 effect is more than compensated for by the reduced mammalian predation.

4.4.5 Limitations

Over the years the development of software that facilitates implementation of PVAs without any modelling expertise has potentially lead to a greater potential for the misuse of models, and problems with the appropriate interpretation of model results (Reed *et al.* 2002). Additionally, all models are abstractions of the real world and are generally limited by a range of uncertainties, such as exact values for parameters and understanding of process representation (Coulson *et al.* 2001; O'Sullivan & Perry 2013).

It is a challenge to appraise how these uncertainties impede the representation and understanding of the system dynamics being explored. For kea there are limited monitoring data, so some assumptions needed to be made when parameterising the model. In addition, even though HIM data was available it is subject to uncertainties. While HWCs are widely reported, it is possible that HIM events are underreported and/or undetected. The accuracy of PVA diminishes over the time simulated as it extremely difficult to accurately account for factors that regulate population dynamics over longer time-frames (Brook *et al.* 1997). For a variety of reasons the parameterisation and validation of stochastic simulation models is problematic (Grimm & Railsback 2005; Hartig *et al.* 2011), and so it is advisable to use PVA as a comparative (and not predictive) tool.

4.4.6 Management implications

The outcomes of my PVA analyses suggest that the biggest threat to kea populations is predation, but as human populations continue to grow in kea habitats, HIM could become a major threat in the future. As is common in conservation, there are limited resources for managing kea (Kemp pers. comm.), and my results suggest that in the short-term, management strategies should prioritise minimising predation (e.g., predator control, protecting nests). However, it is important for managers to make long-term considerations on how best to mitigate human-kea conflict. Having more time to address a threat before it becomes a major problem is beneficial because it provides time to plan and undertake targeted research on how to most effectively reduce HIM rather than relying on reactive methods based on inadequate data. I believe that the framework of my PVA (with species-specific parameterisation) is highly applicable for

exploring the influence of HIM on a range of human-conflict prone species. Future extensions could consider individual-level dynamics in a spatially explicit framework informed by the movement data presented in Chapter 2 (e.g., Heinonen *et al.* 2014).

5 GENERAL DISCUSSION

5.1 Summary of findings

In my thesis I have developed a spatio-temporal framework to inform management of conflict-prone animal species such as the kea. Applying a spatial framework to explore human-wildlife conflict (HWC) requires high-resolution spatio-temporal data to describe movement patterns and their relation to human features in the landscape. I demonstrated that GPS telemetry is a viable way to obtain high-resolution tracking data from kea in Arthur's Pass (Chapter 2). My field trials revealed a high retention rate of GPS loggers with a negligible effect on the birds' health as evidenced by birds having healthy amounts of muscle mass around the keel and no individuals exhibiting noticeable loss of body condition. Using the resultant GPS data, I was able to: 1.) characterise the movement and behavioural patterns of kea; 2.) quantify the nature and extent of kea interactions with anthropogenic infrastructure in their environment; 3.) explore how human activity may be affecting kea behavioural patterns; and 4.) assess the impact of HWC on kea population dynamics relative to other important threats. The outcomes of my research suggest that this spatial-temporal framework is an effective means of assessing human-wildlife interactions and conflict. Kea also overlap with human settlements in Mt Cook, Fox Glacier, Franz Josef and parts of Milford Sound where kea display similar interactions with humans (Josh Kemp pers. comm.) and human property as evidenced in similar levels of lead exposure compared to kea living away from human areas (Reid *et al.* 2012). While I only tracked kea in Arthur's Pass, it is

highly likely that my results would relate to the management of other kea populations overlapping with human areas based on their similar behaviour.

5.2 Characterising the movement and behavioural patterns of kea

Understanding the movement ecology of the kea is a crucial first step in informing improved management of this species. The data obtained during this research provided new insight into the movement ecology of kea. For example, I found that many of the tracked kea showed relatively limited movements, most likely due to human areas such as the village and scenic lookouts creating fixed locations that provide consistently available food resources. In addition, previous evidence has suggested that kea are diurnal (Higgins 1999); however, I found multiple examples of nocturnal activity. For example, one bird consistently visited Arthur's Pass Village during the night, and other individuals showed nocturnal activity in their natural habitat away from human areas. Knowing that kea are sometimes active at night changes our perception of the window of when human-kea conflict can occur. I was also able to locate an individual's nest (subsequently ground-truthed) using information obtained from their movement tracks. For the Department of Conservation being able to locate nests for nest monitoring and management is critically important (e.g. in the context of pest control strategies). In the future it would be useful to track non-human associated kea with GPS telemetry as animals often alter their movement patterns in response to increased spatial heterogeneity (Frair *et al.* 2005), particularly in relation to novel objects (Jander 1975).

5.3 Quantifying the nature and extent of kea interactions with anthropogenic infrastructure

Knowledge of where and when kea are most at risk of HWC is essential for informing the design of management strategies. My results suggest that kea are 'urban adapters'; that is populations that actively use anthropogenic resources as well as natural ones (Blair, 2001). Mitigating human-kea conflict is very challenging as kea are attracted to human areas, and as well as being profoundly intelligent they are also highly mobile. Knowledge of kea behavioural dynamics in human areas is central to understanding the nature of potential conflict with humans and their activities, and ranking the hazards for prioritisation of management objectives. Some human features are more of a potential threat to kea than others (e.g., car parks, cafes, and roads), and at certain times of the day there is a higher probability of conflict occurring. Although my sample size is relatively small (10 tracked individuals), my results suggest that pre-reproductive male kea are more at risk of HWC than are sexually mature males; information which could be integrated into future population models. Obtaining more information about the impact of humans on juvenile mortality is important as much of our current knowledge on juvenile mortality rate is based on re-location studies i.e., if individuals are not re-sighted in the area they were banded they are assumed as dead (Josh Kemp pers. comm.). However, the outcomes of a parallel study using satellite telemetry to track juvenile kea suggests that they often disperse from their natal area in the first year of life and may be being misclassified as dead when they have instead dispersed.

5.4 The effect of human activity on kea

A variety of human activities can influence and modify kea behaviour and, in turn, make kea more susceptible and vulnerable to conflict. I found examples of individuals changing behaviour more frequently in human areas than when they were occupying unmodified habitat(s). Human areas are highly dynamic and present a variety of stimuli that are constantly in flux. Watching videos that were taken during my study it was apparent that kea behaviour often relates to their interaction with human stimuli. For example, kea are often attracted to people with food at the Arthurs Pass café; however, patrons generally attempt to deter kea, leading to a recurring pattern of approach and displacement. These patterns of behaviour are seen in many 'urban adaptors' (e.g. seagulls) and often result in conflict (Møller *et al.* 2015). In contrast, the kaka (a close relative of the kea) are neophobic and although they are known to damage human property, they generally show avoidance behaviour in response to human stimuli (Diamond & Bond 2004; Wilson *et al.* 1991). It is important to understand how human activity influences kea behaviour, particularly for educating the public in terms of how to behave around the birds to minimize negative encounters. For example, it is important that people are educated on why they should not feed kea and also provided with appropriate strategies to prevent kea from stealing human food.

5.5 Qualitatively assess the impact of HWC on kea population dynamics

There are always limitations on the resources available for species management and most populations of management concern face multiple threats. It is important for

managers to be able to rank these threats and also evaluate the success/failure of different management strategies. The outcomes of a population viability analysis suggest that human-induced mortality (HIM) currently does not appear to have a strong effect on kea populations; instead, predation rates by exotic mammals have a larger influence on kea population dynamics. However, it is highly likely that resident human population size and tourist numbers will continue to rise in the Arthurs Pass area, leading to an increase in HIM rates, which is a concern due to the small number of kea remaining. If HIM continues to increase these events could threaten kea population persistence. In addition any reduction in the number of kea has implications for ecosystem services in alpine ecosystems as there may be too few kea to be effective vectors of alpine seed dispersal (Young *et al.* 2012). Finally, my results reveal that the use of the toxin sodium fluoroacetate (1080) for predator control was beneficial for kea populations, despite the unintentional loss of some adults.

5.6 Informing Management examples

While the information obtained during this thesis does not provide all the answers for managing kea, it fills some critical gaps relevant to researchers and managers seeking to create species action plans. Two applied examples of how a spatio-temporal framework can inform management are:

- 1.) Provides a spatio-temporal map of conflict risk to evaluate the placement of deterrents/attractants. For example, the Little Corella (*Cacatua sanguinea*), a cockatoo species from South Australia, is, like the kea, very neophilic, leading to similar patterns of human property damage (Tembley 2010). Managers have

used knowledge of the Little Corella's roosting behaviour to help determine optimal sites to place a variety of chemical, visual and auditory deterrents to help minimize property damage (Tembley 2010). Some research has shown that repellents such as D-pulegone (derived from the oil of pennyroyal mint species) has the potential as a chemical deterrent for kea (Day *et al.* 2011; Feenstra 2012). Alternatively it may be feasible to place attractants (e.g. kea 'play-grounds') in areas away from elevated conflict-risk. For example, kaka have been shown to learn to visit supplementary feeders, likely reducing damage to trees they would normally obtain sap from (Charles 2012).

2.) Characterising movement and behavioural patterns is also important when considering the development of new infrastructure and development. Studies of eiders (*Somateria mollissima*) have revealed that most individuals exhibit behavioural avoidance to windfarms, resulting in increased distance travelled and energy expenditure by individuals (Marsden *et al.* 2009). This information has been used to justify limiting the future development of windfarms along the eiders flyways. For kea the placement of human infrastructure such as electricity stations is important as kea are often electrocuted at these sites (Jackson 1969).

5.7 Potential of approach for other species

Ahearn *et al.* (2001), Treves *et al.* (2006), and Waldron *et al.* (2013) have expressed the need for improved knowledge regarding the spatial and temporal patterns of HWC to inform the development of effective management strategies. A small but growing number of studies are starting to develop methods for exploring the movement and space use of conflict-species in and around human centres of activity (e.g., Whittington

et al. 2004; Kertson *et al.* 2011; Nelson *et al.* 2012). The range of approaches being developed helps to provide a flexible toolkit to meet a wide variety of management objectives. The spatio-temporal approach developed in my thesis has huge potential to provide a framework that improves the understanding of species where data are difficult to obtain. Some particular advantages of the approach developed here include:

1.) The analytical techniques used provide a multi-faceted assessment of human-wildlife interactions, providing a comprehensive understanding of the system being explored;

2.) The data were also of sufficiently high-resolution to infer behavioural states, providing a means to explore the influence of humans on conflict species- very few researchers have used state-space models to explore HWC;

3.) High-resolution movement data has the potential to quantify how patterns of movement may result in intentional or accidental conflict events (e.g. vehicle strike) because lower resolution data (e.g., one location fix per hour) will not record the discrete behaviours of interest (Nathan *et al.* 2008).

4.) This approach could be applied to a wide-range of species and sites. In particular, it can be used to explore the movement patterns of birds, which is typically logistically challenging due to the ability of birds to move large distances very quickly;

5.) The data obtained from the framework I developed allows researchers to explore in detail different types of interactions; e.g., urban adaptors like kea, as well as urban avoiders;

6.) While the use of PVAs is extremely well established (e.g., Morris & Doak 2002), this method has been under-exploited as a means to explore the population-level effects of HWC. PVAs are particularly useful because they provide a method for evaluating the efficiency of alternative management strategies.

All these aspects provide a framework which has great potential to fill the knowledge gaps in the field of HWC management.

5.8 Future directions

The spatio-temporal approach I adopted in my thesis provides a framework for collecting important baseline data, such as where and when wildlife are interacting with human features. The data collected also have promising potential to inform further models further informing HWC management. A modelling approach provides a means to answer questions that occur at spatial and temporal scales too large for experimental work (while also avoiding practical and ethical considerations).

By synthesising the data from the spatio-temporal approach with information obtained from my PVA it is possible to inform dynamic spatially-explicit individual-based models (SEIBMs). SEIBMs provide a 'virtual ecology' that allow investigation of questions that more aggregated modelling approaches are unable to address (Grimm & Railsback 2005; Zurell *et al.* 2010). SEIBMs can represent individuals, their environments, and interactions between the two, with system-level (macroscopic) behaviour arising from traits of individuals and characteristics of the environment (Dunning *et al.* 1995; DeAngelis & Mooij, 2005; Grimm & Railsback 2005). SEIBMs can

be used to understand and predict the spatio-temporal dynamics of conflict species, allowing a range of questions relevant to HWC to be assessed. Some examples of such questions include: 1.) How does the density of human features in the landscape affect the movement dynamics of a conflict species? 2.) How does the spatial distribution of human features influence its movement dynamics? 3.) What is the probability that juveniles will interact with human features while dispersing and how do these interactions affect their survival? 4.) How will the spatio-temporal dynamics of conflicts vary under different management scenarios? This approach provides a useful tool for mapping the spatial and temporal patterns in the abundance of a species, therefore allowing the mapping of conflict areas; this is critical information for wildlife-conflict managers (Heinonen *et al.* 2014).

Improvements in technology also have the potential to greatly extend the applicability of the spatio-temporal framework. Among the most important developments are the ongoing reduction in the size of GPS receivers and advances in the efficiency of batteries and photovoltaic cells, which will greatly increase the operational lifetimes of tracking devices used to quantify HWC (Tarascon 2010; Jung *et al.* 2011). With technological advancements such as solar charging of batteries, remote download of data, geofencing, sensor networks, and real-time tracking, improved management of conflict species will be enabled. For example, mitigation of conflict for a highly endangered species (e.g., tigers, rhinos, elephants) could include use of a two-way satellite/GSM network server so that if a tracked individual comes within a certain proximity of human areas the system will set off deterrents (e.g., electric shock from collar, sirens or lights).

5.9 Concluding remarks

Understanding the movement and behaviour of a conflict-prone species is a fundamental first step in developing effective HWC management strategies (Conover 2001; Treves *et al.* 2006). My research suggests that adopting a spatio-temporal approach provides a means for managers to identify: 1.) potential spatial 'hot-spots' of conflict; 2.) specific time periods during which negative interactions between humans and wildlife are far more likely to occur; 3.) population sub-groups that are more vulnerable to conflict; 4.) the potential influence of human activity on animal behaviour; and 5.) the effect of HIM on long-term population dynamics. This information is collectively important for informing management and mitigation strategies by helping to identify and rank potential anthropogenic threats, allocate conservation resources effectively, and assess whether HIM is currently a threat or may become a threat in the future. In the long-term, adopting a spatial approach could help inform future development of human infrastructure (e.g. wind farms; Roscioni *et al.* 2014) as humans continue to spread further into wildlife areas.

References

- Ahearn, S.C., Smith, J.L.D., Joshi, A.R., & Ding, J. (2001) TIGMOD: an individual-based spatially explicit model for simulating tiger/human interaction in multiple use forests. *Ecological Modelling*, **140**, 81-97.
- Allee, W.C. (1931) *Animal aggregations: a study in general sociology*. vii, 431 pp. University of Chicago Press, Chicago, Illinois.
- Anderson, R. (1986) Keas for keeps. *Forest and Bird*, **17**, 2-5.
- Arthur, S.M. & Schwartz, C.C. (1999) Effects of sample size on accuracy and precision of brown bear home range models. *Ursus*, **11**, 139-148.
- Ascensão, F., Grilo, C., LaPoint, S., Tracey, J., Cleverger, A.P., & Santos-Reis, M. (2014) Inter-individual variability of Stone Marten behavioral responses to a highway. *PLoS ONE*, **9**, e103544.
- Auersperg, A.M., Von Bayern, A.M., Gajdon, G.K., Huber, L., & Kacelnik, A. (2011) Flexibility in problem solving and tool use of kea and New Caledonian crows in a multi access box paradigm. *PLoS One*, **6**, e20231.
- Barua, M., Bhagwat, S.A., & Jadhav, S. (2013) The hidden dimensions of human-wildlife conflict: health impacts, opportunity and transaction costs. *Biological Conservation*, **157**, 309-316.
- Bateman, P.W., & Fleming, P.A. (2012) Big city life: carnivores in urban environments. *Journal of Zoology*, **287**, 1-23.
- Beissinger, S.R. & Snyder, N.F. (1992) *New World parrots in crisis: solutions from conservation biology*. Smithsonian Institution Press, Washington, D.C, USA.

- Beissinger, S.R., & Westphal, M.I. (1998) On the use of demographic models of population viability in endangered species management. *The Journal of Wildlife Management*, **62**, 821-841.
- Berger, J. (2004) The last mile: how to sustain long-distance migration in mammals. *Conservation Biology*, **18**, 320-331.
- Bestley, S., Jonsen, I.D., Hindell, M.A., Harcourt, R.G., & Gales, N.J. (2015) Taking animal tracking to new depths: synthesizing horizontal–vertical movement relationships for four marine predators. *Ecology*, **96**, 417-427.
- Blair, R.B. (2001) *Birds and butterflies along urban gradients in two ecoregions of the United States: Is urbanization creating a homogeneous fauna?* In *Biotic homogenization* (eds J.L Lockwood & M.L McKinney), pp. 33-56, Kluwer Academic Publishers, Norwell, MA, USA.
- Bolnick, D.I., Svanbäck, R., Fordyce, J.A., Yang, L.H., Davis, J.M., Hulse, C.D., & Forister, M.L. (2003) The ecology of individuals: incidence and implications of individual specialization. *The American Naturalist*, **161**, 1-28.
- Bomford, M. & Sinclair, R. (2002) Australian research on bird pests: impact, management and future directions. *Emu*, **102**, 29-45.
- Bond, A.B., Wilson, K.J., & Diamond, J. (1991) Sexual dimorphism in the kea *Nestor notabilis*. *Emu*, **91**, 12-19.
- Bourgoin, G., Garel, M., Dubray, D., Maillard, D. & Gaillard, J.M. (2009) What determines global positioning system fix success when monitoring free-ranging mouflon? *European Journal of Wildlife Research*, **55**, 603-613.

- Boyce, M.S. (1992) Population viability analysis. *Annual review of Ecology and Systematics*, **23**, 481-506.
- Brejarrrt, R. (1994) Aspects of the ecology of Kea, *Nestor notabilis* (GOULD), at Arthur's Pass and Craigieburn Valley, *Doctoral dissertation*, Lincoln University, Lincoln, New Zealand.
- Brook, B.W., Lim, L., Harden, R., & Frankham, R. (1997) Does population viability analysis software predict the behaviour of real populations? A retrospective study on the Lord Howe Island woodhen *Tricholimnas sylvestris* (Sclater). *Biological Conservation*, **82**, 119-128.
- Brouwer, K., Jones, M. L., King, C.E., & Schifter, H. (2000) Longevity records for Psittaciformes in captivity. *International Zoo Yearbook*, **37**, 299-316.
- Brown, W. (2007) Local Civil Defence and Emergency Management (CDEM) Arrangements: A report for the Selwyn District Council. Rolleston, New Zealand.
- Bub, H. (2012) *Bird trapping & bird banding: a handbook for trapping methods all over the world*. Cornell University Press, New York, NY, USA.
- Butler, J. (2000) The economic costs of wildlife predation on livestock in Gokwe communal land, Zimbabwe. *African Journal of Ecology*, **38**, 23-30.
- Cagnacci, F., & Urbano, F. (2008) Managing wildlife: A spatial information system for GPS collars data. *Environmental Modelling and Software*, **23**, 957-959.
- Cagnacci, F., Boitani, L., Powell, R.A., & Boyce, M.S. (2010) Animal ecology meets GPS-based radiotelemetry: a perfect storm of opportunities and

- challenges. *Philosophical Transactions of the Royal Society B: Biological Sciences*, **365**, 2157-2162.
- Cain, M.L. (1985) Random search by herbivorous insects: a simulation model. *Ecology*, **66**, 876-888.
- Cain, J.W., Krausman, P.R., Jansen, B.D. & Morgart, J.R. (2005) Influence of topography and GPS fix interval on GPS collar performance. *Wildlife Society Bulletin*, **33**, 926-934.
- Carter, N.H., Shrestha, B.K., Karki, J.B., Pradhan, N.M.B., & Liu, J. (2012) Coexistence between wildlife and humans at fine spatial scales. *Proceedings of the National Academy of Sciences*, **109**, 15360-15365.
- Cederlund, G., & Sand, H. (1994) Home-range size in relation to age and sex in moose. *Journal of Mammalogy*, **75**, 1005-1012.
- Charles, K.E. (2012) Tree damage in Wellington as a result of foraging for sap and bark-dwelling invertebrates by the North Island Kaka (*Nestor meridionalis septentrionalis*). *Notornis*, **59**, 180-184.
- Chase, M.J., Schlossberg, S., Griffin, C.R., Bouché, P.J., Djene, S.W., Elkan, P.W., Omondi, P., Peltier, A., Selier, J., & Sutcliffe, R. (2016) Continent-wide survey reveals massive decline in African savannah elephants. *PeerJ*, **4**, e2354.
- Choquenot, D. (2006) Bioeconomic modeling in conservation pest management: Effect of stoat control on extinction risk of an indigenous New Zealand passerine, *Mohua ochrocephala*. *Conservation Biology*, **20**, 480-489.

- Clavero, M., Brotons, L., Pons, P. & Sol, D. (2009) Prominent role of invasive species in avian biodiversity loss. *Biological Conservation*, **142**, 2043-2049.
- CliFlo (2014) NIWA's National Climate Database on the Web. <http://cliflo.niwa.co.nz/>
- Collazo, J.A., White Jr, T.H., Vilella, F.J. & Guerrero, S.A. (2003) Survival of captive-reared Hispaniolan parrots released in Parque Nacional del Este, Dominican Republic. *The Condor*, **105**, 198-207.
- Conover, M.R. (2001) *Resolving human-wildlife conflicts: the science of wildlife damage management*. CRC press, Boca Raton, USA.
- Contesse, P., Heggin, D., Gloor, S., Bontadina, F., & Deplazes, P. (2004) The diet of urban foxes (*Vulpes vulpes*) and the availability of anthropogenic food in the city of Zurich, Switzerland. *Mammalian Biology-Zeitschrift für Säugetierkunde*, **69**, 81-95.
- Costa, D.P., Robinson, P.W., Arnould, J.P., Harrison, A.L., Simmons, S.E., Hassrick, J.L., Hoskins, A.J., Kirkman, S.P., Oosthuizen, H., Villegas-Amtmann, S., & Crocker, D. E. (2010). Accuracy of ARGOS locations of pinnipeds at-sea estimated using Fastloc GPS. *PloS one*, **5**, e8677.
- Coulombe, M.L., Massé, A., & Côté, S.D. (2006) Quantification and accuracy of activity data measured with VHF and GPS telemetry. *Wildlife Society Bulletin*, **34**, 81-92.
- Coulson, T., Mace, G.M., Hudson, E., & Possingham, H. (2001) The use and abuse of population viability analysis. *Trends in Ecology & Evolution*, **16**, 219-221.
- Crooks, K.R., & Soulé, M.E. (1999) Mesopredator release and avifaunal extinctions in a fragmented system. *Nature*, **400**, 563-566.

- Dall, S.R., Houston, A.I., & McNamara, J.M. (2004) The behavioural ecology of personality: consistent individual differences from an adaptive perspective. *Ecology Letters*, **7**, 734-739.
- Das, S.K., & Chattopadhyay, S. (2011) Human fatalities from wild elephant attacks-a study of fourteen cases. *Journal of Forensic and Legal Medicine*, **18**, 154-157.
- Day, T.D., Clapperton, B.K., Porter, R.E., Waas, J.R., & Matthews, L.R. (2012) Responses of free-ranging house sparrows to feed containing primary and secondary repellents. *New Zealand Journal of Crop and Horticultural Science*, **40**, 127-138.
- Dean, B., Freeman, R., Kirk, H., Leonard, K., Phillips, R.A., Perrins, C.M., & Guilford, T. (2012) Behavioural mapping of a pelagic seabird: combining multiple sensors and a hidden Markov model reveals the distribution of at-sea behaviour. *Journal of the Royal Society Interface*, rsif20120570.
- DeAngelis, D.L., & Mooij, W.M. (2005) Individual-based modeling of ecological and evolutionary processes. *Annual Review of Ecology, Evolution, and Systematics*, **36**, 147-168.
- DeMaster, D., Angliss, R., Cochrane, J., Mace, P., Merrick, R., Miller, M., & Waples, R. (2004) Recommendations to NOAA Fisheries: ESA listing criteria by the Quantitative Working Group. NOAA Technical Memorandum NMFS-F/SPO-67.
- Diamond, J. & Bond, A.B. (1999) Kea, bird of paradox: the evolution and behavior of a New Zealand parrot. University of California Press, Berkeley and Los Angeles, CA, USA.
- Diamond, J., & Bond, A.B. (2004) Social play in kaka (*Nestor meridionalis*) with comparisons to kea (*Nestor notabilis*). *Behaviour*, **141**, 777-798.

- Dickman, A.J. (2010) Complexities of conflict: the importance of considering social factors for effectively resolving human-wildlife conflict. *Animal Conservation*, **13**, 458-466.
- Distefano, E. (2005) *Human-Wildlife Conflict worldwide: collection of case studies, analysis of management strategies and good practices*. Food and Agricultural Organization of the United Nations (FAO), Sustainable Agriculture and Rural Development Initiative (SARDI), Rome, Italy.
- Drechsler, M. (1998) Sensitivity analysis of complex models. *Biological Conservation*, **86**, 401-412.
- Dundas, K.F. (2008) An all-hazards vulnerability assessment of Arthur's Pass township, South Island, New Zealand.
- Dunning, J., Stewart, D.J., Danielson, B.J., Noon, B.R., Root, T.L., Lamberson, R.H., & Stevens, E.E. (1995) Spatially explicit population models: Current forms and future uses. *Ecological Applications*, **5**, 3-11.
- Edwards, S., & O'Connor, K. (2014) DOC code of practice for aerial 1080 in kea habitat, Department of Conservation, Wellington, New Zealand.
- Egevang, C., Stenhouse, I.J., Phillips, R.A., Petersen, A., Fox, J.W., & Silk, J.R. (2010). Tracking of Arctic terns *Sterna paradisaea* reveals longest animal migration. *Proceedings of the National Academy of Sciences*, **107**, 2078-2081.
- Elliott, G.P. (1996) Mohua and stoats: a population viability analysis. *New Zealand Journal of Zoology*, **23**, 239-247.
- Elliott, G., & Kemp, J. (2004) Effect of hunting and predation on kea, and a method of monitoring kea populations: Results of Kea Research on the St Arnaud Range.

- DOC Science Internal Series 181*. Department of Conservation, Wellington, New Zealand.
- Ellner, S.P., Fieberg, J., Ludwig, D., & Wilcox, C. (2002) Precision of population viability analysis. *Conservation Biology*, **16**, 258-261.
- Evans, J.R. (1982) Running median filters and a general despiker. *Bulletin of the Seismological Society of America*, **72**, 331-338.
- Evans, K.L., Newson, S.E., & Gaston, K.J. (2009) Habitat influences on urban avian assemblages. *Ibis*, **151**, 19-39.
- Feenstra, E. (2012) Curiosity kills the kea: A method to reduce human-kea (*Nestor notabilis*) conflicts, *Honours dissertation*, University of Auckland, Auckland, New Zealand.
- Ferson, S., & Burgman, M.A. (1995) Correlations, dependency bounds and extinction risks. *Biological Conservation*, **73**, 101-105.
- Frair, J.L., Merrill, E.H., Visscher, D.R., Fortin, D., Beyer, H.L., & Morales, J.M. (2005) Scales of movement by elk (*Cervus elaphus*) in response to heterogeneity in forage resources and predation risk. *Landscape ecology*, **20**, 273-287.
- Frair, J.L., Fieberg, J., Hebblewhite, M., Cagnacci, F., DeCesare, N.J. & Pedrotti, L. (2010) Resolving issues of imprecise and habitat-biased locations in ecological analyses using GPS telemetry data. *Philosophical Transactions of the Royal Society B: Biological Sciences*, **365**, 2187-2200.
- Gajdon, G.K., Fijn, N., & Huber, L. (2006) Limited spread of innovation in a wild parrot, the kea (*Nestor notabilis*). *Animal Cognition*, **9**, 173-181.

- Galbraith, J.A., Beggs, J.R., Jones, D.N., & Stanley, M.C. (2015) Supplementary feeding restructures urban bird communities. *Proceedings of the National Academy of Sciences*, **112**, E2648-E2657.
- Gartrell, B.D. & Reid C. (2007) Death by chocolate: A fatal problem for an inquisitive wild parrot. *New Zealand Veterinary Journal*, **55**, 149–151.
- Geffroy, B., Samia, D.S., Bessa, E., & Blumstein, D.T. (2015) How nature-based tourism might increase prey vulnerability to predators. *Trends in Ecology & Evolution*, **30**, 755-765.
- Ginzburg, L.R., Slobodkin, L.B., Johnson, K., & Bindman, A.G. (1982) Quasiextinction probabilities as a measure of impact on population growth. *Risk Analysis*, **2**, 171-181.
- Goswami, V.R., Vasudev, D., & Oli, M.K. (2014) The importance of conflict-induced mortality for conservation planning in areas of human–elephant co-occurrence. *Biological Conservation*, **176**, 191-198.
- Graham, M.D., Douglas-Hamilton, I., Adams, W.M., & Lee, P.C. (2009) The movement of African elephants in a human-dominated land-use mosaic. *Animal Conservation*, **12**, 445-455.
- Greer, A.L., Gajdon, G.K., & Nelson, X.J. (2015) Intraspecific variation in the foraging ecology of kea, the world's only mountain-and rainforest-dwelling parrot. *New Zealand Journal of Ecology*, **39**, 254-261.
- Grimm, V., & Railsback, S.F. (2005) *Individual-based Modeling and Ecology*: Princeton Series in Theoretical and Computational Biology. New Jersey, USA.
- Gubbi, S. (2012) Patterns and correlates of human–elephant conflict around a south Indian reserve. *Biological Conservation*, **148**, 88-95.

- Gurarie, E., Andrews, R.D., & Laidre, K.L. (2009) A novel method for identifying behavioural changes in animal movement data. *Ecology letters*, **12**, 395-408.
- Gurarie, E., Bracis, C., Delgado, M., Meckley, T.D., Kojola, I., & Wagner, C.M. (2016) What is the animal doing? Tools for exploring behavioural structure in animal movements. *Journal of Animal Ecology*, **85**, 69-84.
- Hamby, D.M. (1994) A review of techniques for parameter sensitivity analysis of environmental models. *Environmental Monitoring and Assessment*, **32**, 135-154.
- Hansen, M.C., Garner, G.W., & Fancy, S.G. (1992) Comparison of 3 methods for evaluating activity of dall sheep. *Journal of Wildlife Management*, **56**, 661-668.
- Hansen, M.C. & Riggs, R.A. (2008) Accuracy, precision, and observation rates of global positioning system telemetry collars. *The Journal of Wildlife Management*, **72**, 518-526.
- Harding, E.G., Vehrencamp, S.L., & Curtis, P.D. (2009) External characteristics of houses prone to woodpecker damage. *Human-Wildlife Conflicts*, **3**, 136-144.
- Hartig, F., Calabrese, J.M., Reineking, B., Wiegand, T., & Huth, A. (2011) Statistical inference for stochastic simulation models—theory and application. *Ecology Letters*, **14**, 816-827.
- Hebblewhite, M. & Haydon, D.T. (2010) Distinguishing technology from biology: a critical review of the use of GPS telemetry data in ecology. *Philosophical Transactions of the Royal Society B: Biological Sciences*, **365**, 2303-2312.
- Heinonen, J.P., Palmer, S.C., Redpath, S.M., & Travis, J.M. (2014) Modelling hen harrier dynamics to inform human-wildlife conflict resolution: A spatially-realistic, individual-based approach. *PloS one*, **9**, e112492.

- Heinsohn, R., Webb, M., Lacy, R., Terauds, A., Alderman, R., & Stojanovic, D. (2015) A severe predator-induced population decline predicted for endangered, migratory swift parrots (*Lathamus discolor*). *Biological Conservation*, **186**, 75-82.
- Herrod, A., King, M., Ingwersen, D. & Clarke, R.H. (2013) Tracking devices attached with harnesses influence behaviour but not body mass of Princess Parrots *Polytelis alexandrae*. *Journal of Ornithology*, **155**, 519-529.
- Higgins, P. J. (1999) *Nestor notabilis* Kea. *Handbook of Australian, New Zealand and Antarctic Birds Volume 4: Parrots to Dollarbird* (eds P.J. Higgins), pp. 613-623, Oxford University Press, Melbourne, Australia.
- Hinsley, S.A., & Ferns, P.N. (1994) Time and energy budgets of breeding males and females in sandgrouse *Pterocles* species. *Ibis*, **136**, 261-270.
- Holyoak, M., Casagrandi, R., Nathan, R., Revilla, E., & Spiegel, O. (2008) Trends and missing parts in the study of movement ecology. *Proceedings of the National Academy of Sciences*, **105**, 19060-19065.
- Huber, L., & Gajdon, G.K. (2006) Technical intelligence in animals: the kea model. *Animal Cognition*, **9**, 295-305.
- IUCN (2003) Recommendation 20: preventing and mitigating human-wildlife conflicts, World Parks Congress, Durban, South Africa.
- IUCN (2014) Red List of Threatened Species. <http://www.iucnredlist.org>.
- Jackson, J.R. (1963) The nesting of keas. *Notornis*, **10**, 319-326.

- Jackson, J.R. (1969) What do keas die of? *Notornis*, **16**, 33-44.
- Jackson, T.P., Mosojane, S., Ferreira, S.M., & van Aarde, R.J. (2008) Solutions for elephant *Loxodonta africana* crop raiding in northern Botswana: moving away from symptomatic approaches. *Oryx*, **42**, 83-91.
- Jacobs, J. (1974) Quantitative measurement of food selection. *Oecologia*, **14**, 413-417.
- Jäggi, C. (2008) Management of Large Carnivores in Switzerland. *Proceedings of the International Symposium "Coexistence of Large Carnivores and Humans: Threat or Benefit?"* (ed R.G. Potts & K. Hecker) pp. 45-49, Belgrade, Serbia
- Jander, R. (1975) Ecological aspects of spatial orientation. *Annual Review of Ecology and Systematics*, **6**, 171-188.
- Jetz, W., Wilcove, D.S., & Dobson, A.P. (2007) Projected impacts of climate and land-use change on the global diversity of birds. *PLoS Biol*, **5**, e157.
- Johnson, D.H. (1980) The comparison of usage and availability measurements for evaluating resource preference. *Ecology*, **61**, 65-71.
- Jonsen, I.D., Flemming, J.M., & Myers, R.A. (2005) Robust state-space modeling of animal movement data. *Ecology*, **86**, 2874-2880.
- Jung, H.G., Jang, M.W., Hassoun, J., Sun, Y.K. & Scrosati, B (2011) A high-rate long-life Li₄Ti₅O₁₂/Li [Ni_{0.45}Co_{0.1}Mn_{1.45}]O₄ lithium-ion battery. *Nature Communications*, **2**, 516.
- Karl, B.J. & Clout, M.N. (1987) An improved radio transmitter harness with a weak link to prevent snagging. *Journal of Field Ornithology*, **58**, 73-77.
- Kauhala, K., & Auttila, M. (2010) Estimating habitat selection of badgers-a test between different methods. *Folia Zoologica*, **59**, 16-25.

- Kennedy, E.M., Kemp, J.R., Mosen, C.C., Perry, G.L.W, & Dennis, T.E. (2015) GPS telemetry for parrots: A case study with the Kea (*Nestor notabilis*). *The Auk*, **132**, 389-396.
- Kertson, B.N., & Marzluff, J.M. (2011) Improving studies of resource selection by understanding resource use. *Environmental Conservation*, **38**, 18-27.
- Kertson, B.N., Spencer, R.D., Marzluff, J.M., Hepinstall-Cymerman, J., & Grue, C.E. (2011) Cougar space use and movements in the wildland-urban landscape of western Washington. *Ecological Applications*, **21**, 2866-2881.
- Kilpatrick, H.J., & Stober, W.A. (2002) Effects of temporary bait sites on movements of suburban white-tailed deer. *Wildlife Society Bulletin*, **30**, 760-766.
- Kissui, B.M. (2008) Livestock predation by lions, leopards, spotted hyenas, and their vulnerability to retaliatory killing in the Maasai steppe, Tanzania. *Animal Conservation*, **11**, 422-432.
- Kumar, V., & Kumar, V. (2015) Seasonal electrocution fatalities in free-range rhesus macaques (*Macaca mulatta*) of Shivalik hills area in northern India. *Journal of medical primatology*, **44**, 137-142.
- LaFever, D.H., Schmidt, P.M., Perry, N.D., Faulhaber, C.A., Lopez, R.R., Silvy, N.J., & Forsys, E.A. (2008) Use of a population viability analysis to evaluate human-induced impacts and mitigation for the endangered Lower Keys marsh rabbit. *Human-Wildlife Interactions*, **50**, 260-269.
- Landa, A., Gudvangen, K., Swenson, J.E., & Røskaft, E. (1999) Factors associated with wolverine *Gulo gulo* predation on domestic sheep. *Journal of Applied Ecology*, **36**, 963-973.
- Leggetter, C.J., & Woodland, P.C. (1995) Maximum likelihood linear regression for speaker adaptation of continuous density hidden Markov models. *Computer Speech & Language*, **9**, 171-185.

- Lendrum, P.E., Anderson, C.R., Long, R.A., Kie, J.G., & Bowyer, R.T. (2012) Habitat selection by mule deer during migration: effects of landscape structure and natural-gas development. *Ecosphere*, **3**, 1-19.
- Le Souef, A.T., Stojanovic, D., Burbidge, A.H., Vitali, S.D., Heinsohn, R., Dawson, R. & Warren, K. S. (2013) Retention of transmitter attachments on black cockatoos (*Calyptorhynchus* spp.). *Pacific Conservation Biology*, **19**, 55-57.
- Lind, N.M., Vinther, M., Hemmingsen, R.P., & Hansen, A.K. (2005) Validation of a digital video tracking system for recording pig locomotor behaviour. *Journal of Neuroscience Methods*, **143**, 123-132.
- López-López, P., Gil, J.A., & Alcántara, M. (2014) Post-fledging dependence period and onset of natal dispersal in Bearded Vultures (*Gypaetus barbatus*): new insights from GPS satellite telemetry. *Journal of Raptor Research*, **48**, 173-181.
- Loss, S.R., Will, T., Loss, S.S., & Marra, P.P. (2014) Bird-building collisions in the United States: Estimates of annual mortality and species vulnerability. *The Condor*, **116**, 8-23.
- Loveridge, A.J., Searle, A.W., Murindagomo, F., & Macdonald, D.W. (2007) The impact of sport-hunting on the population dynamics of an African lion population in a protected area. *Biological Conservation*, **134**, 548-558.
- Lowry, H., Lill, A., & Wong, B. (2013) Behavioural responses of wildlife to urban environments. *Biological Reviews*, **88**, 537-549.
- Mace, G.M., & Lande, R. (1991) Assessing extinction threats: toward a reevaluation of IUCN threatened species categories. *Conservation Biology*, **5**, 148-157.

- Madden, F. (2004) Creating coexistence between humans and wildlife: global perspectives on local efforts to address human–wildlife conflict. *Human Dimensions of Wildlife*, **9**, 247-257.
- Manfredo, M.J. (2015) Essays on Human–Wildlife Conflict 10 Years After the Durban World Parks Congress: An Introduction. *Human Dimensions of Wildlife*, **20**, 285-288.
- Månsson, J., Nilsson, L., & Hake, M. (2013) Territory size and habitat selection of breeding Common Cranes (*Grus grus*) in a boreal landscape. *Ornis Fennica*, **90**,
- Masden, E.A., Haydon, D.T., Fox, A.D., Furness, R.W., Bullman, R., & Desholm, M. (2009) Barriers to movement: impacts of wind farms on migrating birds. *ICES Journal of Marine Science: Journal du Conseil*, **66**, 746-753.65- 72.
- Mateo-Tomás, P., Olea, P.P., Sánchez-Barbudo, I.S., & Mateo, R. (2012) Alleviating human–wildlife conflicts: identifying the causes and mapping the risk of illegal poisoning of wild fauna. *Journal of Applied Ecology*, **49**, 376-385.
- Mattisson, J., Andrén, H., Persson, J. & Segerström, P. (2010) Effects of species behavior on global positioning system collar fix rates. *The Journal of Wildlife Management*, **74**, 557-563.
- McCaskill, M. (1954) The Poutini coast: a geography of Māori settlement in Westland. *New Zealand Geographer*, **10**, 134-150.
- McFarland, D. C. (1991) The Biology of the Ground Parrot, *Pezoporus wallicus*, in Queensland. I. Microhabitat Use, Activity Cycle and Diet. *Wildlife Research*, **18**, 169-184.
- McKinney, M.L. (2002) Urbanization, biodiversity, and conservation. *BioScience*, **52**, 883-890.

- Messmer, T.A. (2000) The emergence of human-wildlife conflict management: turning challenges into opportunities. *International Biodeterioration and Biodegradation*, **45**, 97-102.
- Meyers, J.M., Arendt, W.J. & Lindsey, G. D. (1996) Survival of radio-collared nestling Puerto Rican Parrots. *The Wilson Bulletin*, **108**, 159-163.
- Mills, L.S., & Lindberg, M.S. (2002) Sensitivity analysis to evaluate the consequences of conservation actions. *Population viability analysis*. (eds R. Beissinger & D. McCullough), pp. 338-366. University of Chicago Press, Chicago, Illinois, USA.
- Millspaugh, J., & Marzluff, J. M. (2001) *Radio tracking and animal populations*. Academic Press, Cambridge, MA, USA.
- Ministry of Water, Land and Air Protection. (2003) Wildlife-human conflict prevention strategy. Victoria: Ministry of Water, Land and Air Protection.
- Mishra, C., Allen, P., McCarthy, T.O., Madhusudan, M.D., Bayarjargal, A., & Prins, H.H. (2003) The role of incentive programs in conserving the snow leopard. *Conservation Biology*, **17**, 1512-1520.
- Moll, R.J., Millspaugh, J.J., Beringer, J., Sartwell, J., & He, Z. (2007) A new 'view' of ecology and conservation through animal-borne video systems. *Trends in ecology & evolution*, **22**, 660-668.
- Møller, A.P, Tryjanowski, P., Díaz, M., Kwieciński, Z., Indykiewicz, P., Mitrus, C., Goławski, A., & Polakowski, M. (2015) Urban habitats and feeders both contribute to flight initiation distance reduction in birds. *Behavioral Ecology*, arv024.
- Moraes, E.A., & Chiarello, A.G. (2005) Sleeping sites of woolly mouse opossum *Micoureus demerarae* (Didelphimorphia, Didelphidae) in the Atlantic Forest of south-eastern Brazil. *Revista Brasileira De Zoologia*, **22**, 839-843.

- Morales, J.M., Haydon, D.T., Frair, J., Holsinger, K.E., & Fryxell, J.M. (2004) Extracting more out of relocation data: building movement models as mixtures of random walks. *Ecology*, **85**, 2436-2445.
- Morris, W.F., & Doak, D.F. (2002) *Quantitative conservation biology*. (eds W. Mossis & D. Doak). Sinauer, Sunderland, Massachusetts, USA.
- Morzillo, A.T., de Beurs, K.M., & Martin-Mikle, C.J. (2014). A conceptual framework to evaluate human-wildlife interactions within coupled human and natural systems. *Ecology and Society*, **19**, 44.
- Nathan, R., Getz, W.M., Revilla, E., Holyoak, M., Kadmon, R., Saltz, D., & Smouse, P.E. (2008) A movement ecology paradigm for unifying organismal movement research. *Proceedings of the National Academy of Sciences*, **105**, 19052-19059.
- Nelson, A.A., Kauffman, M.J., Middleton, A.D., Jimenez, M.D., McWhirter, D.E., Barber, J., & Gerow, K. (2012) Elk migration patterns and human activity influence wolf habitat use in the Greater Yellowstone Ecosystem. *Ecological Applications*, **22**, 2293-2307.
- Northrup, J.M., Anderson, C.R., Hooten, M.B., & Wittemyer, G. (2016) Movement reveals scale dependence in habitat selection of a large ungulate. *Ecological Applications*.
- Obbard, M.E., Pond, B.A., & Perera, A. (1998) Preliminary evaluation of GPS collars for analysis of habitat use and activity patterns of black bears. *Ursus*, **10**, 209-217.
- Ogada, M.O., Woodroffe, R., Oguge, N.O., & Frank, L.G. (2003) Limiting depredation by African carnivores: the role of livestock husbandry. *Conservation Biology*, **17**, 1521-1530.
- Ogden, J., Stewart, G.H., & Allen, R.B. (1996) Ecology of New Zealand *Nothofagus* forests. *The Ecology and Biogeography of Nothofagus forests*. (eds T. Veblen, R. Hill & J. Read), pp. 25-82. Yale University Press, New Haven, USA.

- Orams, M.B. (2002) Feeding wildlife as a tourism attraction: a review of issues and impacts. *Tourism management*, **23**, 281-293.
- Orr-Walker, T., & Roberts, L. (2009) Population estimations of wild Kea (*Nestor notabilis*). Kea Conservation Trust.
- Orr-Walker, T. (2010) Kea (*Nestor notabilis*) husbandry manual. Kea Conservation Trust.
- Orr-Walker, T., Adams, N.J., Roberts, L.G., Kemp, J.R., & Spurr, E.B. (2012) Effectiveness of the bird repellents anthraquinone and d-pulegone on an endemic New Zealand parrot, the kea (*Nestor notabilis*). *Applied Animal Behaviour Science*, **137**, 80-85.
- O'Sullivan, D., & Perry, G.L. (2013) *Spatial simulation: exploring pattern and process*. John Wiley & Sons, Chichester, U.K.
- Otway, N.M., Bradshaw, C.J., & Harcourt, R.G. (2004) Estimating the rate of quasi-extinction of the Australian grey nurse shark (*Carcharias taurus*) population using deterministic age-and stage-classified models. *Biological Conservation*, **119**, 341-350.
- Owen-Smith, N., & Goodall, V. (2014) Coping with savanna seasonality: comparative daily activity patterns of African ungulates as revealed by GPS telemetry. *Journal of Zoology*, **293**, 181-191.
- Palomares, F., Delibes, M., Ferreras, P., Fedriani, J.M., Calzada, J., & Revilla, E. (2000) Iberian lynx in a fragmented landscape: predispersal, dispersal, and postdispersal habitats. *Conservation Biology*, **14**, 809-818.
- Panzacchi, M., Van Moorter, B., Jordhøy, P., & Strand, O. (2013) Learning from the past to predict the future: using archaeological findings and GPS data to quantify reindeer sensitivity to anthropogenic disturbance in Norway. *Landscape Ecology*, **28**, 847-859.

- Patterson, T.A., Thomas, L., Wilcox, C., Ovaskainen, O., & Matthiopoulos, J. (2008) State-space models of individual animal movement. *Trends in Ecology & Evolution*, **23**, 87-94.
- Patterson, T.A., Basson, M., Bravington, M.V., & Gunn, J.S. (2009) Classifying movement behaviour in relation to environmental conditions using hidden Markov models. *Journal of Animal Ecology*, **78**, 1113-1123.
- Pepperberg, I. M. (2006) Ordinality and inferential abilities of a grey parrot (*Psittacus erithacus*). *Journal of Comparative Psychology*, **120**, 206-216.
- Postlethwaite, C.M., & Dennis, T.E. (2013) Effects of temporal resolution on an inferential model of animal movement. *PLoS ONE*, **8**, e57640.
- Prugh, L.R., Hodges, K.E., Sinclair, A.R., & Brashares, J.S. (2008) Effect of habitat area and isolation on fragmented animal populations. *Proceedings of the National Academy of Sciences*, **105**, 20770-20775.
- Pullar, T. (1996) Kea (*Nestor notabilis*) captive management plan and husbandry manual. Department of Conservation, Threatened Species Unit.
- Rabiner, L.R. (1989) A tutorial on hidden Markov models and selected applications in speech recognition. *Proceedings of the IEEE*, **77**, 257-286.
- Reed, J.M., Mills, L.S., Dunning, J.B., Menges, E.S., McKelvey, K.S., Frye, R., Beissinger, S.R., Anstett, M., & Miller, P. (2002) Emerging issues in population viability analysis. *Conservation Biology*, **16**, 7-19.
- Reid, C., McInnes, K., McLelland, J.M., & Gartrell, B.D. (2012) Anthropogenic lead (Pb) exposure in populations of a wild parrot (kea *Nestor notabilis*). *New Zealand Journal of Ecology*, **36**, 56-63.

- Rempel, R.S. & Rodgers, A.R. (1997) Effects of differential correction on accuracy of a GPS animal location system. *The Journal of Wildlife Management*, **61**, 525-530.
- Robertson, C.J., Hyvonen, P., Fraser, M.J., & Pickard, C.R. (2007). *Atlas of bird distribution in New Zealand, 1999-2004*, pp. 533. Wellington, Ornithological Society of New Zealand Inc.
- Robertson, H.A., Dowding, J.E., Elliott, G.P., Hitchmough, R.A., Miskelly, C.M., O'Donnell, C.F., Powlesland, R.G., Sagar, P.M., Scofield, R.P. & Taylor, G.A. (2013) Conservation status of New Zealand birds, 2012. *NZ Threat Classification Series*, 4. Department of Conservation, Wellington, New Zealand.
- Robinet, O., Bretagnolle, V., & Clout, M. (2003) Activity patterns, habitat use, foraging behaviour and food selection of the Ouvéa Parakeet (*Eunymphicus cornutus uvaeensis*). *Emu*, **103**, 71-80.
- Rodgers, A.R., Rempel, R.S., & Abraham, K.F. (1996) A GPS-based telemetry system. *Wildlife Society Bulletin*, **24**, 559-566.
- Roscioni, F., Rebelo, H., Russo, D., Carranza, M.L., Di Febbraro, M., & Loy, A. (2014) A modelling approach to infer the effects of wind farms on landscape connectivity for bats. *Landscape Ecology*, **29**, 891-903.
- Ryan, D.A., & Larson, J.S. (1976) Chipmunks in residential environments. *Urban Ecology*, **2**, 173-178.
- Saggese, K., Korner-Nievergelt, F., Slagsvold, T. & Amrhein, V. (2011) Wild bird feeding delays start of dawn singing in the great tit. *Animal Behaviour*, **81**, 361-365.
- Saïd, S., Gaillard, J.M., Widmer, O., Débias, F., Bourgoïn, G., Delorme, D., & Roux, C. (2009) What shapes intra-specific variation in home range size? A case study of female roe deer. *Oikos*, **118**, 1299-1306.

- Sanz, V., & Caula, S. (2015) Assessing bird assemblages along an urban gradient in a Caribbean island (Margarita, Venezuela). *Urban Ecosystems*, **18**, 729-746.
- Sawyer, H., Kauffman, M.J., & Nielson, R.M. (2009) Influence of well pad activity on winter habitat selection patterns of mule deer. *The Journal of Wildlife Management*, **73**, 1052-1061.
- Schofield, G., Scott, R., Dimadi, A., Fossette, S., Katselidis, K. A., Koutsoubas, D., Lilley, M., Pantis, J.D., Karagouni, A.D., & Hays, G. C. (2013) Evidence-based marine protected area planning for a highly mobile endangered marine vertebrate. *Biological Conservation*, **161**, 101-109.
- Schwing, R., Nelson, X.J., Wein, A., & Parsons, S. (2017) Positive emotional contagion in a New Zealand parrot. *Current Biology*, **27**, R213-R214.
- Seal, U., Garland, P., Butler, D., Grant, A., & O'Donnell, C. (1991) Kea-kaka population viability assessment. Workshop for kea and kaka. Christchurch, New Zealand, 2-5 December.
- Siex, K.S., & Struhsaker, T.T. (1999) Colobus monkeys and coconuts: a study of perceived human-wildlife conflicts. *Journal of Applied Ecology*, **36**, 1009-1020.
- Silva, M., Johnson, K.M., & Opps, S.B. (2009) Habitat use and home range size of red foxes in Prince Edward Island (Canada) based on snow-tracking and radio-telemetry Data. *Central European Journal of Biology*, **4**, 229-40.
- Simpkins, C., Perry, G.L., Glaser, A., Allerby, T., & Dennis, T.E. (2015) Effects of predation by introduced mammals and mortality due to severe floods on population viability of the endangered Blue Duck (*Hymenolaimus malacorhynchos*). *Emu*, **115**, 146-157.

- Sinha, A., Kumar, R.S., Gama, N., Madhusudan, M.D., & Mishra, C. (2006) Distribution and conservation status of the Arunachal macaque, *Macaca munzala*, in western Arunachal Pradesh, northeastern India. *Primate Conservation*, **21**, 145-148.
- Smilie, Shaun (2002). "Killer Cats Hunted Human Ancestors". National Geographic News. National Geographic Society.
- Smith, E.A., Newsome, S.D., Estes, J.A., & Tinker, M.T. (2015) The cost of reproduction: differential resource specialization in female and male California sea otters. *Oecologia*, **178**, 17-29.
- Snyder, N.F., McGowan, P., Gilardi, J. & Grajal, A. (2000) *Parrots: status survey and conservation action plan*. IUCN, Gland, Switzerland and Cambridge, UK.
- Spiegelhalter, D.J., Thomas, A., & Best, N.G. (1999). WinBUGS version 1.2 user manual. *MRC Biostatistics Unit*, 83.
- Tarascon, J.M. (2010) Key challenges in future Li-battery research. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, **368**, 3227-3241.
- Temby, I.D. (2010) Managing Impacts of the Little Corella on the Fleurieu Peninsula. Unpublished Management Report.
- <https://www.alexandrina.sa.gov.au/webdata/resources/files/Fleurieu%20Corella%20Report%20IAN%20TEMBY%20FINAL%20REPORT.pdf>
- Temple, P. (1996) *Book of the kea*. Hodder Moa Beckett Publishers, Auckland, New Zealand.
- Tennyson, A.J., Easton, L.J., & Wood, J.R. (2014) Kea (*Nestor notabilis*)—another North Island human caused extinction. *Notornis*, **61**, 174-176.

- Thirgood, S., & Redpath, S. (2008) Hen harriers and red grouse: science, politics and human-wildlife conflict. *Journal of Applied Ecology*, **45**, 1550-1554.
- Thomas, B., Holland, J.D. & Minot, E.O. (2011) Wildlife tracking technology options and cost considerations. *Wildlife Research*, **38**, 653-663.
- Thouless, C.R. (1994) Conflict between humans and elephants on private land in northern Kenya. *Oryx*, **28**, 119-127.
- Treves, A., Wallace, R.B., Naughton-Treves, L., & Morales, A. (2006) Co-managing human-wildlife conflicts: a review. *Human Dimensions of Wildlife*, **11**, 383-396.
- Treves, A., Wallace, R. B., & White, S. (2009). Participatory planning of interventions to mitigate human-wildlife conflicts. *Conservation Biology*, **23**, 1577-1587.
- Tukey, J.W. (1977), *Exploratory Data Analysis*. Addison-Wesley, Reading, PA, USA.
- UNEP, C., & IUCN, T. (2013) Elephants in the Dust-The African Elephant Crisis. A Rapid Response Assessment. UNEP, GRID-Arendal 2013.
- Vijayan, S., & Pati, B.P. (2002) Impact of changing cropping patterns on man-animal conflicts around Gir Protected Area with specific reference to Talala Sub-District, Gujarat, India. *Population and Environment*, **23**, 541-559.
- Votier, S.C., Grecian, W.J., Patrick, S., & Newton, J. (2011) Inter-colony movements, at-sea behaviour and foraging in an immature seabird: results from GPS-PPT tracking, radio-tracking and stable isotope analysis. *Marine Biology*, **158**, 355-362.
- Waldron, J.L., Welch, S. M., Holloway, J., & Mousseau, T.A. (2013) Using occupancy models to examine human-wildlife interactions. *Human Dimensions of Wildlife*, **18**, 138-151.

- Wall, J., Wittemyer, G., Klinkenberg, B. & Douglas-Hamilton, I. (2014) Novel opportunities for wildlife conservation and research with real-time monitoring. *Ecological Applications*, **24**, 593-601.
- Wilson, P.R., Toft, R.J., Shepard, C.A. & Beggs, J.R. (1991) Will supplementary feeding of South Island kaka improve breeding success? - DSIR Land Resources Contract Report No. 91/55, Dept. of Conservation, New Zealand.
- Weathers, W.W., & Sullivan, K.A. (1993) Seasonal patterns of time and energy allocation by birds. *Physiological Zoology*, **66**, 511-536.
- Weber, N., Duengkae, P., Fahr, J., Dechmann, D.K., Phengsakul, P., Khumbucha, W., Siriaroonrat, B., Wacharapluesadee, S., Maneorn, P., Wikelski, M., & Newman, S. (2015) High-resolution GPS tracking of Lyle's flying fox between temples and orchards in central Thailand. *The Journal of Wildlife Management*, **79**, 957-968.
- Weller, F., Cecchini, L.A., Shannon, L., Sherley, R.B., Crawford, R.J., Altwegg, R., & Jarre, A. (2014) A system dynamics approach to modelling multiple drivers of the African penguin population on Robben Island, South Africa. *Ecological Modelling*, **277**, 38-56.
- Wells, A.G., Blair, C.C., Garton, E.O., Rice, C.G., Horne, J.S., Rachlow, J.L., & Wallin, D.O. (2014) The Brownian bridge synoptic model of habitat selection and space use for animals using GPS telemetry data. *Ecological Modelling*, **273**, 242-250.
- Westgate, M.J., Likens, G.E., & Lindenmayer, D.B. (2013) Adaptive management of biological systems: a review. *Biological Conservation*, **158**, 128-139.
- Weston, M.K. & Memon, M.A. (2009) The illegal parrot trade in Latin America and its consequences to parrot nutrition, health and conservation. *Bird Populations*, **9**, 76-83.

- Whitcomb, R.G., Robbins, C.S., Lynch, J.F., Whitcomb, B.L., Klimkiewicz, M.K., & Bystrak, D. (1981) Effects of forest fragmentation on avifauna of the eastern deciduous forest. In *Forest island dynamics in man-dominated landscapes* (eds R.L. Burgess & D.M. Sharpe), pp. 125–205, Springer-Verlag, New York City, NY, USA.
- White Jr, T.H., Collazo, J.A. & Vilella, F.J. (2005) Survival of captive-reared Puerto Rican parrots released in the Caribbean National Forest. *The Condor*, **107**, 424-432.
- Wittemyer, G., Northrup, J.M., Blanc, J., Douglas-Hamilton, I., Omondi, P., & Burnham, K.P. (2014) Illegal killing for ivory drives global decline in African elephants. *Proceedings of the National Academy of Sciences*, **111**, 13117-13121.
- White, G.C., & Garrott, R.A. (1990) *Analysis of radio-tracking data*. Academic, San Diego, California, USA.
- White, P.C., & Ward, A.I. (2011) Interdisciplinary approaches for the management of existing and emerging human–wildlife conflicts. *Wildlife Research*, **37**, 623-629.
- Whittington, J., St Clair, C.C., & Mercer, G. (2004) Path tortuosity and the permeability of roads and trails to wolf movement. *Ecology and Society*, **9**, 4-18.
- Whittington, J., St Clair, C.C., & Mercer, G. (2005) Spatial responses of wolves to roads and trails in mountain valleys. *Ecological Applications*, **15**, 543-553.
- Wirringhaus, J.O., Downs, C.T., Perrin, M.R., & Symes, C.T. (2001) Abundance and activity patterns of the Cape Parrot (*Poicephalus robustus*) in two afro-montane forests in South Africa. *African Zoology*, **36**, 71-77.
- Woodroffe, R., Thirgood, S., & Rabinowitz, A. (2005) The impact of human-wildlife conflict on natural systems. *People and wildlife, conflict or co-existence?* (eds R. Woodroffe, S. Thirgood & A. Rabinowitz), pp. 1-12. Cambridge University Press, Cambridge, UK.

- Wong, B.B., & Candolin, U. (2015) Behavioral responses to changing environments. *Behavioral Ecology*, **26**, 665-673.
- Young, J.C., Marzano, M., White, R.M., McCracken, D.I., Redpath, S.M., Carss, D. N., Quine, C.P., & Watt, A.D. (2010) The emergence of biodiversity conflicts from biodiversity impacts: characteristics and management strategies. *Biodiversity and Conservation*, *19*(14), 3973-3990.
- Young, L.M., Kelly, D., & Nelson, X.J. (2012) Alpine flora may depend on declining frugivorous parrot for seed dispersal. *Biological Conservation*, **147**, 133-142.
- Zhang, L., Hua, N., & Sun, S. (2008) Wildlife trade, consumption and conservation awareness in southwest China. *Biodiversity and Conservation*, **17**, 1493-1516.
- Zurell, D., Berger, U., Cabral, J.S., Jeltsch, F., Meynard, C.N., Munkemuller, T. (2010) The virtual ecologist approach: simulating data and observers. *Oikos*, **119**, 622-635.