Understanding attacks by kea (*Nestor notabilis*), an endemic parrot, on sheep (*Ovis aries*) in the South Island high country

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This thesis is dedicated to the memory of my dad

Dr Robert G. B. Reid

And our irreplaceable friend

Dr Dawna G. Brand

Both of whom passed during the course of writing this thesis.

You are sorely missed.

Abstract

Human-wildlife conflict is a complex global issue that can have negative impacts on wildlife species and human livelihoods. An ongoing example of such conflict in Aotearoa New Zealand occurs between high country sheep farmers and kea (*Nestor notabilis*). This study is the first to document the conflict since attempts were made in the early 20th century. My aims were to: 1.) review the historical records of the conflict, and estimate the number of kea killed under a 100+ year bounty scheme; 2.) characterise sheep wounds attributed to kea attacks ('kea strike'), and estimate the current prevalence and associated risk factors; 3.) survey high country farmers' experiences with and perspectives of kea strike; 4.) examine behaviours that potentially underpin kea strike via experimental tasks presented to wild kea. I estimated that at least 116,869 kea were killed historically as a result of the bounty scheme. The majority of sheep wounds attributed to kea strike were in the loin (lumbar) region, and the wound prevalence was low (0–1.25%). However, it should be noted that the prevalence reported by farmers can be higher, and that higher kea strike frequency results in considerable economic and welfare costs for some high country sheep stations. Risk factors included station location, breed (Perendale), class (ram), and age (>1 yr). The results of an anonymous online survey of high country sheep farmers showed that less than half of the farmers reported kea strike, with low estimates of sheep injuries and losses, and a decrease of kea strike over the past 25+ years, which may have resulted from decreasing kea numbers and changes in sheep flock management. More than half of the farmers thought that only some kea attack sheep, which is consistent with the long-standing concept that kea strike is instigated by 'rogue' kea (problem individuals). Individual kea differed in innovative problem solving performance, exploration tendency and neophobia, and exploration tendency was linked with social rank and

innovation. I propose that high ranking males that are innovative and exploratory may initiate kea strike. Understanding the drivers of kea strike can be used to inform conservation management decisions regarding farmer-kea conflict, to the benefit of kea, high country sheep farmers and their stock.

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Thesis structure and format

This thesis comprises six chapters, including four research chapters (chapters 2 – 5) that have been prepared as independent manuscripts for publication in peer reviewed journals. As such, there is inevitably some overlap between chapters, although they have been reformatted to fit into the overall style of the thesis. References are included at the end of each chapter. A brief outline of the content of each chapter follows:

Chapter one

The **General introduction** provides context for the research content of this thesis and outlines the aims of this study.

Chapter two

The history of human-wildlife conflict between high country sheep farmers and kea (*Nestor notabilis*), including an estimate of the scale of the historical kea bounty reviews the historical literature on the long-standing conflict between high country sheep farmers and kea. It also presents annual data collected from historical sources, such as local and central government records, on the number of kea killed for bounty.

Chapter three

Prevalence and characterisation of wounds in sheep (*Ovis aries*) attributed to kea (*Nestor notabilis*) attacks on high country stations in New Zealand presents data collected from sheep flocks on five high country stations with prior history of kea attacks. Wounds in sheep that were attributed to kea attacks were characterised, and this chapter reports their prevalence and associated risk factors.

Chapter four

Farmers' perceptions of kea (*Nestor notabilis*) on high country sheep stations in the context of human-wildlife conflict reports on the results of an online survey of high country sheep farmers about kea and their impact on the farmers' sheep.

Chapter five

The role of personality, social rank and innovative problem solving in responses of kea (*Nestor notabilis*) to a mechanical analogue of a sheep (*Ovis aries*) presents the results of a study on the potential behavioural foundations of kea attacks on sheep. The relationships between two personality traits – neophobia and exploration tendency – as well as the roles of social rank and sex are examined in relation to innovation. These factors are discussed in the context of 'problem individuals' that initiate attacks on sheep.

Chapter six

The **General discussion** summarises the findings of chapters 2 to 5. The relevance and implications of the results of this study are discussed and future research directions are addressed.

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Chapter 1

General Introduction

Human-wildlife conflict

Human-wildlife conflict is a widespread and complex global issue that has existed since prehistory (Nyhus, 2016). It can be defined as occurring when the requirements and behaviour of wildlife impact negatively on human goals, or vice versa (Dickman & Hazzah, 2016). The interdisciplinary field of human-wildlife conflict research is growing rapidly, with the literature expanding almost exponentially within the past 20 years (Nyhus, 2016); this thesis focusses on the effects of such a conflict in the context of wildlife conservation. Human-wildlife conflict can directly cause material damage to crops, livestock and property, and consequently result in economic losses (Linnell et al. 2010; Woodroffe et al. 2005). Conflict can become especially challenging to address in cases where the protection of endangered species must be balanced with the needs of local communities (Woodroffe et al. 2005). In some taxa, such as large carnivores, species that are subject to conflicts with people are the most vulnerable to extinction (Woodroffe, 2001). Lethal control resulting from conflicts has led to the extinction of several species, and severe range collapses in many others (Woodroffe et al. 2005). The effects of human-wildlife conflict may also extend beyond populations, impacting on ecosystems – many ‘conflict’ species are also keystone species, the removal of which affects ecosystem structure (Woodroffe et al. 2005). Considering the wide-ranging effects of human-wildlife conflict, both for the people and the wildlife involved, effective mitigation plans are urgently needed to resolve these conflicts. Effective efforts to address and mitigate the impacts of conflicts between humans and threatened species require scientific documentation of the conflict (e.g. Acharya et al. 2016; Löe & Röskaft, 2004; Siex & Struhsaker, 1999). This is especially important where there is a paucity of quantitative data, and conservation managers are reliant on anecdotal information about conflict scenarios involving endangered species. For example, highly endangered Zanzibar red colobus monkeys *(Procolobus kirkii)* were perceived by farmers to have a negative impact on coconut harvests. But when the impact was quantified the monkeys were found to have no significant negative effect, but rather a positive impact, probably due to a pruning effect via the consumption of immature coconuts (Siex & Struhsaker, 1999). Investigating the history of human-wildlife conflict scenarios can also provide information on the historical impacts of these conflicts on wildlife species, especially where harvest data are available (e.g. Logiudice 2006). Gauging stakeholder experiences also provides data that are unavailable from other sources, and are also key to informing a balanced approach to conflict scenarios (Anthony et al. 2010; Thorn et al. 2013). Data from these various sources can be used in tandem to inform conservation management of conflict-prone threatened species, especially regarding the assessment of mitigation options. A prime example of an ongoing but understudied human-wildlife conflict scenario in Aotearoa New Zealand (hereafter 'New Zealand') occurs between people and kea (*Nestor notabilis*) wherever their activities overlap.

Kea (*Nestor notabilis*)

The kea is a large (46–50 cm length, 700–1100 g weight) olive-green parrot (family Strigopidae) with a long slender bill and bright orange-red underwing coverts. (Note that the name 'kea' is a Māori word, and the plural does not include an 's'.) Endemic to New Zealand, kea are now restricted to Te Wai Pounamu/South Island (hereafter 'South

Island’), fossil evidence indicates that their range included Te Ika a Māui/North Island (hereafter ‘North Island’) during the Holocene (the past 11,700 years) (Tennyson et al. 2014). Today they inhabit primarily montane forests and nearby subalpine and alpine areas from 600 to 3000 m above sea level (a.s.l.), including southern beech (*Nothofagus* sp.) forest, subalpine scrub, and alpine grassland, but are also widespread in lowland forest in Westland, and have been observed down to sea level (Forshaw, 2006; Higgins, 1999; Jackson, 1960; O’Donnell & Dilks, 1986; Wilson, 1990). Kea’s current range includes approximately four million hectares along the axial ranges of the South Island, from northwest Nelson and Marlborough to Fiordland and Central Otago Districts, as well as the Seaward and Inland Kaikoura Ranges (Kemp, 2013).

Kea have a high degree of behavioural flexibility and a broad generalist strategy (Diamond & Bond, 1999). They are highly omnivorous, their diet including a wide range of plant species and invertebrates (Greer et al. 2015), as well as animal carcasses (Jackson, 1960; Schwing, 2010), live animals including Hutton’s shearwater (*Puffinus huttoni*) chicks (Cuthbert, 2003), mice (*Mus musculus*) (Beggs & Mankelow, 2002), sheep (*Ovis aries*) (Thomas, 1972), and also human rubbish (Diamond & Bond, 1999; Gajdon et al. 2006). Kea have demonstrated excellent problem solving skills (O’Hara et al. 2012), including innovation in a foraging context in the wild (i.e. opening rubbish bins with hinged lids; Gajdon et al. 2006). Further, kea have demonstrated inter-individual differences in innovative problem solving (Gajdon et al. 2006) and personality, specifically the trait of neophobia (the avoidance of novelty), where some individuals approach novelty more readily than others (Reid, 2008).

Kea nest on the ground annually between July and January, with peak activity in July and August, and pairs are monogamous (Elliott & Kemp, 1999, 2004; Jackson, 1963; Wilson, 1990; Wilson & Brejaart, 1992). A female will lay 1 to 5 eggs with an incubation period of 22–26 days, and a nestling period of 13 weeks (Kemp, 2013). Kea have an extended juvenile period (Diamond & Bond, 1999) and are estimated to be dependent on their parents for at least 5 months (Diamond & Bond, 1991, 1999; Jackson, 1960, 1963), although they may continue to associate with and be fed by their parents throughout their first year (Reid, 2008; Stamm, 2007). From the time of initial independence from their parents, young kea will often gather in social flocks with juveniles and sub-adults until they form breeding pairs at the age of 4 to 5 years (Diamond & Bond, 1999; Jackson, 1960, 1963). Kea are highly social, forming dominance hierarchies (Diamond & Bond, 1999).

Kea are listed as nationally endangered by the New Zealand Department of Conservation (DOC) (Robertson et al. 2017), and endangered and rapidly declining by the International Union for Conservation of Nature (IUCN) (BirdLife International, 2017). The wild population is estimated at 6,000 individuals (4,000 mature individuals), and continues to decline rapidly – the total population decline over the last three generations (36 years) is likely to have been between 50% and 80% (BirdLife International, 2017; Kemp, 2013). Kea may still appear to be common due to their attraction to human activities and consequent habit of congregating near ski fields and tourist stops (Elliott & Kemp, 2004).

Human-kea conflict

Human conflict with kea arises wherever their habitats overlap, such as at tourist stops, ski fields, alpine and resort villages, farms, forestry blocks, and around fishing vessels (Diamond & Bond, 1999; Peat, 1995). Kea are attracted to anthropogenic food sources such as unsecured rubbish collection points, dumps, and areas where kea are regularly given handouts (Diamond & Bond, 1999; Gajdon et al. 2006; Jackson, 1969; Peat, 1995). A long-standing source of conflict stems from the overlap of kea and high country sheep farming since the latter was introduced to the South Island in the 1850s. Kea are known to attack domestic sheep (*Ovis aries*), which can cause illness, injury and death in sheep (Grant, 1993; Peat, 1995). However, anecdotal reports indicate that kea strike is initiated by 'rogue' kea (i.e. problem individuals), typically thought to be only a few older birds, and that removal of those individuals stops kea strike at least in the short- to medium-term (Aspinall, 1990; Campbell, 1976; McLeod, 1974; Marriner, 1908; Newton, 1983; Thomas, 1972). It has been hypothesised that the kea that initiate attacks on sheep may have a particular personality type – e.g. exploratory, innovative, bold (i.e. risk-taking) with low neophobia – and consequently may have been, and continue to be, targeted for culling (Fidler, 2011; Reid, 2008). The discovery of kea strike behaviour triggered a period of open persecution of kea lasting approximately 100 years (Peat, 1995; see also chapter 2). The impact of the cull is estimated to have been considerable, contributing to their heightened extinction risk (Elliott & Kemp, 2004). This conflict continues today (see chapter 3), and although kea are now fully protected (Peat, 1995), lethal control is still used as a management option to address it (B. Lawrence, DOC, personal communication, 2011). The effects of farmer-kea conflict should also be considered in the context of the overall pressures on the kea population: illegal killing of kea occurs in other contexts (Elliott & Kemp, 2004; Steffens &

Gasson, 2009), and kea are subject to a number of other anthropogenic hazards, such as predation by and competition with invasive mammals, exposure to toxins such as lead (Pb), and misadventure such as electrocution, entrapment and drowning (Jackson, 1969; Kemp et al. 2018; Peat, 1995; Reid et al. 2012).

Thesis objectives

This thesis focusses on documenting the conflict between high country sheep farmers and kea. This issue has not been well studied, and the information available until now has been primarily historical and/or anecdotal. In light of kea's current conservation status and rapid decline, as well as the ongoing impact on high country sheep farming, scientific research of the impacts on the kea population is needed to inform effective conservation management of this species.

My aims were to:

1. Review the historical literature of farmer-kea conflict, and examine the available data therein to estimate the numbers of kea killed as a result of the conflict.
2. Characterise wounds in sheep attributed to kea attacks, and report on their current prevalence and associated risk factors on high country stations in an area with a history of farmer-kea conflict.
3. Survey high country farmers' experiences with and perspectives of kea strike on their stations.
4. Examine the potential behavioural foundations of kea attacks on sheep via experimental tasks presented to wild kea.

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Chapter 2

The history of human-wildlife conflict between high country sheep farmers and kea (*Nestor notabilis*), including an estimate of the scale of the historical kea bounty

Abstract

Since humans first settled in New Zealand c.1280 AD considerable anthropogenic environmental changes have occurred. Consequently many of New Zealand's surviving species are threatened with extinction, and some are in direct conflict with humans. An unresolved example of such human-wildlife conflict occurs between high country sheep farmers and the kea (*Nestor notabilis*), an endangered endemic parrot. The kea's range was significantly reduced following the arrival of humans, and the establishment of the South Island high country sheep stations by Europeans by 1850 soon resulted in direct conflict between farmers and kea after kea were observed attacking sheep (*Ovis aries*) (a phenomenon referred to as 'kea strike') in 1868. Kea strike prompted a period of open persecution from 1868 to 1970, and I found reports in the historical literature of 116,869 kea killed during this period. Kea strike still occurs at a low and irregular prevalence, and an unconfirmed number of kea are still killed as a result despite their endangered status. Notwithstanding the ongoing nature of kea strike and the impact of the consequent human-wildlife conflict on kea, this phenomenon has not been well studied and is still poorly understood, the literature being largely historical. In this chapter, I investigate the history of human-kea conflict, with a primary focus on kea strike and the persecution of kea, using a range of historical sources of data. Examining the impact of human settlement and persecution on kea populations can contribute to an

improved understanding of this phenomenon, be used to inform the conservation management of this species and in turn mitigate human-kea conflict.

Introduction

The past, both paleoenvironmental and historical, is important in the appraisal of current ecology and conservation management (e.g. Leopold, 1940; Ogden et al. 2006). Human activities have long had major impacts on habitats and species, putting pressures on them that often bring the latter into conflict with humans (e.g. Fernández & De Azua, 2010; Marker & Dickman, 2004; Saberwal et al. 1994). An unresolved example of such human-wildlife conflict in New Zealand occurs between high country sheep farmers and the kea (*Nestor notabilis*), an endangered endemic parrot species. Kea are known to attack domestic sheep (*Ovis aries*) (a phenomenon referred to as 'kea strike'), which can cause illness, injury and death in sheep and prompted a period of open persecution lasting from 1868 to 1970 (Grant, 1993; Peat, 1995; this study). Despite its history, kea strike has not been well studied and is poorly understood, with reports of the issue in the literature being largely historical accounts and/or anecdotal in nature (e.g. Marriner, 1908). Much information about kea strike is only to be found in old newspaper articles, such as reports of county council and farmers' meetings, and archived official government records. Recent digitisation projects are now making much of this information far more accessible in the form of searchable electronic documents. Here I review the history of farmer-kea conflict in New Zealand and collate the archived information on this subject. Using this material I provide a detailed account of the numbers of kea killed annually for bounty during the period of open persecution.

First contact: kea and humans

European settlers were not the first to encounter kea. The Polynesian ancestors of Māori were the first humans to settle in New Zealand, arriving c.700–800 years before the present (BP) (Wilmshurst, 2008). Although there are few historical accounts of Māori interacting with kea, they occasionally feature in Māori mythology (e.g. Riley, 2001). In a Waitaha Māori legend, kea are kaitiaki (guardians), and are said to "[walk] with us on the trails" (Temple, 1996), which may reflect the real experiences of warriors encountering kea while passing through the area (Riley, 2001). This is consistent with later European accounts (e.g. Harper, 1896) and the experiences of mountain visitors today, who are often followed by kea as they walk through kea habitat. Kea were not often eaten by Māori as they found them too tough and lean, and exuding a strange smell when cooked (Beattie, 1994; Riley, 2001). Māori are reported to have caught kea in the alpine regions of the North Island (Taylor in Riley, 2001). Although kea are now restricted to the South Island, recently discovered fossil evidence suggests that they may have been uncommon residents of the North Island during the Holocene (the past 11,700 years) (Tennyson et al. 2014a). The lack of historical records of kea in the North Island indicates that they probably became locally extinct before the 19th century, and that this was most likely due to prehistoric human modification of the environment, and predation by kiore (Pacific rats, *Rattus exulans*) and humans (Holdaway, 1999; Tennyson et al. 2014a; Tennyson & Martinson, 2006).

At this time rapid and widespread habitat modification may have significantly affected kea's distribution in the South Island. Before the arrival of humans, an estimated 85–90% of late Holocene New Zealand was covered with forest and between the arrival of Polynesians c.1280 AD and European settlement c.1840 AD, forest cover was reduced by 40% (McGlone, 1983, 1989). In the eastern South Island burning by Māori destroyed much of the lowland podocarp forests between 800 and 600 yr BP, and in the inland inter-montane basins of the same region beech forest disappeared from 700–500 yr BP (McGlone, 1983). Fossil deposits in lowland Canterbury indicate that kea once lived there as far as the east coast of the South Island in the Late Holocene (6,000–1,000 yr BP), and were likely resident there (Holdaway & Worthy, 1997, 2008). The same factors indicated in the extirpation of kea from the North Island may also have restricted kea to the South Island high country. As Tennyson et al. (2014a, b) point out, if there were natural kea populations in relatively warm lowland environments in the North Island prior to human settlement, then apparently the kea is not an obligate alpine species as previously posited (e.g. Diamond & Bond, 1999; Fleming, 1979; Wood et al. 2014). Like other New Zealand avifauna, the modern distribution of kea may simply reflect where kea survived human-caused extinctions (Tennyson et al. 2014a). The fossil evidence that kea were likely also resident in lowland areas of the South Island in the late Holocene (Holdaway & Worthy, 2008) also support this (Tennyson et al. 2014a).

There have also been major changes in the availability of food sources for kea since humans first settled in New Zealand c.1280 AD. Human settlement has had a considerable impact overall on New Zealand's fauna, resulting in the extinction of 41% of its endemic avifauna (Holdaway et al. 2001), and the considerable range reduction of many other species (Bell, 1991). Prior to the arrival of humans, procellariid seabirds (petrels, shearwaters, fulmars, and prions) occupied colonies on the New Zealand mainland from lowland to alpine areas (Worthy & Holdaway, 2002), and may have formed part of the kea's diet. Kea are predators of Hutton's shearwaters (*Puffinus* *huttoni*), now listed as nationally vulnerable and restricted to only three colonies, the two natural ones of which are in remote alpine areas at 1200 to 1800 m a.s.l. in the Seaward Kaikoura Range on the northeast coast of South Island (Cuthbert & Davis, 2002; Robertson et al. 2017). Kea may have preyed on Hutton's shearwaters in lowland forest where the shearwaters were formerly abundant (Hawke & Holdaway, 2005; Holdaway & Worthy, 1997). Nest predation by kea has also been observed on whio (*Hymenolaimus malacorhynchos*), and is known or suspected to occur on several species of kiwi (*Apteryx australis* "northern Fiordland", *A. haastii*) – all of which are currently listed as nationally vulnerable by the New Zealand Department of Conservation/Te Papa Atawhai (DOC) (Forder, 2014; Robertson et al. 2017; Tansell et al. 2016; Whitehead et al. 2008). Fossil evidence indicates that kea may also have regularly scavenged moa (Aves: Dinornithiformes) carcasses, and that they may have killed moa already trapped in swamps or snow drifts or at least attended hokioi/Haast's eagle (*Aquila moorei*) kills (Holdaway & Worthy, 1997; Rawlence et al. 2011; Worthy & Holdaway, 2002). Moa were hunted to extinction during the period of Polynesian settlement from c.1280 AD to c.1450 AD (Holdaway & Jacomb, 2000; Rawlence & Cooper, 2013), and Haast's eagle became extinct possibly by c.1400 AD as a result of habitat destruction and the loss of most of its suitable prey species (Tennyson & Martinson, 2006). Damage observed in fossil moa pelves is consistent with the method of attack attributed to modern kea attacking sheep, in which the bird focuses on the hindquarters (Holdaway & Worthy, 1997). Kea may have transferred this behaviour from moa, a prey that was no longer around, to sheep, a new prey animal that was provided by European settlers (Holdaway & Worthy, 1997; Worthy & Holdaway, 2002).

European settlement

Europeans began settling in New Zealand from the 1840s, and most of the South Island high country was divided into runs by the late 1850s (O'Connor, 1982). Large tracts of native tussock grasslands and subalpine shrublands were burned to promote access for stock and maintain pasture growth (O'Connor et al. 1999), which further degraded kea habitat (Diamond & Bond, 1999). Other mammalian browsers were also either deliberately introduced to or invaded the high country. These included rabbits (*Oryctolagus cuniculus*), hares (*Lepus europaeus occidentalis*), chamois (*Rupicarpa rupicarpa*), Himalayan tahr (*Hemitragus jemlahicus*), red deer (*Cervus elaphus scoticus*), and goats (*Capra hircus*) that intensified and extended the impact of grazing by sheep and cattle (*Bos taurus*) on high country food resources (O'Connor, 1982). Stoats (*Mustela erminea*), which prey on kea and other birds, were introduced to South Island high country areas in the mid-1880's to control rabbits and within 20–30 years had spread into the bush throughout the South Island (Brown et al. 2015; King, 2017; Thomson, 1922).

Kea were first recorded in 1856 by Walter Mantell when he obtained two specimens in the Murihiku district in the southern South Island, and forwarded them to John Gould, who formally described them (Gould, 1856). Mantell informed Gould that he had first heard of kea from several elder Māori in about 1848, who distinguished kea from kākā (*Nestor meridionalis*), and indicated that kea used to come to the coast in severe winters, but that they had not seen them lately (Gould, 1856).

Kea began frequenting high country sheep stations, where they were reported to have fed on sheep carcasses, offal and drying skins (Potts, 1870). Signs of kea strike were first noticed by shepherds in 1867 on Wanaka Station in Otago, in the form of wounds on sheep's loins (Marriner, 1908). First thought to be a new disease, the lesions ranged from mere patches of bare skin, to partially healed or fresh wounds, or large holes torn in the sheep's side from which the entrails were often protruding (Marriner, 1908). By 1868 kea were suspected as the culprits and witnessed attacking sheep on Wanaka Station, and persecution of the birds began (Marriner, 1908). At the same time kea strike was first noticed on Mt Cook Station in Canterbury (Burnett, 1927; Marriner, 1908). The first published report of kea strike appeared in a newspaper in 1871 (Buller, 1888; 'Otago Daily Times,' 1871), followed by the first account in the scientific literature, a letter by T.H. Potts, in the same year (Potts, 1871; Wood, 1872). At the time of the first newspaper reports, kea strike was being discovered on Mt Nicholas Station in Otago (MacKenzie, 1948; White, 1894). In 1883 Mr Henry Campbell, the farmer at Wanaka Station, presented the problem to the Lake County Council, which approached the government about a bounty for exterminating the kea (NZPD, 1883a; 'Otago Daily Times,' 1883). County councils and the government agreed to provide a bounty for the destruction of kea (e.g. 'Local and General,' 1884; NZPD, 1883b).

From 1868 to 1905, the scientific literature about kea strike only reported hearsay evidence of the problem (e.g. Buller, 1883, 1888; Potts, 1882; Reischek, 1885) and evidence of kea as the cause of this problem was questioned in 1899 by Cockayne (Marriner, 1906; Myers, 1924). Two scientific papers were published in 1906 (Benham, 1906; Marriner, 1906) with evidence provided by eyewitness reports, and were the first records in the scientific literature to provide names and details of witnesses to kea strike. Marriner (1908) travelled to kea country to investigate, and although he didn't witness kea strike, he described wounds on sheep that had reportedly been attacked by kea. The controversy in the scientific literature appears to have died down for a time after the publication of Marriner's work (1906, 1907, 1908) and Benham's paper (1906).

Myers (1924) reviewed the kea strike literature and concluded that, "it may be accepted as provisionally true that some kea attack sheep". Some debate continued as to the extent of sheep losses resulting from kea strike, and the reality of kea strike itself (e.g. Moncrieffe, 1924). Later, Myers (1938) published a short piece decrying what he considered as scant evidence on which the kea bounty was sustained. In his presidential address to the Royal Society of New Zealand in 1950, R. A. Falla indicated that one of the Society's "most competent biologists attempted to suggest a different method of approach" to a bounty, his report was officially suppressed (Falla, 1950). Falla does not name the biologist, but as Myers was a biologist who researched kea strike in the 1920s and was member of the Royal Society, it seems likely that Falla was referring to him.

In the 1930s the debate was rekindled by the New Zealand Native Bird Protection Society (now known as Royal Forest & Bird Protection Society of New Zealand, hereafter Forest & Bird) – an article was published in their journal (Porter, 1934) defending kea against the charges of attacking sheep. The Society, backed by its founder, Captain Sanderson, argued that kea did more good than harm as seed dispersers for groundcover plants that helped to prevent erosion, and that high country farmers had no right to expect the general public to help them in their campaign against kea ('Keas useful,' 1938). Johannes Andersen also weighed in, trying to bring some balance to the general debate. He conceded that kea did attack sheep and that farmers had the right to defend their stock, but argued against a mass cull because only a few kea were responsible for kea strike (Andersen, 1938). Andersen's assertion that kea strike was initiated by a limited number of individuals was consistent with reports elsewhere (e.g. Marriner 1908), and usually older birds were considered to be the culprits. By 1949, Forest & Bird were still championing kea, at the same time conceding that the protection of farmers' flocks against the few 'killer' kea was necessary (Harper, 1949). When the society approached the Minister of Internal Affairs to ask that the kea bounty be removed in the county of Westland from Ross southwards, the Minister of Agriculture took the requested action a step further and removed the bounty for the whole of Westland (Harper, 1949). The Westland county council confirmed that most kea beaks submitted to its office had been sent from alpine areas where there were very few, if any, sheep (Harper, 1949). At the same time that the bounty was stopped in Westland, the official deer cullers in the district were asked to refrain from killing kea in the area (Harper, 1949). Persecution of kea in this area may have resulted from pressure in parliament, based on the belief that kea were breeding in South Westland and causing problems on high country stations elsewhere, and it was suggested that the government deer-cullers should be instructed to kill kea (NZPD, 1936). It was often asserted that kea bred on government land, including reserves and national parks, and then invaded sheep stations and killed sheep (e.g. 'General News,' 1932; NZPD, 1883b).

As of the late 1940s kea were protected within the existing national parks along with all other native fauna, but not on sheep-farming land (NZPD, 1948). The Minister of Internal Affairs, Mr Parry, stated that a field investigation had been made and reported that kea were not very numerous in the national park reserves in Canterbury, and that the kea's protection there was not considered to have much effect on the degree of kea strike in pastoral areas in that district (NZPD, 1948). Birds were protected in national parks under the Public Reserves, Domains and National Parks Act (1928). However, in 1949 Mr Parry said that kea were being destroyed in national parks by the government, but that it was not giving permission for “all and sundry” to go into the national parks to destroy kea (NZPD, 1949).

Field studies of kea were carried out by R. Jackson in Arthur’s Pass in the 1950s and ‘60s. Jackson (1962) argued that if kea attacked sheep, it only involved trapped, injured or sick sheep, and would occur only very rarely. However, anecdotal reports throughout the history of the farmer-kea conflict indicate that kea strike is initiated by ‘rogue’ kea, typically thought to be only a few older birds, and that removal of those individuals stopped the attacks at least in the short- to medium-term (Aspinall, 1990; Campbell, 1976; McLeod, 1974; Marriner, 1908; Newton, 1983; Thomas, 1972). No scientist appears to have reported, historically, ever witnessing kea strike first-hand. Several farmers (and former farmers) published accounts of kea strike in the peer-reviewed literature (e.g. Aspinall, 1967, 1972; Huddlestone, 1891; Scott, 2012; Thomas, 1972; White, 1894). Of those, only Thomas (1972) reported witnessing kea strike first-hand, although he named two other farmers who were eyewitnesses. At least one farmer reported witnessing kea strike first-hand in his memoirs (McLeod, 1980).

Apart from the protection in national parks, the only other reference to legal protection I found was to a three-month period under the Animals Protection Amendment Act 1910, which initially granted a blanket protection to indigenous birds until kea were exempted (Miskelly, 2014). Kea did not become legally protected on Crown land (i.e. government-owned land including reserves, domains and national parks) until 1970, when they were granted partial protection under Schedule 2 of the Wildlife Act 1953, and the government stopped the kea bounty (Miskelly, 2014). Aspinall mentions a fine of NZ$100 introduced in 1970 for shooting kea on Crown land, which is approximately equivalent to NZ$1,565 today (Aspinall in Runga, 1972). A campaign for full protection of kea was pursued by the New Zealand Wildlife Service (the predecessor of DOC), Phillip Temple, and Forest & Bird, leading to a fully protected status for kea in 1986 under the Wildlife Act 1953 (Miskelly, 2014). The Ngāi Tahu Claims Settlement Act 1998 also formally recognised kea as a taonga species (i.e. one of special cultural significance and importance to Ngāi Tahu, a South Island iwi/tribe) (Department of Conservation, 2006). Several years later, the first indisputable evidence of kea strike took the form of film footage of a kea attacking a sheep at night, taken during documentary filming (Paine & Morris, 1993; Temple,1994).

In the context of this history, I examined the historical records to estimate the number of kea killed annually during the period of open persecution (1868–1970) to give a detailed indication of the impact of organised persecution on this species.

Methods

I located information about the number of kea killed during the period of open persecution (1868–1970) via searches of online, digital and paper-based archives. I searched the National Library of New Zealand/Te Puna Mātauranga o Aotearoa's AtoJs Online archive, which contains digitised volumes of the Appendices to the Journal of the House of Representatives (AJHR) from 1858 to 1950, and the National Library's PapersPast archive, which contains digitised New Zealand newspapers and periodicals from 1839 to 1948. I also searched the database of the New Zealand Gazette (NZG, the official newspaper of the New Zealand government) at the National Library, an archive that contains digitised volumes from 1841 to 2004. Paper-based archives that I searched were bound volumes of the AJHR (1950–1972), and New Zealand Parliamentary Debates (NZPD) (1883–1972) at the National Library. Additional sources of data that I used in my estimates included Marriner (1906), Myers (1924), and Peden (2011). These records included reports of numbers of kea killed on high country sheep stations, submitted to county councils by farmers, and for which the government paid a bounty to county councils.

Where numbers of kea were not directly reported, but financial records for the kea bounty pay-outs were provided, I estimated the numbers of kea killed based on the reported bounty rate for that period. To prevent possible duplication of numbers, government records were used preferentially wherever possible and council and station reports that fell within those financial years (ending March 31st) were disregarded. For years that government records were not reported or the government was known not to have paid a bounty, available council and sheep station reports were used. Accordingly, individual station reports were not included for financial years that council records were available for the same region.

The records are incomplete – for example, for some years, records indicate that the government paid a bounty but specific information on the number of kea killed or financial amounts spent on the bounty were not provided. Also council records of kea destruction efforts were only reported in local newspapers sporadically, and accounts of specific numbers of kea killed on sheep stations are rare. However, partial to full records were found for all but six years of the persecution period of 1868 to 1970. Years for which I could find no records of kea numbers killed were 1868–1870, 1893, 1896 and 1968.

Results

The historical records for the years 1868 to 1970 indicate that at least 116,869 kea were killed during that period (Figure 2.1). Annual reports of government spending alone indicate that at least 108,685 kea were killed for the government bounty (Table 2.1). Government bounty payments peaked in the period of 1920–1930 (Figure 2.1), and I found that annual takes exceeded the estimated maximum number of kea extant today (6,000) in one of those years (1921). Between 174 and 6,315 kea ($\bar{x}$ = 1,782) were submitted annually for the government bounty during the years that it was reported (excluding years in which the bounty was not paid throughout the full year, i.e. 1930 and 1935).

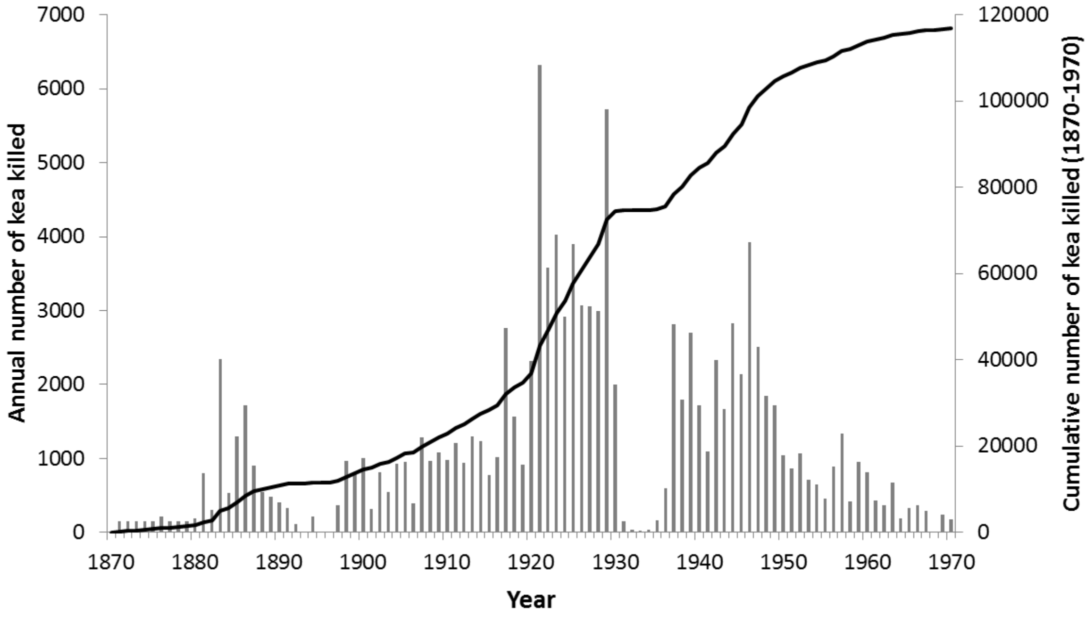

Figure 2.1 Annual totals and cumulative number of kea (*Nestor notabilis*) reported killed for bounty in the historical literature in New Zealand 1870–1970, based on reported numbers of kea and estimated numbers from government and county council reports. Bars represent annual totals, and the line represents the cumulative total. Note: zero values are reported for years where no record of kea numbers killed were found in the literature.

Table 2.1 Estimated number of kea paid for by New Zealand government bounty for the years 1883–1970. Numbers in bold indicate actual reported numbers of kea submitted. Estimates are based on the reported financial amounts spent by the government on the kea bounty at the corresponding reported rates.

Calendar Years	**Number of kea killed**	**Status of government subsidy**
1883–1884	2,870	Provided
1885	N/A	Provided (amount not reported)
1886	**1,712**	Provided
1887–1897	N/A	No records found
1898–1919	22,710	Provided
1920–1928	**32,164**	Provided
1929	5,720	Provided
1930	2,000	Provided (only for five months of the financial year)
1931–1934	0	Subsidy not paid by government
1935	168	Provided (only for four months of the financial year)
1936	N/A	Subsidy amount not reported
1937–1941	10,120	Provided
1942–1944	**6,819**	Provided
1945–1967	23,992	Provided
1968	N/A	Subsidy amount not reported
1969–1970	410	Provided
Total	108,685	

Bounty payments

Farmers affected by kea strike began paying a reward per head of kea killed on their stations from 1868 (Marriner, 1908), and county councils began paying farmers a bounty per head of kea killed in 1884 (e.g. ‘Local and General,’ 1884). The government began paying county councils a pound-for-pound bounty from 1884, and continued the bounty until at least 1886, presumably at the pound-for-pound rate that the government had initially set (NZPD, 1883a). From 1887 to 1897 I found no records of a direct government bounty. By 1889, the Lake County Council had received a telegram from the local sheep inspector indicating that the government was no longer paying a bounty (‘Lake County Council,’ 1889), and Huddlestone (1891) indicated the government bounty had been discontinued some time prior to 1891. A direct government bounty was reinstated in 1898 (Muir, 1929), from this time presumably paying a set rate per head of kea killed (e.g. Marriner, 1908). Records indicate government payments were made continuously from 1898 to 1930 (Table 2.1).

The suspension of government payments was announced in August 1930 (NZG, 1930), presumably due to financial considerations. New Zealand experienced a long economic depression in the 1920s and early 1930s (Greasley & Oxley, 2009), and at least one source cited the depression as the reason for the withdrawal of the government bounty during the early 1930s ('Menace of keas,' 1934). The government kea bounty was not re-instated until December 1st, 1935 ('Selwyn County,' 1935). The government finally terminated the bounty scheme completely in 1970, but continued payments until 1971 (AJHR, 1972; Miskelly, 2014).

As with the government, county councils do not appear to have paid subsidies on a continual basis. Both parliament and the councils voted internally regarding whether to pay subsidies, and there are records of subsidies being voted down in some years (e.g. 'Lake County Council,' 1891). The government, councils, and farmers paid out bonuses for kea at their discretion, and it appears that kea were continuously being killed for bounty (either at station, council, or government level) from 1868 to 1970. During the depression years when the government did not pay a bounty, some farmers and councils continued to pay a bounty (e.g. 'Vincent County,' 1935).

Bounty rates varied over time, between bodies offering payment (e.g. individual county councils and government) and areas (e.g. between stations). Council subsidies varied between 6 pence (e.g. 'Lake County Council,' 1887, ≈NZ$13 today, Reserve Bank of New Zealand Inflation Calculator, www.rbnz.govt.nz/monetary-policy/inflation-calculator) and 5 shillings (e.g. 'County Councils,' 1928, ≈NZ$59 today). Government subsidies varied from 6 pence (e.g. 'County Councils,' 1907, ≈NZ$10 today) to 5 shillings (e.g. AJHR, 1949, ≈NZ$45 today). I found that reported rates for subsidies paid by farmers generally varied between 2 shillings and 6 pence (e.g. 'The Kea and Rabbit Pests,' 1883, ≈NZ$55 today) and 10 shillings (Marriner, 1908, ≈NZ$203 today). However, on some stations higher subsidies would be offered. For example, in one report of an instance in the 1920s, £1 (≈NZ$97 today) was offered per kea, with £5 (≈NZ$485 today) paid for proven "killer kea" (i.e. kea witnessed by staff attacking sheep, and then killed in situ) (Newton 1983).

Discussion

The total number of kea killed during the period of open persecution (1868–1970) that I report here (116,869) is very likely an underestimate of the total number of kea actually killed. Reports of the numbers of kea killed during the depression years, for example, in the sources used in this study are sparse, although county councils and at least some sheep stations were reported to have continued paying subsidies for kea (e.g. 'General News,' 1932). Reports of the number of kea killed in the years prior to county council and government subsidies (1868–1883) are also sparse, county council reports of kea subsidies are sporadic, and reports of specific numbers of kea killed on individual sheep stations are rare. There are also at least some years during which the government paid a bounty but did not publish records of them in the AJHR reports (Table 2.1). I have no method of estimating the number of kea that were killed and not recovered, or killed but a bounty was not received. Besides shooting, poison was used to kill kea (Marriner, 1908; Hansard, 1936), and therefore it seems likely that an unknown number of kea may have died from poisoning but not been recovered. It is also likely that significant numbers of kea would have been killed in years that councils had voted not to pay a bounty, but back-country farmers had been unaware of the vote (e.g. ‘Lake County Council,’ 1889). I also found a record of one large bounty claim that was refused: in 1886 R. Stewart of Wanaka submitted 1,300 kea beaks to the local sheep inspector, but did not receive payment for them from the county council because they had not been killed within the current financial year (‘Lake County Council,’ 1886).

There are previous estimates of the number of kea killed during the period of open persecution (1868–1970), but these are in non-peer-reviewed reports (e.g. Anderson 1986; Temple 1996). Temple (1978) initially estimated that approximately 120,000 kea were killed between 1868 and 1978, and revised his estimate to approximately 150,000 kea killed from 1870 to 1970 (Temple, 1996). Although Temple did not provide specific details of the number of kea killed per annum, he gave a breakdown of his estimate for three parts of the period of persecution: the initial part of the period during which records were incomplete (~1870–1897), the second part of the period during which government records were nearly complete (1898–1928), and an isolated figure for 1942–44 (Temple, 1996). (Note that wherever Temple reported financial years – e.g. 1943–1945, which represent the calendar years 1942–1944 – I refer to calendar years for consistency with my reporting.) Both of Temple’s latter estimates (1898–1928 and 1942–44) are either similar to my own (54,204 reported by Temple versus 55,242 in this study for the period of 1898–1928), or match them exactly (6,819 for 1942–44). The exact match for 1942–44 is likely because the numbers of kea killed for bounty for these years were recorded directly in the AJHR reports for those years. Temple’s estimate for the initial part of the overall period of persecution (1870–1897) of 20,000–30,000 is considerably larger than the reported numbers that I obtained (11,557). For the period of persecution prior to council and government subsidies (i.e. 1868–1883), I only found annual records of kea killed on one station (2,600 kea on Wanaka Station for the period of 1871–1881) ('Public Meeting,' 1883), although I found references to kea strike occurring on at least six additional stations (Hawea, Mt Cook, Mt Nicholas, Five Rivers, Windley, and "Mr. Rodgers's") during that period (White, 1894; 'The Kea and Its Ways,' 1919; Burnett, 1927; 'The Kea,' 1929). If I were to make an estimate based on the reported annual number of kea killed on Wanaka Station and apply it to all seven stations for the years 1870–1883, that would add another 20,300 kea to the reported numbers I found for the period of 1870–1897, totalling 29,529, bringing it closer to Temple's estimate. This exercise may provide an overestimate for the six additional stations, but as it seems unlikely that these were the only stations with kea strike during this period, it may provide at least a rough estimate of the number of kea killed in these districts (i.e. Canterbury, Southland and Otago). The lack of availability of complete records for that period, and for the depression period during which the government did not pay a bounty (1931–1934) but some farmers and county councils did, indicate that the numbers of kea killed were under-reported. Temple based his estimates on many of the same resources I used (P. Temple, personal communication, 2016), although some additional sources are now more accessible because of digitisation of historical documents such as newspapers. Temple (1996) indicated that his personal belief was that the estimate of 150,000 was conservative. Given the deficits in the existing historical data, it seems likely that the estimated death toll of kea from 1868 to 1970 will climb beyond 150,000 as further records continue to become available (e.g. as further historical documents are digitised, which is an ongoing process).

Impact on the kea population

Kea are a K-selected species, slow to reproduce and recover from imposed mortality (Diamond & Bond, 1999; Spurr, 1979). Prior to the bounty, kea were more numerous than they are today, as demonstrated by the fact that the annual number of kea killed during one year of the bounty alone exceeded the maximum estimated number of kea that exist today (i.e. 6,000) (Figure 2.1) (Kemp, 2013). Even Marriner (1908) noted that in some districts, where kea were once to be seen in large flocks, the persecution had already greatly reduced their numbers. Kea are currently listed as nationally endangered by DOC (Robertson et al. 2017), and endangered and rapidly declining by the IUCN (International Union for Conservation of Nature) (BirdLife International, 2017). The wild population is estimated at 6,000 individuals (4,000 mature individuals), and continues to decline rapidly – the total population decline over the last three generations (36 years) is likely to have been between 50% and 80% (BirdLife International, 2017; Kemp, 2013).

Despite their protected status, kea are still persecuted, although the full extent of this persecution is unknown. Kea strike still occurs at a low and irregular prevalence (chapter 3). Farmers who experience problems with kea strike on their stations may apply to DOC for permission to kill kea on a case-by-case basis – a condition by which Federated Farmers agreed to the granting of fully protected status to kea in 1986 (B. Lawrence, DOC, personal communication, 2011; Miskelly, 2014). It has also been suggested that a few farmers may take matters into their own hands and kill kea illegally (B. Lawrence, DOC, personal communication, 2011). Kea are still illegally killed in other contexts, but the annual toll is unknown (Elliott & Kemp, 2004; K. McInnes, DOC, personal communication, 2016; Steffens & Gasson, 2009). Of 109 dead wild kea submitted to Massey University/Te Kunenga ki Pūrehuroa for necropsy between 1991 and 2017, the cause of death for 15 (14%) birds was confirmed as deliberate killing by either gunshot or poisoning (B. D. Gartrell, Wildbase, Massey University, unpublished data).

Kea now face a host of threats, many of them anthropogenic and introduced since European settlement. Invasive mammalian predators such as stoats and possums (*Trichosurus vulpecula*) are known nest predators of kea, and stoats have been shown to have a significant impact on kea nesting success and survival (Brown et al. 2015; Kemp et al. 2018). Competition with invasive mammalian browsers has also been posited as a possible contributor towards kea's decline (Elliott & Kemp, 1999). The diets of possums, ungulates and lagomorphs in the Southern Alps overlap with the diet of kea, and presumably these mammals compete with kea for these food resources (e.g. Clarke, 1970; Campbell, 1976; Parkes & Thomson, 1995; Wong & Hickling, 1999). Hazards such as lead (Pb) are present throughout the kea's habitat from sources such as buildings and hunter-killed game carcasses, and previous studies have shown that all tested kea had lead present in their bodies, many at elevated and sometimes lethal levels (McLelland et al. 2010; Reid et al. 2012).

Remarkably, despite the large scale of anthropogenic habitat destruction and its effects on kea, this factor alone is unlikely to have pushed them to extinction. Elliott and Kemp (2004) estimate that kea's 100-year risk of extinction in the 1850s was only 0.8%. The combined effects of the bounty and predation by introduced mammalian predators have, however, resulted in much smaller, more isolated kea populations that are now much more vulnerable to extinction than they used to be (Elliott & Kemp, 2004). Stoat predation has presumably had some level of impact on kea since stoats were introduced to the South Island high country in the mid-1880s, but possums did not colonise these areas until after the 1950s (Cowan, 2005; Elliott & Kemp, 2004). Possums continue to disperse in some parts of the South Island and they have yet to reach their peak densities in others, including areas where kea are found (Cowan, 2005). Although the effects of stoat predation and the bounty cannot be easily separated because of their historical concurrence, it could be argued that without the impact of the bounty, kea populations today would be more resilient to predation pressure and the decline to their current low numbers would at least have been delayed. Elliott and Kemp (2004) point out that, based on their modelling of kea populations, the kea bounty and predation by introduced mammalian predators have had a significant effect on kea, causing their populations to decline since the onset of kea persecution and the introduction of stoats and possums. Elliott & Kemp (2004) also indicate that the process of kea population decline has likely been reasonably complicated, with persecution, stoats and possums causing successive waves of decline in kea numbers. Based on this data, they estimate that the pressure of the bounty on kea was unsustainable, and given their increased extinction risk, continued killing of kea is unjustifiable (Elliott & Kemp 2004).

Conclusions

Human arrival and settlement in New Zealand since c.1280 AD has resulted in kea's extirpation from the North Island, and a restriction of their range to limited parts of the South Island. Soon after European settlement c. 1840, conflict arose between sheep farmers and kea after the establishment of stations in the South Island high country. Consequently, kea were openly persecuted for 102 years, endorsed largely by a government bounty. I provide evidence that the persecution resulted in the deaths of at least 116,869 kea during that period, and my results confirm that it contributed significantly to the kea's recent dramatic population decline. Kea are now classified as endangered and rapidly declining, and face a high risk of extinction. They are also formally recognised as taonga (treasures) to Ngāi Tahu, a South Island Māori iwi/tribe (Department of Conservation, 2006). Under the Treaty of Waitangi/Te Tiriti o Waitangi the nature of the relationship between DOC and Māori is that of a partnership, and although the Crown is entitled to govern, Māori retain tino rangatiratanga (full authority) over their taonga (Ministry of Justice, 2011; Waitangi Tribunal, 2011). In this light, iwi should be equal partners in management decisions involving kea, including cases of human-kea conflict. Based on the kea's extinction risk, continued killing of kea is not considered justifiable (Elliott & Kemp, 2004). However, kea are still deliberately killed via both legal and illegal means, and their survival is also threatened by invasive mammalian competitors and predators and other anthropogenic hazards. The fact of their continued existence is likely due to their sheer adaptability and tenacity.

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Chapter 3

Prevalence and characterisation of wounds in sheep (*Ovis aries*) attributed to kea (*Nestor notabilis*) attacks on high country stations in New Zealand

Abstract

Human-wildlife conflict is a growing global problem, and is especially problematic when it involves human livelihoods and endangered species. An ongoing example of such conflict in New Zealand occurs between high country sheep farmers and kea (*Nestor notabilis*), an endangered endemic parrot. Kea are known to attack domestic sheep (*Ovis aries*) (a phenomenon referred to as ‘kea strike’), which can cause illness, injury and death in sheep. Kea have been persecuted since the discovery of this phenomenon in 1868. Although kea strike has declined over time, it still causes economic losses to farmers and contributes to continuing persecution of kea. Despite its history, kea strike has not been well studied and is poorly understood, with reports of the issue in the literature being largely historical accounts and/or anecdotal in nature. In the first quantified study of kea strike injuries in sheep, I characterise and classified wounds in sheep (*Ovis aries*) suspected to have been caused by kea (*Nestor notabilis*) attacks on five high country stations in the Whakatipu area, Central Otago, on the South Island of New Zealand. The prevalence of wounds that I attributed to kea strike on all stations was low (0–1.25%), with the majority of wounds (80%) being in the loin (lumbar) region. Logistic regression models were applied to identify risk factors for the presence of wounds that I attributed to kea strike in the categories of location, breed, sheep class, and age, and showed that wound numbers were significantly higher on

particular stations (4 and 5), and for Perendales, rams, and sheep >1 year old. Given the opportunistic nature of this study, it is recommended that the results of the logistic regression models be further verified. Kea strike contributes to economic losses to high country sheep farmers and is a welfare issue for their stock, and leads to kea mortality via lethal control to mitigate the problem. Given the endangered conservation status of kea and the potential economic impact on high country sheep stations, an improved understanding of kea strike is needed to mitigate the effects of the conflict on both the kea population and high country sheep farming.

Introduction

Human-wildlife conflict is a growing global problem that is ancient in origin and especially concentrated in agriculture (Dickman & Hazzah, 2016; Woodroffe et al. 2005). Such conflict is particularly problematic when it involves human livelihoods and endangered species, and its conservation impacts only began to become apparent relatively recently (e.g. Madden, 2004). An unresolved example of such conflict in New Zealand occurs between high country sheep farmers and the kea (*Nestor notabilis*), an endangered endemic parrot. Kea are known to attack domestic sheep (*Ovis aries*) (a phenomenon referred to as 'kea strike'), which can cause illness, injury and death in sheep (e.g. Grant, 1993; Peat, 1995). When kea strike was discovered it was attributed with causing high sheep losses on high country stations, and prompted a period of open persecution of kea, lasting from 1868 to 1970 (chapter 2). Despite its history, kea strike has not been well studied and is poorly understood, with reports of the issue in the literature being largely historical accounts and/or anecdotal in nature (e.g. Marriner, 1908).

The primary pathways via which kea strike can result in illness and death in sheep are by septicaemia and bacterial toxaemia caused by *Clostridium* spp., (commonly referred to as blood poisoning, see below) or trauma (Campbell, 1976; Grant, 1993). The group of *Clostridium* spp. that causes what is recognised in New Zealand as blood poisoning include *Clostridium septicum* (malignant oedema), *C. chauvoei* (blackleg), and *C. novyi* (black disease) (West et al. 2009). However, *C. novyi* is only suspected as a cause of some wound infections in sheep in New Zealand, and only blackleg and malignant oedema have been specifically cited as the major causes of sheep mortality via kea (Campbell, 1976; West et al. 2009). All of the above clostridial diseases are toxaemic, acute and rapidly fatal (1–2 days), and *C. septicum* and *C. chauvoei* are known to infect wounds (Lewis, 2007; West et al. 2009). Tetanus (caused by *Clostridium tetani*) and secondary flystrike (myiasis) have also been cited as causes of death via kea strike (Scott, 2012).

Kea strike can also have an impact on the welfare of sheep that have been attacked. Although there are no scientific data on the extent of the distress that kea strike wounds cause sheep, they are likely to cause pain and morbidity to varying degrees. Kea strike injuries may remain untreated for an unknown period due to the extensive nature of the high country farming systems they are managed under, in which sheep may be rarely checked on except during routine husbandry procedures (e.g. shearing, parasite control, etc.). Regular checks are recommended for sheep that are set-stocked (i.e. grazed on an area of land for a long period, such as an entire grazing season) in areas that kea are present (e.g. Scott, 2012).

Attacks on livestock by mammalian carnivores and raptors are well documented, but to the best of my knowledge, kea strike is the only phenomenon involving livestock predation by a parrot species. Corvids have also been reported to occasionally attack livestock – primarily weak and/or dying lambs (e.g. Burgess, 1963; Houston, 1977; Rowley, 1969) – and there are historical reports of black-billed magpies (*Pica hudsonia*) attacking adult sheep, as well as other livestock (Berry, 1922; Schorger, 1921; Stephens, 1921). The conflict between high country farmers and kea is further complicated by kea's endangered status (Robertson et al. 2017), and the use of lethal control in attempts to mitigate it (B. Lawrence, New Zealand Department of Conservation/Te Papa Atawhai (DOC), personal communication, 2011). Here I report on the prevalence of wounds I attributed to kea strike in sheep mustered for shearing and characterise the nature of these wounds in the first quantified study of kea strike.

Methods

Data were collected on wounds I attributed to kea strike in sheep between August 2012 and October 2013 (Austral winter/spring) on five high country sheep stations in the Whakatipu area, Central Otago, on the South Island of New Zealand. Stations were chosen based on the previous history of kea strike, and visited during shearing in 2012 (Stations 1–4) and 2013 (Station 5 – this station was not visited in 2012 for logistical reasons). The prevalence of injuries that were consistent with kea strike was measured in lieu of sheep losses (i.e. sheep killed as a result of kea strike) because of the logistical difficulty of measuring the latter. Losses are very difficult to verify due to the mountainous terrain, large size of the stations (~8,000–19,000 ha), and sporadic, unpredictable nature of kea strike. Sheep were examined opportunistically according to the shearing schedules on the five stations. On Stations 1–4, sheep were examined immediately post-shearing in drenching races for signs of wounds caused by kea. On Station 5, Merinos were examined in a footbath pen immediately post-shearing, rams were checked from outside a small holding pen, and Perendales were examined in either a drenching race or footbath pen 5–6 days after shearing. I conducted all examinations, and a veterinarian assisted in wound identification during visits to Stations 1–4. Sheep on Stations 1 and 2 were shorn with hand shears and were not as closely shorn as sheep on the other stations, which were all machine shorn. As this was an observational study, and because injuries that I attributed to kea strike wounds were either healed or healing (except in cases where they had been accidentally reopened during shearing), wounds were not treated. Treatment of wounds was at the discretion of the farmers in this study. Ear tag colours were noted for age data (different colours are used each year to indicate birth year of each sheep). The demographics of sheep examined are presented in Table 3.1.

Table 3.1 Demographic data (%) of sheep (*Ovis aries*) examined for wounds attributed to kea (*Nestor notabilis*) attacks on five high country stations in Whakatipu, New Zealand in 2011–2012 (Stations 1–4) and 2012–2013 (Station 5).

Station	**Breed**				**Class**					**Age (years)**			
	Merino	**Merino X Dohne**	**Polwarth X South African meat Merino**	**Perendale**	**Ewe**	**Wether**	**Hogget**	**Ram**	**Unknown**	**1**	**1–5**	**>5**	**Unknown†**
1*	10	90	NA	NA	39	35	26	NA	0	26	69	3	2
2	100	NA	NA	NA	55	37	NA	NA	8	<1	60	39	1
3	100	NA	NA	NA	NA	100	NA	NA	0	0	75	22	3
4	NA	NA	100	NA	100	NA	NA	NA	0	0	63	36	1
5	67	NA	NA	33	59	14	26	1	0	26	38	7	28

*Sheep born on this station before 2008 were purebred Merino; sheep born after 2008 were Merino/Dohne crossbreds.

†Sheep with missing ear tags are included in the 'unknown' age category.

The characterisation and classification of wounds as being attributable to kea strike was made based on published images (both historical and recent, including video footage of kea strike from Paine & Morris (1993)), descriptions of wounds and kea behaviour in the kea strike literature and from farmers spoken to during this study, and from my observations of kea-induced damage to sheep carcasses prior to this study. Where possible, wounds I attributed to kea strike were double-checked with the farmer or farm staff familiar with kea strike wounds to differentiate them from other common causes such as shearing wounds. When sheep with injuries consistent with documented kea strike wounds were found, photographs were taken of the wounds and, where practical, a wooden ruler was placed adjacent to the wound. Age and sex of wounded sheep were also recorded. All wounds photographed with a ruler were subsequently measured visually on a laptop computer screen to the nearest half-centimetre. Wound categories and descriptions are presented in Table 3.2.

Table 3.2 Categorisations of wounds attributed to kea (*Nestor notabilis*) attacks that were observed in sheep (*Ovis aries*) on five high country stations in Whakatipu, New Zealand 2011–2013.

Wound Category	**Wound description**
Recent wound	Fresh exudative crust(s), usually accompanied by purulent or serosanguinous discharge and alopecia of the skin.
Healing wound	Old exudative crusts, often accompanied by hyperkeratosis and alopecia of the surrounding skin and exudate in the surrounding wool.
Recently healed wound	Fibrotic scars surrounded either by skin with alopecia, or wool regrowth shorter than the surrounding fleece. Sometimes accompanied by hyperkeratosis of the surrounding skin, and/or crusty/exudative discharge in the surrounding wool.
Older healed wound	Fibrotic and contracted scars without crusts or exudate, surrounding dirty/stained wool all of one length (i.e. not recent regrowth).

Statistical analyses

The required sample sizes to detect wounds on each station were calculated online using Frecalc version 2.0 (sample size for freedom testing with imperfect results, http://epitools.ausvet.com.au) (Sergeant, 2012). The statistical and epidemiological parameters used to determine sample size were as follows: confidence level, 95%; design prevalence, 0.1%; test sensitivity, 1.0; and test specificity, 1.0. Estimated true prevalence of wounds I attributed to kea strike was calculated online using EpiTools estimated true prevalence calculator (http://epitools.ausvet.com.au) (Sergeant, 2017). Confidence level was set at 95%; test sensitivity at 1.0; and test specificity at 1.0.

Logistic regressions were applied to identify risk factors for the presence of wounds I attributed to kea strike. Analyses were conducted using the R program for statistical computing, version 3.3.3 (R Core Team, 2017). Separate models were run for the following four risk factor categories: location (station); sheep breed; sheep class; and sheep age group. Sheep demographic categories used for analyses were as follows: breed (Merino, Polwarth/South African meat Merino cross, Merino/Dohne cross, and Perendale); class (hogget, ewe, wether, or ram); and age category (1 year old, 1–5 years old, and >5 years old). The reference variables for each model were Station 2 for location, Merino for sheep breed, ewe for sheep class, and one year of age for sheep age group. A risk factor was considered statistically significant if its odds ratio was greater than zero and its confidence interval was either less than or greater than zero.

Hoggets were young sheep (~one year old) that on Stations 2–5 had not yet been placed with other classes (i.e. ewes or wethers). On Station 1, hoggets that had been drafted in with either the ewes or the wethers prior to shearing were included with those respective classes, rather than in the hogget category. Lambs (sheep born the year of sampling) were not examined for logistical reasons, and because the consensus amongst the farmers spoken to in this study, and in the kea strike literature, is that kea do not attack young lambs (e.g. Marriner, 1908; Aspinall, 1990).

Results

Prevalence of injuries consistent with kea strike wounds

I identified injuries consistent with kea strike wounds in 0.5% (70 of 13,978) of sheep examined, but there was a clear difference in prevalence between the five stations examined. The individual station prevalence estimates were 0%, 0.033%, 0.067%, 0.46% and 1.25% (Table 3.3). None of the farmers on Stations 1–3 reported having observed signs of kea strike for several years prior to this study (Station 1 ~10 years, Station 2 ~8 years, Station 3 ~6–8 years), nor did they report any deaths attributed to kea strike in the year of sampling (2011–2012). Estimated losses attributed to kea strike for Stations 1–3 over the tenure of the farmers on these stations were ~1–5% per year, occurring one year in every 6–12 years. Station 4 reported low annual losses due to kea strike (~4 of 6,000 sheep, or 0.07%, 95% CI 0.03–0.17). Station 5 reported lower losses for the year sampled (2012–2013) than in previous years (~5 sheep of 5,000, 0.10% (95% CI 0.04–0.23) for 2012–2013). At the height of kea strike on Station 5, in 2009–2010, estimated overall losses to kea strike of ~8% (~400 of 5,000 sheep, 95% CI 7.28–8.78) were reported.

Table 3.3 Estimated true prevalence of wounds attributed to kea (*Nestor notabilis*) attacks in sheep (*Ovis aries*) examined on five high country sheep stations in Whakatipu, New Zealand in 2011–2012 (Stations 1–4) and 2012–2013 (Station 5).

Station	**Approximate flock size**	**Number sampled from flock**	**Number of affected sheep**	**Prevalence (%)**	**95% C.I.(%)**
1	3,500	2,464	0	0	0-0.16
2	4,000	3,039	1	0.03	0-0.19
3	5,000*	1,493	1	0.07	0-0.38
4	6,000	2,417	11	0.46	0.25-0.81
5	5,000	4,565	57	1.25	0.97-1.61

*The target flock size – i.e. Merino wethers – was 1,500. Ewes were also run on this station, but for logistical reasons only the Merino wethers were sampled.

The farmer on Station 5 reported a kea strike wound prevalence for previous years, during which kea strike rates were considered highest, of approximately 10% (e.g. ~5 wounded sheep in a drenching race of 50, 95% CI 4.35–21.36) for wethers. In this study, no injuries consistent with kea strike wounds were detected in wethers on Station 5, but the true prevalence was estimated to be 1.96% (53 of 2,704 sheep, 95% CI 1.50–2.55) for ewes overall (Perendale ewes 2.97% (34 of 1,144 sheep, 95% CI 2.13–4.12); Merino ewes 1.41% (22 of 1,560 sheep, 95% CI 0.93–2.13)). On Station 5, the prevalence of injuries consistent with kea strike wounds in Perendales overall was 2.35% (35 of 1,490 sheep, 95% CI 1.69–3.25), and for Merinos was 0.72% (22 of 3,075 sheep, 95% CI 0.47–1.08). The wound prevalence for rams on Station 5 was 6.45% (2 of 31 sheep, 95% CI 1.79–20.72), and for hoggets was 0.17% (2 of 1194 sheep, 95% CI 0.05–0.61).

Although I did not measure the number of shearing injuries during examinations, the following estimate of their frequency, based on a visual assessment of photographs of sheep in holding pens post-shearing on each station, may be useful for comparative purposes: across all stations, frequency of shearing injuries varied from approximately 30 – 78%.

Characterisation of injuries as kea strike wounds

Sheep were closely examined for signs consistent with kea strike wounds (Figure 3.1). Of the wounds I examined (n = 76), most consisted of full-thickness ulceration of the skin (97%), but also included evidence of injuries to deeper layers, including muscle (1%) and bone (1%). Wounds I attributed to kea strike were often accompanied by scabby material and/or exudate, patches of dirty or exudate-stained wool, and accumulated vegetative matter (e.g. twigs, leaves, and seed pods of manuka (*Leptospermum scoparium*)). Some wounds had also been reopened during shearing, therefore shearing wounds were also checked for signs of pre-existing injury. Injuries consistent with kea strike wounds were not always plainly visible, and were sometimes covered by wool or obscured by shearing wounds, therefore any suspect wounds or abnormalities were examined for underlying injuries that I would classify as kea strike wounds. Upon close examination, wounds I attributed to kea strike were distinguishable from simple shearing wounds, dermatophilosis (caused by the bacterium *Dermatophilus congolensis*), and abscesses caused by puncture wounds (e.g. from sharp vegetation such as matagouri (*Discaria toumatou*) (Figure 3.2). Injuries consistent with kea strike wounds that had been reopened during shearing usually had part of the original wound still visible. Patches of dermatophilosis lacked the tell-tale scabs or scars of injuries consistent with kea strike wounds, and puncture wounds were small (typically 1.5–2 cm), circular and pus-filled, whereas the wounds I attributed to kea strike were rarely circular and, with one exception (Figure 3.1), did not visibly contain pus. One ewe with a wound I attributed to kea strike was observed both prior to and after shearing on Station 4, and I also photographed her shorn fleece (Figure 3.1).

Measurements of injuries consistent with kea strike wounds

I detected a total of 76 wounds that I attributed to kea strike in 70 sheep across all five stations. Multiple injuries consistent with kea strike wounds in a single sheep (n = 6 sheep) were classified as separate only if they were at least 10 cm apart (n = 5 sheep), or had obviously occurred at different times because they were at distinct stages of healing (n = 1 sheep). All but three of the wounds were located on the dorsal skin. These three wounds were located on the shoulders (n = 2) or flank (n = 1). Sixty-one (80%) wounds were located in the loin (lumbar) region, four (5%) in the rump (pelvic/sacral) region, five (7%) in the shoulder (thoracic) region, five (7%) in the back (thoracolumbar) region, and one (1%) in the neck (cervical) region. Of the wounded sheep that had wounds that were measured (n = 54), 63 wounds were detected, with a mean length of 7.0 (± 4.5 SD) cm (range: 1–23.5). Based on the stage of wound healing, wounds were categorised as follows: two (3%) were older healed wounds, 10 (13%) were recently healed wounds, 47 (62%) were healing wounds, and 17 (22%) were recent wounds. At least five (7%) wounds I attributed to kea strike had been reopened during shearing.

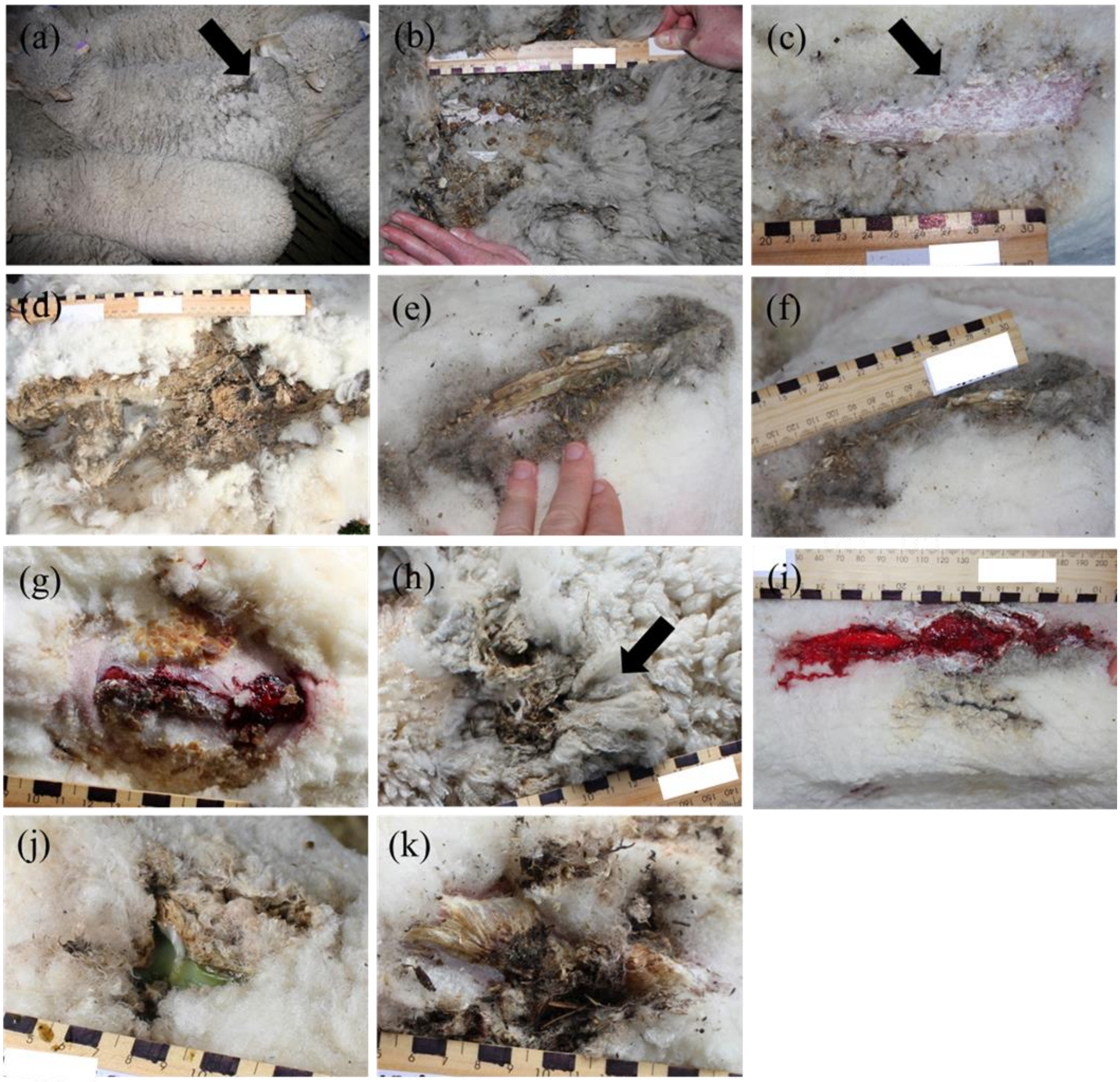

Figure 3.1 Images of wounds I attributed to kea (*Nestor notabilis*) attacks in sheep (*Ovis aries*) examined post-shearing on five high country sheep stations in Whakatipu, New Zealand in 2011–2013. Photos a–d show a ewe with an injury consistent with a kea strike wound on the loin, and her fleece after shearing: (a), an injury consistent with a kea strike wound (indicated by arrow) on loin prior to shearing; (b), the area of affected fleece visible after it was parted manually, revealing collected vegetative matter, dried exudate, and alopecia of the skin at the wound site; (c), a recently healed wound (indicated by arrow) photographed after shearing; (d), the underside of the shorn fleece from the same ewe with dried exudate visible. Photos e–k show injuries consistent with kea strike wounds, including: (e & f), an older healed wound (15cm in length) with exposed section of dead vertebral process protruding; (g), a recent wound; (h), a wound in an unshorn, short-fleeced ewe (arrow indicates 'flagged' wool, i.e. staples of wool that has been pulled from the sheep's back so that they project above the normal lie of the fleece); (i), a previously healed wound that was re-opened during shearing; (j), a pus-filled recent wound in a ram; (k), a healing wound with accumulated vegetative matter in the surrounding fleece. (NB: the ruler shown in the photos is 30 cm long with 1 cm increments marked in black.)

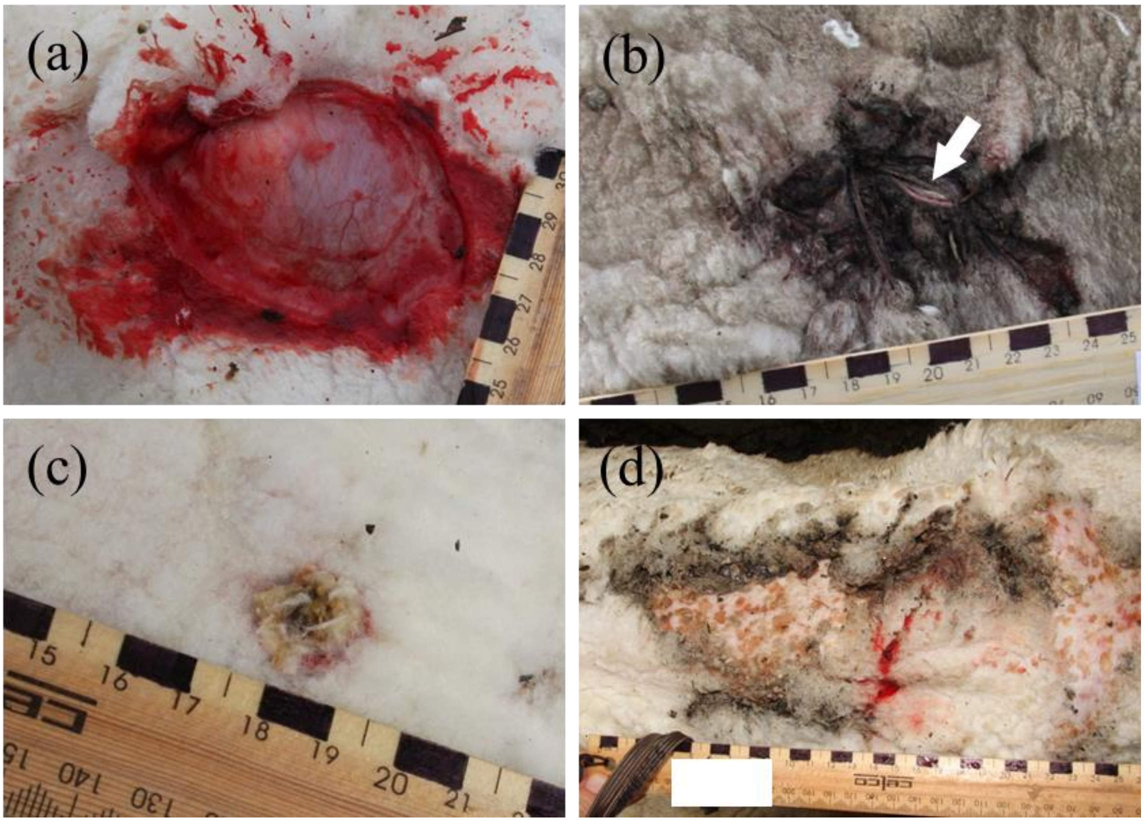

Figure 3.2 Images of wounds identified as those resulting from causes other than kea (*Nestor notabilis*) attacks, observed in sheep (*Ovis aries*) examined post-shearing on five high country sheep stations in Whakatipu, New Zealand in 2011–2013. Photos ‘a’ and ‘b’ show shearing wounds: (a), a fresh shearing wound; (b), a recent shearing wound (arrow indicates stitches); (c), a healing puncture wound; (d), advanced dermatophilosis. (NB: the ruler shown in the photos is 30 cm long with 1 cm increments marked in black.)

Sheep demographics

Sheep classes examined included hoggets, ewes, wethers and rams, although not all classes were examined on each station. A total of 13,978 sheep were examined, with a mean age across all stations of 3.8 (± 2.2 SD) years (range: 1–10). Sheep with wounds I attributed to kea strike (n = 70) had a mean age of 4.4 (± 1.6 SD) years (range: 1–7) (Table 3.4). Fifty-seven (81%) wounded sheep were detected on Station 5, 11 (16%) on Station 4, one (1%) on both Stations 2 and 3, and none on Station 1.

Table 3.4 Demographic data of sheep (*Ovis aries*) detected with wounds attributed to kea (*Nestor notabilis*) attack on five high country stations in Whakatipu, New Zealand in 2011–2012 (Stations 1–4) and 2012–2013 (Station 5).

Station	**No. wounded sheep**	**Breed**				**Sheep Class**				**Age**			
		Merino	**Merino X Dohne**	**Polwarth X South African meat Merino**	**Perendale**	**Ewe**	**Wether**	**Hogget**	**Ram**	**1**	**1 to 5**	**>5**	**Unknown†**
1*	0	0	0	NA	NA	0	0	0	NA	0	0	0	0
2	1	1	NA	NA	NA	0	1	NA	NA	NA	1	0	0
3	1	1	NA	NA	NA	NA	1	NA	NA	NA	1	0	0
4	11	NA	NA	11	NA	11	NA	NA	NA	NA	1	7	3
5	57	22	NA	NA	35	53	0	2	2	2	39	9	7

*Sheep born on this station before 2008 were purebred Merino; sheep born after 2008 were Merino/Dohne crossbreds.

†Sheep with missing ear tags are included in the ‘unknown’ age category.

Risk factors

I used data collected during station visits to identify risk factors for wounds I attributed to kea strike at the individual sheep level. In the categories of location, sheep breed, sheep class and age category, I found significantly higher wound numbers for two locations (Stations 4 and 5) Perendales, rams, and sheep >1 year old (Table 3.5). Complete separation occurred when Station 1 was included as a variable in the location logistic regression model, therefore it was removed from analyses.

Table 3.5 Logistic regression results for risk factors associated with wounds in sheep (*Ovis aries*) attributed to kea (*Nestor notabilis*) attack on five high country stations in Whakatipu, New Zealand in 2011–2012 (Stations 1–4) and 2012–2013 (Station 5). Risk factors in bold were significantly associated with wound numbers. (Note: Station 1 was omitted from the regression model for location due to complete separation.)

			97.5% Confidence Interval	
Variable	**n**	**Odds Ratio**	**Lower**	**Upper**
Station 2	3038	0.000	0.000	0.001
Station 3	1492	2.036	0.080	51.515
Station 4	**2406**	**13.889**	**2.700**	**253.992**
Station 5	**4508**	**38.413**	**8.465**	**679.336**
Merino	7840	0.003	0.002	0.004
Merino X Dohne	2161	0.000	0.000	6726.577
Polwarth X South African meat Merino	2406	1.493	0.702	2.981
Perendale	**1455**	**7.858**	**4.686**	**13.400**
Ewe	8028	0.008	0.006	0.010
Hogget	1192	0.210	0.035	0.672
Ram	**29**	**8.651**	**1.380**	**29.551**
Wether	4412	0.057	0.009	0.181
Age 1 year	1830	0.001	0.000	0.003
Age 1–5 years	**8148**	**4.829**	**1.489**	**29.626**
Age >5 years	**2505**	**5.844**	**1.661**	**36.998**

Discussion

Prevalence of injuries consistent with kea strike wounds

The prevalence of wounds that I attributed to kea strike on the high country sheep stations sampled was low (Table 3.3). Although I did not measure losses in this study, my findings appear to reflect the level of annual kea strike activity previously reported anecdotally on these stations. The wound prevalence on Stations 1–3 indicate that kea strike was either not occurring at the time (Station 1), or was only occurring at very low levels (Stations 2–3). On Station 4, where low annual losses were reported, I found correspondingly low wound prevalence. On Station 5, I found the highest wound prevalence, but reduced from the estimated prevalence reported by the farmer in previous years.

Risk factors

I have limited the description of the data collected to the level of individual sheep. Logistic regression and penalised logistic regression were explored but, given the opportunistic nature of the sampling in this study, the epidemiological unit of the data (sheep), and the aim of my study, the results of these models should be further verified. It is recommended that future research in this area should be designed as a case control study, given the low prevalence of wounds I attributed to kea strike (both at the station and at the individual animal level). Such a study will present many challenges for the researcher, including recall bias, sample size and statistical power.

Location (station)

The odds ratios for location were significant for only Stations 4 and 5, which indicate that the likelihood of sheep being non-lethally wounded was very low at the time of sampling for the other stations. This is consistent with the reports from farmers on Stations 1–3 that they had not encountered kea strike within at least the past six years. The significance of location (Stations 4 and 5) as a risk factor may be explained by differences in kea strike management on these stations. On stations 1–3, when losses to kea strike occur, kea are lethally controlled by permit from DOC. Kea that are regarded as probable culprits are targeted, and once kea strike stops, lethal control is ceased. It is commonly accepted that only a few kea (often referred to as 'killer' or 'rogue' kea, but hereafter referred to as 'problem individuals') initiate kea strike (e.g. Marriner, 1908; Newton, 1983; Thomas, 1972; see also chapter 5). On Station 4, losses occur annually at a low level and are regarded as an acceptable part of the overall annual losses, and part of farming in the high country. On this basis, kea are not controlled on this station. On Station 5, the farmer did not wish to use lethal control, partly for logistical reasons. Detecting and singling out individual kea responsible for initiating kea strike can be labour- and time-intensive (e.g. Aspinall, 1990; Marriner, 1908; Thomas, 1972). Previous farmers on Station 5 used lethal control, which usually – but not always – stopped kea strike for an interval of years similar to that reported on Stations 1–3 (B. Lawrence, DOC, personal communication, 2011). If only one or a limited number of individual kea initiate kea strike, its occurrence on Stations 4 and 5 may be due to the same individual(s) attacking sheep annually, whereas problem individuals are culled on the other stations, removing the problem until new ones come along. Detailed information on the distribution of kea on the stations in this study was not available, but all farmers reported seeing kea on their stations and stated that they were more likely to occur in high altitude pastures. Tenure review reports also recorded kea sightings on all stations during previous surveys (LINZ 2017). It is recommended that any future studies of kea strike include kea density and distribution in their risk analyses.

Sheep breeds

All of the stations in this study had different sheep breed compositions (Table 3.1). Purebred Merinos were run on all but Station 4. Merino/Dohne crosses were only run on Station 1, and Polwarth/South African meat Merino crosses were only run on Station 4. It should be noted that Perendales were run on Stations 3 and 5, but for logistical reasons, this breed was not sampled on Station 3 (see below). Because of the small sample size for stations in this study, and because breed composition was not evenly distributed across stations, the odds ratios that I report here (Table 3.5) should be examined in the context of location. The higher odds ratios for Perendales compared to other breeds included in this study are, arguably, supported by the estimated true prevalence at the breed level on Station 5 (i.e. Merinos vs Perendales), the prevalence for Merinos being closer to the prevalence found on Station 4. Perendales were also run on Station 3 (but not sampled), and the farmer there reported that this breed was only run on low elevation pasture, and that he had not observed any kea strike wounds or losses with this breed on this station. The higher prevalence for Perendales than Merinos is notable, considering the difference in temperament between these breeds. Perendales might be expected to sustain fewer kea strike wounds than Merinos because Perendales are less tolerant of handling (Whateley et al. 1974). However, the higher wound prevalence in Perendales may be at least in part explained by the fact that they have more flesh and subcutaneous fat than Merinos (Kirton et al. 1974), and therefore may be more attractive targets for kea attacks. The farmer on Station 5 reported that kea attacked sheep that were large and in good condition, which is consistent with historical accounts (e.g. Benham, 1906; ‘Keas and Sheep,’ 1934a; ‘Lakes Wanaka and Hawea,’ 1881; Marriner, 1908; ‘The Kea,’ 1906a; ‘The Kea,’ 1906b).

The farmer on Station 3 reported that the Merino wethers, which were run on the back blocks (i.e. more remote, subalpine/alpine pasture, often referred to as ‘the tops’), were the class affected by kea strike on that station. In my discussions with farmers and others working in the sheep and wool industry during this study, it was reported that some farmers who no longer use the highest elevation pastures on their stations report lower kea strike rates, or even a cessation of kea strike on their stations (see also chapter 4). Kea strike can vary widely by location, and there are reports of stations with chronic problems neighbouring those with no kea strike at all (e.g. Huddlestone, 1891). Kea strike can also vary within the level of individual stations, and some blocks (large, fenced high country pastures) are more prone to kea strike than others – this was reported by at least four of the five farmers in this study. Blocks that are located at a high elevation can be especially prone to kea strike. A common feature of stations in the Whakatipu area that do not have kea strike problems is the practice of keeping sheep below 700m a.s.l. from autumn (~April) onwards (B. Lawrence, DOC, personal communication, 2011). Although this may not be practicable on every station – ‘high country’ in New Zealand is generally defined as ≥700m a.s.l., and the stations in this study were 75–88% above >700m a.s.l. (LINZ 2017) – it may be a useful guideline for lowering the risk of kea strike during large snowfalls. The farmer on Station 4 reported leaving gates open between blocks to allow sheep to move with the weather conditions. One of the predisposing conditions for kea strike is a large winter snowfall, causing sheep in high elevation blocks to become stuck in snow, making them susceptible to kea strike (e.g. Aspinall, 1967; Marriner, 1908). Considering that the highest pastures on high country stations may also be the most remote, and therefore the most difficult to manage from a husbandry perspective, it follows that retirement of these blocks from grazing may be helpful for mitigating kea strike (see chapter 4).

Sheep classes

As with sheep breeds, sheep classes were not evenly distributed across stations (Table 3.1). Most stations included all classes, but Station 4, for example, primarily ran ewes and did not run wethers. Due to the opportunistic nature of this study and for logistical reasons, even on stations that included all classes, not all classes were sampled. Ewes were the only class sampled on all stations. Rams were only sampled on Station 5, and the sample size of this class was small (n = 31). Although my findings suggest that rams may be at a higher risk of injuries consistent with kea strike wounds than other classes, I suggest that due to the small sample size and geographical restriction of sampling for this class, further study with a larger sample size (both at the sheep class and station levels) would be required to be able to draw the conclusion that rams are at a higher risk of kea strike overall. However, the farmer on Station 5 reported that rams were prone to kea strike there, and that there had been two rams euthanised in 2012–2013 because of severe kea strike wounds. These were in addition to the two wounded rams I observed, bringing the total to 4 of 31 rams (13%) attacked by kea on Station 5 that season. There are several other reports of rams being attacked by kea. A farmer cited in Campbell (1976) reported that 12 of 15 (80%) Merino rams being held in a block with ewes at mating time were attacked by kea, and six (40%) had wounds too severe to survive. Another account reported the loss of eight of 20 (40%) Halfbred rams within a fortnight of being put out with ewes (‘Keas and Sheep,’ 1934a). This may indicate that, as with Perendales vs Merinos, kea may target rams in preference to classes that are smaller in body size with lower muscle mass and subcutaneous fat, and that differ from rams behaviourally.

The reduction in the kea strike rate in wethers on Station 5 from previous years may be due to the fact that the farmer on that station stopped using one of the most problematic blocks for kea strike, and ran the wethers elsewhere in 2012–2013. That I did not detect wounds that appeared to ≥1 year old may indicate that scars from injuries consistent with kea strike wounds are not detectable from previous seasons. Based on the estimated kea strike prevalence reported by the farmer on this station for previous years, I would have expected to detect more wounds than I found. Kea strike scars ≥1 year old may not be easily detectable once the wounded sheep's wool has regrown and covered it completely.

Sheep age

Sheep over the age of one year were at a higher risk of injuries consistent with kea strike wounds (Table 3.5). Hoggets (~one year) had an insignificant risk of these wounds. I observed two hoggets with wounds I attributed to kea strike on Station 5, and the farmer there reported that another three died as a result of kea strike that season (bringing the total detected number of hoggets attacked by kea that season to five of 1197, or 0.42% of hoggets on that station). When it was observed that hoggets had been attacked, they were moved to another location that was considered to pose less risk of kea strike, and no further problems were observed. Scott (2012) also reported that moving sheep upon the discovery of kea strike can stop the problem (see also chapter 4).

Injuries consistent with kea strike wounds

Most wounds I attributed to kea strike (80%) were located along the dorsal backline, on the loin area, which is consistent with some reports in the literature (e.g. Marriner, 1908; Scott, 2012). Newton (1983) reported seeing sheep wounded anywhere on the back between the shoulder and the rump, and indicated that kea strike wounds were generally made near the kidneys (i.e. lumbar region) because they happen to be in an unprotected area between the ribs and the rump. It has been pointed out that the loin area is the easiest, and sometimes the only, possible point of attack (Benham, 1906; Huddlestone, 1891; Marriner, 1908; Scott, 2012; White, 1894). The loin is also the most stable part when the sheep is in motion (i.e. has the least vertical motion and is the least involved in limb or neck movement), and is wide and flat, likely making it the best point for kea to grip a sheep's fleece and stay in place as it moves around. Newton (1983) also observed that when kea feed on sheep carcasses (rather than live sheep) they appear to show no preference for the loin, which is consistent with my observations elsewhere prior to this study (C. Reid and K. McInnes (DOC), personal observation).

Because my sampling technique only included sheep that returned to the shearing sheds after mustering, my sample likely did not include the full range of severity of injuries consistent with kea strike wounds – possibly as an effect of the time of year. Although all the wounds I attributed to kea strike were survivable injuries, they were likely to have resulted in varying degrees of pain and morbidity for the sheep involved and the welfare impact of kea strike on sheep should not be ignored. For example, two rams that were euthanised on Station 5 in 2012–2013 prior to sampling were so severely wounded by kea strike that they were not predicted to survive, and their condition was considered a significant welfare issue. The wounds of one ram were described by the farmer as being wide and deep enough that the animal's spine was exposed. More severe wounds than the ones I detected have been reported elsewhere, e.g. where the peritoneum has been punctured and visceral organs (such as part of the intestine) have been extracted (Benham, 1906; Marriner, 1908; Scott, 2012; see Aspinall, 1972 for a photograph).

There are also several historical reports of kea strike wounds resulting in a fistula or ‘false anus’ (Benham, 1906; Huddlestone, 1891; White, 1894), and one specimen from a sheep wounded in this manner was forwarded to London to be described in the Transactions of the Pathological Society of London by Wood (1872). The fistula in the specimen described by Wood (1872) was located midway between the crest of the ilium and the last (13th) rib on the right side, approximately 7.6 cm from the spinous processes of the lumbar vertebrae.

I have attributed the wounds in the sheep to kea strike based on my discussions with farmers and examination of the kea strike literature (including photographs, both historical and recent, of kea strike injuries and video footage of a kea attacking a sheep and the wounds resulting from the attack), as well as my own prior observations of kea-induced damage to sheep carcasses. I was able to confidently distinguish these wounds from both fresh and healing shearing wounds, puncture wounds, and dermatophilosis. I also consider it improbable that the wounds were caused by other species resident in high country areas, such as karoro/black-backed gulls (*Larus dominicanus*), kāhu/harrier hawks (*Circus approximans*), kārearea/New Zealand falcons (*Falco novaeseelandiae*), or makipae/Australian magpies (*Gymnorhina tibicen*). Although black-backed gulls and harrier hawks have been reported to attack adult sheep, these reports indicate that gulls restrict their attacks to the eyes, faces and perineal regions of lambing ewes, whereas hawks and magpies attack the eyes of already injured or ill sheep (Marriner, 1908; McCaskill, 1945; McLeod, 1974; Scott, 2012). I have not encountered any reports of gulls, hawks or magpies attacking sheep in the regions of sheep’s bodies where kea strike is reported to occur (i.e. the dorsal, flank, and shoulder areas) and where I observed injuries that I characterised as kea strike wounds. Neither have I come across any reports of falcons attacking sheep. On this basis, I am confident that kea strike is the most probable cause of these wounds, but I acknowledge a lack of definitive proof. Given the rare nature of these events and the remote country in which they occur, definitive proof of causation is not readily achievable.

Economic consequences of kea strike

Although the reported instances of kea strike have decreased considerably since the peak of the phenomenon (e.g. Aspinall, 1990), it is an ongoing issue that continues to cause financial losses to high country farmers. The farmer on Station 5 estimated the losses to kea strike sustained in 2009–2010 were worth ~NZ$20,000 at the time. For historical comparison, estimated losses to kea across 27 stations in the year ending 1944 were 6625 sheep, averaging 245 sheep per station at a cost of £245 (£1 per head), totalling £6,625 for all 27 stations ('Ministerial Visit,' 1945). The estimated cost of losses in 1944 (£245) is equivalent to NZ$20,233.75 today (Reserve Bank of New Zealand Inflation Calculator, http://rbnz.govt.nz/monetary-policy/inflation-calculator). On one station, the total estimated losses to kea strike for 1949–1950 and 1950–1951 were 500 sheep (250 sheep/year) (Aspinall, 1990). Wool prices at that time were high, resulting in an estimated annual loss to kea strike on this station equivalent to NZ$25,154.91 today. On another station in 1971, estimated losses were 128 sheep totalling NZ$1,280 (Thomas, 1972) – equivalent to NZ$17,150.60 today.

Outright sheep losses are not the only source of financial loss to kea strike, as damage to fleece may also contribute. Flagging (a 'flag' is a staple of wool that has been pulled from the sheep's back so that it projects above the normal lie of the fleece) resulting from kea strike can also reduce the quality of the fleece (Peat, 1995; Figure 3.1). A wool sorter who presented us with a fleece from a kea-struck ewe (Figure 3.1) pointed out a wool break in the fleece ~2–3 months old, indicating that it coincided with the injury I attributed to kea strike. The sorter also informed us that the wool break would result in the whole fleece being downgraded to 'tender' (i.e. wool that is weakened by stress and breaks when put under tension). This is consistent with reports that maternal stress in sheep can result in wool tenderness (e.g. Schlink & Hynd, 1994).

Clostridial diseases

Although the kea's beak has often been suggested as the physical mechanism for the introduction of clostridial infections associated with kea strike (e.g. Aspinall, 1972; Thomas, 1972), it should be noted that clostridia are ubiquitous in the environment, especially in soil (Lewis, 2007). *Clostridium* spp. are also present in small numbers in clinically unaffected animals, and in most cases, clostridial disease is initiated by 'trigger factors' (Lewis, 2007) – in this case wounds inflicted by kea. Sheep can also develop clostridial infections via minor wounds such as punctures from matagouri spines (Peat, 1995). The group of clostridial diseases referred to as 'blood poisoning' in New Zealand (*C. septicum*, *C. chauvoei*, and *C. novyi*) are all endemic in sheep flocks throughout the country and are of major importance to livestock (West et al. 2009). Although the widespread use of multi-component vaccines has noticeably reduced losses from these diseases, they are still prevalent, and reported losses have occurred almost invariably when preventative vaccination has not been conducted, or vaccination programmes have lapsed (West et al. 2009). Routine vaccination against clostridial diseases is carried out by almost all prime lamb producers, stud sheep farmers and significant numbers of hill country farmers in New Zealand, and it is inexpensive and usually highly effective if carried out correctly (West et al. 2009).

All stations included in this study had a vaccination regime using a multi-component 5-in-1 vaccine for *Clostridium* spp. (containing toxoids for *C. septicum*, *C. chauvoei*, *C. novyi* type B, *C. tetani*, and *C. perfringens* type D, West et al. 2009). Vaccination is recommended by DOC to mitigate kea strike (e.g. Grant, 1993), although it does not guarantee complete protection from kea strike losses. Vaccination requires an initial injection followed by a booster four weeks later, and protection against infection is not complete until after the second vaccination, and annual boosters are required (Lewis, 2011). Losses to clostridial infection following kea strike that occurred between initial and booster 5-in-1 vaccinations were reported on Station 5 prior to my study (B. Lawrence, DOC, personal communication, 2011). Some losses to kea strike may also occur despite vaccination, due to trauma or in sheep that have not yet been vaccinated or have been missed for vaccination. Four hoggets that were missed during muster, and therefore missed vaccination, were lost to kea strike on Station 4 in 2011–2012. Several farmers in this study indicated that the use of clostridial vaccines has made a considerable difference in reducing losses to kea strike. Elsewhere, the practice has been credited with reducing losses to kea strike, and in at least one case almost eliminating the problem (Aspinall, 1990; Jessep, 1965; Scott, 2012; Soper, 1976; see also chapter 4).

Sheep losses

Mean annual sheep losses from all causes in the South Island high country are ~5%, not including lamb losses (e.g. Sheep and beef farm survey 2015). Historically, annual losses to kea strike were reported to be as high as 40%, but Marriner (1908) pointed out that these were likely exaggerated, because if that level had been sustained annually there would have soon been no sheep left in the affected areas. Marriner (1908) estimated that a more realistic estimate of annual losses to kea strike was 5%, although he acknowledged that at times losses may have greatly exceeded that on some stations. Potts (1882) reported that the annual losses on stations where kea strike was highest varied between 3 and 5%, but that in some instances, “very heavy” exceptional losses occurred. This appears to be supported by losses reported in the sparse records available (n = 9, see ‘A Noxious Bird,’ 1919; ‘Guilty or Not Guilty?,’ 1921; Marriner 1906; ‘Menace of Keas,’ 1935; NZPD, 1935; ‘Public Meeting,’ 1883; ‘The Murderous Kea,’ 1906), which indicate a mean annual loss to kea strike of 7.73% (± 3.35 SD) (range 1–13%) between 1883 and 1935. Historical records of kea strike wound rates are rare, but the available reports (n = 7, see Buller, 1883; ‘Habits of Keas,’ 1934; ‘Keas and Sheep,’ 1934b; ‘Menace of Keas,’ 1935; Menzies, 1878; ‘The Kea,’ 1906c; ‘The Meat-eating Kea,’ 1934;) indicate a mean of kea strike wound rate of 7.04% (± 8.52 SD) (range: 0.3–25%) between 1878 and 1934. It should be noted, however, that these numbers may not reflect annual losses applicable across years and locations as they were likely to have fluctuated, and reporting may have been biased towards more severe years.

Mitigating kea strike

Maintaining an active vaccination programme against clostridial disease is recommended as an important tool for minimising mortality related to kea strike (Grant, 1993). Translocation of ‘problem’ kea (i.e. those found to be engaging in kea strike) was previously considered a viable mitigation option (Grant, 1993), but this technique is no longer considered by conservation managers because it is thought to merely move the problem to another location, and survivorship of relocated kea is unknown (B. Lawrence, DOC, personal communication, 2011). Lethal control is considered as a final option, and farmers that experience problems with kea strike on their stations may apply to DOC for a permit to kill kea on a case-by-case basis (B. Lawrence, DOC, personal communication, 2011). It has also been suggested that a few farmers may kill kea illegally (B. Lawrence, DOC, personal communication, 2011). Kea are still illegally killed in other contexts, but the annual toll is unknown (Elliott & Kemp, 2004; Steffens & Gasson, 2009). Fourteen percent of dead wild kea submitted to Massey University/Te Kunenga ki Pūrehuroa for necropsy between 1991 and 2017 were confirmed to have been deliberately killed by either gunshot or poisoning (B. D. Gartrell, Wildbase, Massey University, unpublished data).

Kea conservation status

Kea are a K-selected species, long-lived and slow to reproduce, resulting in slow population recovery from even a small mortality event (Diamond & Bond, 1999; Spurr, 1979). The historical period of persecution initiated by the discovery of kea strike resulted in the deaths of an estimated 116,869 birds over 102 years (chapter 2), and contributed substantially to their extinction risk (Elliott & Kemp, 2004). Kea are currently listed as nationally endangered by DOC (Robertson et al. 2017), and endangered and decreasing by the International Union for Conservation of Nature (IUCN) (BirdLife International, 2017). The wild population is estimated at 6,000 individuals (consisting of 4,000 mature individuals), and continues to decline rapidly – the total population decline over the last three generations (36 years) is likely to have been between 50% and 80% (BirdLife International, 2017; Kemp, 2013).

Conclusions

The prevalence of wounds that I attributed to kea strike on all stations was low (0–1.25%), with the majority of wounds (80%) being in the loin (lumbar) region. Logistic regression models applied to identify risk factors showed that attributed kea strike wound numbers were significantly higher on particular stations (4 and 5), and for Perendales, rams, and sheep >1 year old. However, given the opportunistic nature of this study, it is recommended that the results of the logistic regression models be further verified. Considering the conservation status of kea, the potential economic impact on high country sheep stations and the livestock welfare issues involved, an improved understanding of kea strike is needed to address it in ways that balance the effects of the conflict on the kea population and the viability of high country sheep farming. Scientific study of kea strike is long overdue to verify what farmers have reported for years, and to understand and further mitigate kea strike and persecution of kea, as well as to aid kea conservation advocacy. Mitigating kea strike will benefit the welfare of high country sheep by reducing stock injuries, illness and losses, as well as reducing stress and financial losses to farmers. It will also benefit kea conservation efforts by reducing lethal control, and limiting potential illegal retaliation against kea.

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Chapter 4

Farmers' perceptions of kea (*Nestor notabilis*) on high country sheep stations in the context of human-wildlife conflict

Abstract

An ongoing case of human-wildlife conflict in New Zealand occurs between high country sheep farmers and the kea (*Nestor notabilis*), an endemic parrot, as a result of intermittent predatory behaviour of kea towards sheep (*Ovis aries*). Although the conflict has occurred for over 150 years, it is not well documented. Kea are now listed as endangered and rapidly declining, and as the conflict continues to have an economic impact on farmers and results in kea mortality via lethal control, an understanding of the phenomenon and its implications is required to address the problem. In this study I conducted an anonymous, voluntary online survey of South Island high country sheep farmers to try to gain an insight into their experiences with, and perceptions of, kea on their stations. Although the sample size of my study is small (n = 16; representing ~7.4% of South Island high country sheep stations), I present a descriptive study of the survey results. Less than half of the farmers reported kea strike on their stations, with low estimates of sheep injuries (≤ 10%) and losses (≤ 1%), and a decrease of kea strike over the past 25+ years, which may have resulted from decreasing kea numbers and changes in sheep flock management. More than half of the respondents thought that only some kea attack sheep, which is consistent with the long-standing concept that kea strike is initiated by 'rogue' kea (problem individuals). Equal numbers of respondents that either had or had not experienced kea strike on their stations reported seeing kea at least occasionally (once or twice a year) on their stations, which may indicate that kea

presence on a station in itself is not a predictor of kea strike. Station management practices that were considered at least moderately effective for mitigating kea strike were, where possible, keeping stock below ~700m a.s.l. and/or retiring kea strike hot spots (e.g. winter de-stocking of high elevation pasture, or retiring the ‘tops’), moving stock regularly (e.g. rotational grazing), vaccinating against *Clostridium* spp., approaching DOC for advice and/or assistance, and even changing the timing of shearing. Lethal control (carried out under permit) was considered effective by at least one respondent, although several other respondents did not favour its use because of kea’s conservation status. Several respondents indicated an awareness of kea’s threatened status, which may reflect a shift over the past few decades in high country farmers’ attitudes towards kea. This study presents a limited but valuable insight into the range in high country farmers’ experiences and perceptions of kea strike and its associated human-wildlife conflict. This study also provides an important contribution to the limited kea strike literature and an improved understanding of high country farmers’ experiences with kea strike, which is needed to mitigate the effects of conflict on both the kea population and high country sheep farming.

Introduction

An ongoing case of human-wildlife conflict occurs between high country sheep farmers and the kea (*Nestor notabilis*), an endemic New Zealand parrot, as a result of intermittent predatory behaviour of kea towards sheep (*Ovis aries*). Although the conflict has occurred since the 1860s, it has not been recently studied (see chapter 2). Kea are now classified as endangered and rapidly declining (BirdLife International, 2017; Robertson et al. 2017), and the conflict continues to have an economic impact on farmers and result in lethal control of kea. To better understand the issues underlying farmer-kea conflict, information is needed about farmers' experiences and perspectives of kea on their stations. Human-wildlife conflict can be challenging to address in cases where the needs of local communities must be balanced with those of endangered species (Woodroffe et al. 2005). Obtaining information from affected communities provides important data that are not available elsewhere, which is key to designing effective human-wildlife conflict solutions (Anthony et al. 2010; Thorn et al. 2013). To this end, I attempted to gauge South Island high country sheep farmers' experiences with and perceptions of kea on their stations via an online survey. Here I provide a descriptive study of the survey results with the aim of contributing to an improved understanding of high country farmers' experiences with kea strike, which is needed to mitigate the effects of conflict on both the kea population and high country sheep farming.

Methods

I conducted an anonymous online survey of South Island high country sheep farmers during 2014–2015. Participation was voluntary. The study was approved by the Massey University Human Ethics Committee: Southern A (application 14/82).

The platform used for the survey was Qualtrics (http://www.qualtrics.com). Participants' responses were included in the analysis if they had answered at least 80% of the questions relevant to their experience with kea strike. The members of four Regional Associations of Merino Inc. (Otago, Marlborough, Canterbury and Mackenzie/Waitaki) and Federated Farmers High Country Industry Group were sent email invitations with a request to complete the survey. There is some overlap between the memberships of the two above organisations. The survey was also mentioned on the radio show The Farming Show, and the link to the survey was embedded on the show's website (http://www.farmingshow.co.nz[1]), inviting South Island high country sheep farmers to complete the survey. By sending the invitation via the above sources, I anticipated that the survey would reach the majority of the approximately 215 high country stations in the South Island (Sheep and beef farm survey 2017), and that it included farmers that had some experience with kea on their stations.

Data collection

The survey (see Appendix 1) included both forced-choice and open-ended questions in three sections with a total of 23 questions. Section 1 (11 questions) asked for information about the station and flock characteristics, and the respondents' experiences with kea on the stations, including whether kea strike had been experienced. Respondents that had experienced kea strike on their stations were directed to section 2 (nine questions) to answer questions about those experiences, including estimated stock losses, signs of kea strike observed in the flocks, and husbandry methods that were useful in mitigating kea strike. These respondents were then directed to section 3 (two questions), which asked about the perceived effectiveness of lethal control of kea, and invited general comments. Respondents that had not experienced kea strike automatically skipped section 2 and were taken directly to section 3. Because the sample size of responses was so low (n = 16), I elected to confine my analyses to a description of the results.

[1] This website is now defunct.

Results

Responses from 16 participants were analysed (representing ~7.4% of all South Island high country sheep stations), 15 of which finished the survey. The remaining respondent met the 80% minimum requirement for the number of questions answered, therefore their survey responses were included in the descriptive analysis. The mean time spent by respondents answering the survey was 7.2 minutes (± 3.97 SD, range 3–18). Station and flock data of the respondents are presented in Table 4.1. Seven respondents (44%) reported having experienced kea strike on their stations, and nine (56%) reported not having experienced kea strike. The mean tenure of respondents on their stations was 25 years (± 16 SD, range 2–54), and the mean size of respondents' stations was 8,269 ha (± 6,727 SD, range 1,400–25,000). The mean area of high country (> 700m a.s.l.) on the stations was 5,402 ha (± 5,949 SD, range 130–20,000), and the mean proportion of high country was 51% (± 31 SD, range 9.1–100). The mean number of sheep on the stations was 6,906 (± 3,894 SD, range 2,000–15,500). Twelve (75%) of the respondents ran Merinos; three (19%) ran Merino crossbreds; three (19%) ran Perendales; three (19%) ran New Zealand Halfbreds; two (13%) ran Romneys; and one (6%) ran Texels. No respondents reported keeping Corriedales on their station. The breed and class compositions of the respondents' sheep flocks are presented in Figures 4.1 and 4.2, respectively. Data regarding the respondents' experiences with kea strike are presented in Tables 4.2 and 4.3, and their perceptions of sheep susceptibility to kea strike in Table 4.4.

Table 4.1 Station and flock characteristics of participants in an online survey of high country sheep farmers in the South Island, New Zealand.

Demographic information	**Farmers reporting kea strike**	**%***	**Farmers reporting no kea strike**	**%***	**Total (N)**	**% of total***
District						
Nelson/Marlborough	2	29	1	11	3	19
West Coast	0	0	0	0	0	0
Canterbury	0	0	4	44	4	25
Otago	3	43	4	44	7	44
Southland	2	29	0	0	2	13
Years on station						
≤10 years	2	29	1	11	3	19
11 to 20	2	29	1	11	3	19
21 to 30	0	0	3	33	3	19
>30	3	43	3	33	6	38
Invalid answers	0	0	1	11	1	6
Size of station (ha)						
≤2000	1	14	2	22	3	19
2001 to 5000	2	29	2	22	4	25
5001 to 10000	3	43	1	11	4	25
>10000	1	14	4	44	5	31
% high country (>700m a.s.l.)						
≤25	2	29	2	22	4	25
26 to 50	2	29	3	33	5	31
51 to 75	1	14	1	11	2	13
>75	2	29	3	33	5	31
Number of sheep on station (winter)						
≤2000	1	14	0	0	1	6
2001 to 5000	3	43	2	22	5	31
5001 to 10000	2	29	5	56	8	50
>10000	1	14	2	22	2	13
Breed composition of flock						
1 breed	4	57	6	67	10	63
2 breeds	2	29	2	22	4	25
3 breeds	1	14	1	11	2	13

* % may not add up to 100 due to rounding.

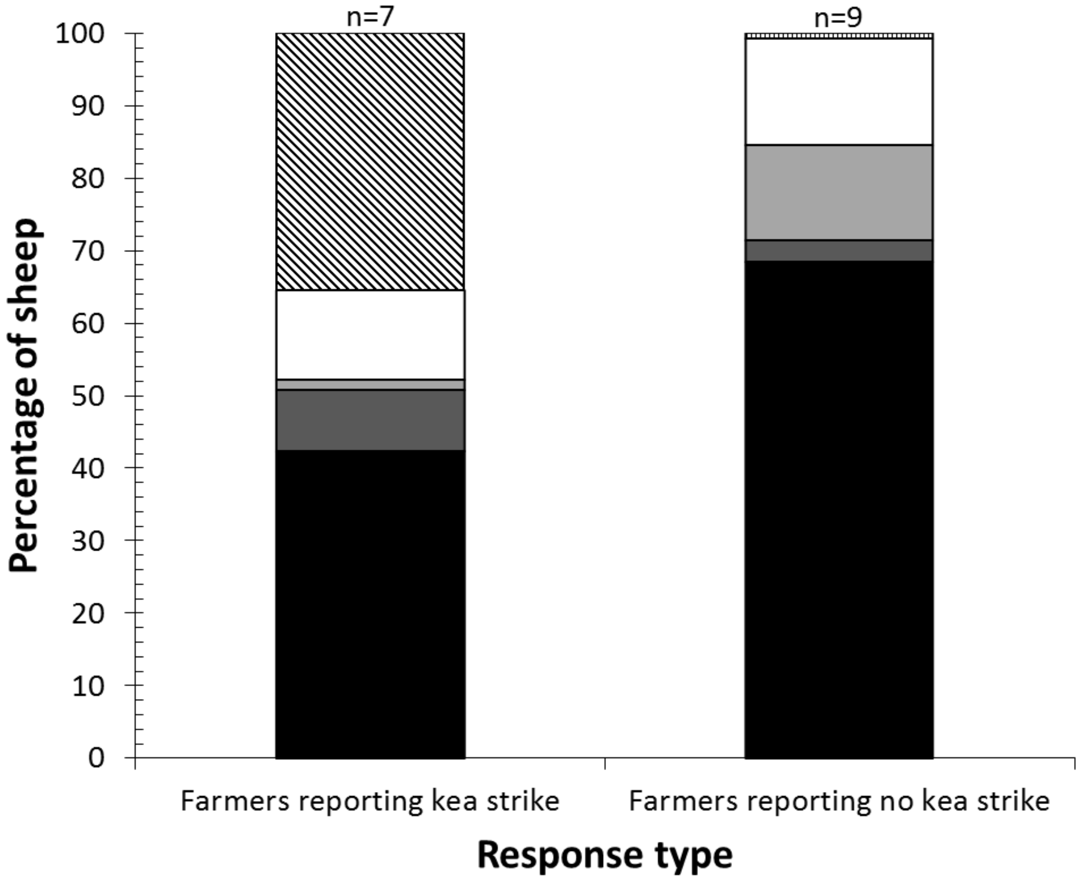

Figure 4.1 Breed composition of sheep (*Ovis aries*) flocks of participants in an online survey of high country sheep farmers in the South Island, New Zealand. The two bars represent two response groups: farmers that reported experience of kea (*Nestor notabilis*) attacks on their sheep, and those that reported no attacks. The bars show the percentage composition of each sheep breed for the two response groups (i.e. the number of sheep of each breed within a response group divided by the total number of sheep within that response group). Breeds included are: Merino (black), Merino crossbreds (dark grey), New Zealand Halfbred (light grey), Perendale (white), Romney (diagonal lines), and Texel (vertical lines). Sample sizes of survey respondents for each response category are given above each bar.

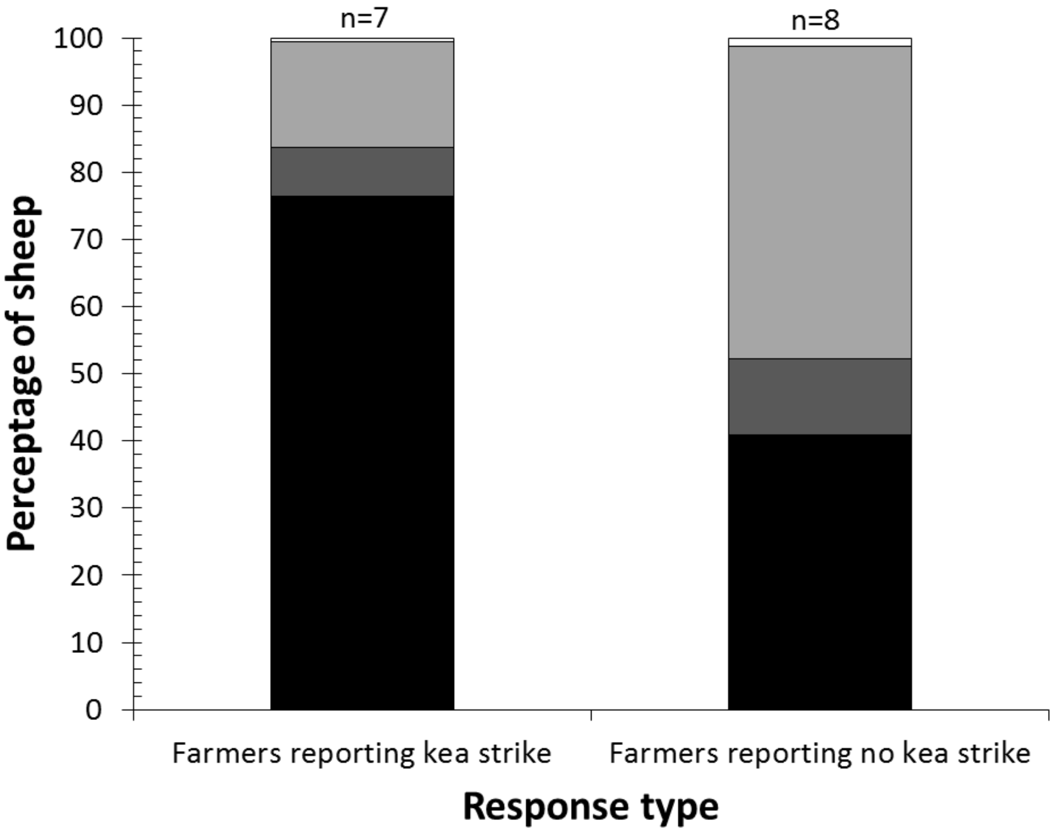

Figure 4.2 Class composition of sheep (*Ovis aries*) flocks of participants in an online survey of high country sheep farmers in the South Island, New Zealand. The two bars represent two response groups: farmers that reported experience of kea (*Nestor notabilis*) attacks on their sheep, and those that reported no attacks. The bars show the percentage composition of each sheep class for the two response groups (i.e. the number of sheep of each class within a response group divided by the total number of sheep within that response group). Sheep classes included are: ewes (black), wethers (dark grey), hoggets (light grey), and rams (white). Sample sizes of survey respondents for each response category are given above each bar.

Table 4.2 Perspectives of kea (*Nestor notabilis*) among participants in an online survey of high country sheep farmers in the South Island, New Zealand.

Farmer observation/view	**Total (N)**	**% of eligible responses***
Frequency of kea sightings on station		
Frequently (daily; weekly; at least once every 3 months)	4	25
Occasionally (~ once or twice a year)	4	25
Rarely (~ once every few years)	3	19
Never	5	31
Kea seen scavenging sheep carcasses on station		
Yes	3	19
No	13	81
Farmer's perception of kea's tendency to attack sheep		
All kea would attack sheep if given the chance	2	13
Only some kea would attack sheep if given the chance	10	63
No kea attack sheep	1	6
Don't know	3	19
Frequency of kea attacks on station		
>10 years since last attack	4	25
Every 5–10 years	3	19
Every 2–5 years	0	0
Annual	0	0
Never	6	38
Don't know	3	19
Are some sheep classes more prone to kea strike than others?		
Yes	3	43
No	0	0
Don't know	4	57
Are some sheep breeds more prone to kea strike than others?		
Yes	3	50
No	0	0
Don't know	3	50
Is shooting and/or poisoning 'problem kea' an effective technique to stop or reduce kea strike?		
Yes	5	33
No	3	20
Don't know	7	47

* % may not add up to 100 due to rounding.

Table 4.3 High country sheep farmers' observations of signs of attack by kea (*Nestor notabilis*) on sheep (*Ovis aries*) on sheep stations in the South Island, New Zealand.

	Wool flagging	**Survivable injuries**	**Fatal injuries**	**Kea strike witnessed**	**Dead sheep with signs of kea strike**	**Kea strike wounds seen at shearing**	**Total**
Respondent 1	1	1	0	0	0	1	3
Respondent 2	1	1	0	1	1	1	5
Respondent 3	1	1	1	0	0	1	4
Respondent 4	1	1	1	0	1	1	5
Respondent 5	1	0	0	0	1	0	2
Respondent 6	0	1	1	0	0	0	2
Total	5	5	3	1	3	4	21

Table 4.4 High country sheep farmers' perceptions of the susceptibility of sheep (*Ovis aries*) to attacks by kea (*Nestor notabilis*) on sheep stations in the South Island, New Zealand.

Assessment	**Ewes**	**Wethers**	**Hoggets**	**Rams**	**Lambs**	**Merino**	**Merino crossbred**	**New Zealand Halfbred**	**Perendale**	**Other***
Very susceptible	0	2	0	0	0	3	0	0	0	0
Moderately susceptible	3	1	2	0	0	0	2	1	0	0
Not at all susceptible	1	2	2	4	4	0	0	0	1	1
Not applicable	0	0	0	0	0	2	3	5	3	2
Total	4	5	4	4	4	5	5	5	4	3
Average score†	2.3	2	2.5	3	3	1	2	2	3	3
Sample size	4	5	4	4	4	3	2	1	1	1

* Two farmers reported Romney as the 'other' breed category, and the other did not specify the breed.

† 1 = highly susceptible, 2 = moderately susceptible, 3 = not at all susceptible.

Observations of kea activity

Of the seven farmers that reported experience of kea strike on their stations, two reported seeing kea frequently (i.e. at least once every three months) on their stations, two saw them occasionally (i.e. once or twice a year), and three saw them rarely (i.e. approx. once every few years). Three farmers reported observing kea scavenging sheep carcasses on their stations, and four reported that they had not. Of kea's tendency to attack sheep, six of these farmers answered that only some kea would attack sheep if given the chance, and one answered that no kea attack sheep.

Of the nine farmers who reported not having experienced kea strike on their stations, two reported seeing kea frequently, two saw them occasionally, and five reported never seeing them on their stations. None of this group of farmers reported observing kea scavenging sheep carcasses on their stations. Regarding kea's tendency to attack sheep, two thought that all kea would attack sheep if given the chance, four thought that only some kea would, and three answered "don't know".

Sheep injuries and losses from kea strike

The seven respondents that reported experience of kea strike on their stations answered questions about the estimated numbers of sheep injured or killed by kea strike and the financial losses incurred. The answers of one respondent were excluded because they could not be interpreted and were therefore classified as invalid, therefore six sets of answers were analysed. Based on five valid responses (one respondent answered "don't know" for this question), the estimated average annual losses to kea strike in years that it occurred was 0, 0, 2, 20, and 20 sheep killed per year, which represented a mean loss of 0.3% (± 0.4 SD, range 0–1) of the affected sheep flocks.

Based on six valid responses, the estimated mean number of sheep affected (i.e. injured but not killed) by kea strike in years that it occurred was 92 (± 111 SD, range 0–250), representing a mean of 2% (± 3 SD, range: 0–10) of the affected flocks across all stations. Based on six valid responses, the estimated average financial losses to kea strike in years that it occurred was NZ$700 (± 787 SD, range 0–2,000) across all stations.

Kea strike mitigation

Of the seven respondents that reported experience of kea strike on their stations, six answered the question about effectiveness of farm practices in mitigating kea strike. The responses are presented in Table 4.5.

Table 4.5 High country sheep farmers' perceived effectiveness of farm practices in mitigating kea attacks on sheep (*Ovis aries*) on sheep stations in the South Island, New Zealand (percentage in brackets).

Farm practice	**Very effective**	**Moderately effective**	**Not at all effective**	**Not applicable**	**No response**
No longer using areas where kea strike has occurred	0	1 (17)	0	5 (83)	0
In winter, keeping sheep where they are less likely to be attacked by kea (e.g. < 700 m above sea level)	0	4 (67)	0	2 (33)	0
Moving stock around regularly, especially in winter	1 (17)	2 (33)	0	2 (33)	1 (17)
No longer stocking the tops (i.e. the highest elevation pastures)	0	1 (17)	0	5 (83)	0
Changing the timing of shearing (i.e. shearing earlier or later than previously)	1 (17)	0	0	4 (67)	1 (17)
Changing breed of sheep (this includes crossing Merino with other breeds)	0	2 (33)	0	3 (50)	1 (17)
Approaching the Dept. of Conservation (DOC) for advice and/or assistance	0	2 (33)	0	3 (50)	1 (17)
Approaching other farmers or organisations for advice and/or assistance	0	0	0	5 (83)	1 (17)
Vaccinating against blood poisoning (i.e. annual application of 5-in-1 *Clostridium* vaccine)	2 (33)	1 (17)	0	2 (33)	1 (17)
Other	0	1 (17)*	0	1 (17)	4 (67)

*The method was not specified by the respondent.

Discussion

Although the sample size of my study is small, it presents useful data regarding farmer perspectives and experiences of kea strike. One previous unpublished study (Campbell, 1976) included the results of a postal questionnaire of high country sheep farmers about kea, although its focus was kea movements and range. There was, however, at least one point of overlap with my study. Campbell (1976) canvassed farmers from Southland to Canterbury, and 59% (n = 17) of the respondents to his survey saw kea at least annually on their stations, while 41% (n = 12) reported either “very rare” or no sightings on their properties. Of the respondents in my study, 50% saw kea at least annually and 50% rarely or not at all. Several farmers in Campbell (1976)’s study also commented on a decrease in kea flock sizes during their tenures (e.g. 30 years prior to his study, flocks of 30–70 kea were seen, but not by 1976). One of the farmers from Campbell (1976)’s study later reported that kea numbers on his station had not resurged, and that evidence of kea strike was no longer seen there (Aspinall, 1990). Four of the seven respondents in my study that had experienced kea strike on their stations reported that kea strike had not occurred for at least 10 years on their stations, one of whom reported that it had not occurred for at least 30 years, and that this was related to the fact that kea were now only seen occasionally on their station – implying that kea numbers there may now be so low that they do not attack sheep. Another respondent commented that kea strike was common on their station 30–40 years ago, but had dropped to such a low level (1–2 attacks) within the last 25 years that it wasn’t worth a response. A decrease in the frequency of kea strike may have coincided with the overall decline in kea numbers, and these reports by farmers in both Campbell (1976)’s and my study may reflect that. Kea numbers are in rapid decline (BirdLife International, 2017; Robertson et al. 2017), and two farmers in my study expressed an awareness of kea’s threatened status. The total population decline of kea over the last 36 years is estimated to have been between 50% and 80% (BirdLife International, 2017; Kemp, 2013). Campbell (1976) did not indicate that conservation of kea was a concern among his survey participants, although he reported that the status of the kea population at the time was unknown, and raised the issue of a potential decline in the future. Farmer concerns for kea numbers were raised in parliament as early as 1968 (NZPD, 1968).

Observations of kea activity

The frequency of kea sightings in my study did not appear to be directly related to whether or not respondents experienced kea strike on their stations. Interestingly, equal numbers from both groups reported seeing kea frequently (i.e. at least once every three months) or occasionally (i.e. once or twice a year) on their stations, which would suggest that the presence of kea in itself is not necessarily a predictor of kea strike. All of the farmers in the first group (i.e. those who reported experience of kea strike on their stations) observed kea at least rarely on their stations, whereas more than half of those in the second group (i.e. those who had not experienced kea strike) never saw kea on their stations. Although a lack of kea sightings does not preclude the presence of kea on these stations, it may be an indicator of kea's rarity in those locations (or possibly their absence), which may explain the lack of kea strike there. The number of respondents from each group differed in their observations of kea scavenging sheep carcasses, with almost half of the first group having witnessed scavenging, and none of the second group having done so. Whether this is due to bias (i.e. farmers who have had kea strike on their stations may be watching more carefully for kea interacting with sheep or carcasses), or that kea strike is related to scavenging is difficult to say. Kea scavenge carcasses of various species, such as lagomorphs, hunter-killed game, and sheep (Aspinall, 1972; Schwing, 2010; C. Reid, personal observation), and there is also fossil evidence that kea may have regularly scavenged moa (Aves: Dinornithiformes) carcasses (Holdaway & Worthy, 1997). Scavenging is part of kea's behavioural repertoire, but whether scavenging of sheep carcasses facilitates kea strike, or different behavioural pathways are involved is beyond the scope of this study. Only one survey respondent reported that they had witnessed kea strike first-hand, which reinforces that it is a difficult phenomenon to observe (Aspinall, 1967).

The difference between the two groups of farmers regarding kea's perceived tendency to attack sheep was also notable: the majority of the first group considered that only some kea would attack sheep if given the chance (one answered "don't know"). Of the second group, almost half thought that only some kea would attack sheep, and about a third reserved judgement, answering "don't know". Interestingly, the remainder of the second group thought that all kea would attack sheep given the chance to do so, which seems at odds with the common perception that it is a 'rogue' behaviour (i.e. one initiated by 'problem individuals') (e.g. Marriner, 1908; Newton, 1983; Thomas, 1972).

Sheep injuries and losses from kea strike

Respondents reported an estimated annual percentage of their flocks affected (i.e. sheep that were injured but not killed) by kea strike of 0–10% (n = 6 stations). In a study of kea strike wound prevalence on high country stations in Whakatipu, I found a prevalence range of 0–1.25%, although on one of these stations the injury prevalence was estimated to have been as high as 10% in years of heavy kea strike (see chapter 3). For historical comparison, I calculated from reports that annual kea strike injury rates in years that kea strike occurred ranged from 0.3–25% of affected flocks between 1878 and 1934 (see chapter 3).

In my survey respondents reported an estimated average annual loss of 0–20 sheep to kea strike in years that attacks occurred, at an estimated cost of NZ$0–2,000. A farmer involved in my study of kea strike injury prevalence estimated that at the height of kea strike on his station in 2009–10, losses of up to 400 sheep at NZ$20,000 were sustained (see chapter 3). In the year that I visited the station to investigate kea strike injury prevalence, the annual loss to kea strike was much lower – ~5 sheep at ~NZ$250, and the farmer reported that kea strike had not been severe that year. I also calculated that, based on historical reports between 1944 and 1971, annual losses to kea strike in years that it occurred ranged from 128–250 sheep – valued in today's prices at NZ$17,256.86–26,283.29 (see chapter 3). Although the sample size is very small (n = 6), the respondents' estimates outlined above may indicate that injury rates and losses to kea strike are generally low, but can still be high on some stations in extreme kea strike years. Diamond & Bond (1999) reported that the annual loss to kea strike on one station was ~0.2%, which falls within the range reported by the farmers in my study. Kea strike injury rates and losses appear to have decreased over the years (e.g. Aspinall, 1990), possibly because of changing farming practices (see for example Hunt et al. 2011), and a decline in kea numbers (BirdLife International, 2017; Robertson et al. 2017).

Farmer perceptions of sheep susceptibility to kea strike

Respondents' perceptions of susceptibility of different sheep classes to kea strike varied for ewes, wethers and hoggets, but were consistent for rams and lambs. This may be due to various factors, such as differences in farm practices between stations. Wethers scored highest for susceptibility, followed by ewes and hoggets. Wethers tend to be put in more remote, higher altitude pasture (e.g. Hunt et al. 2011), which is associated with a higher risk of kea strike (Aspinall, 1967; Marriner, 1908). Respondents' perceptions of the low susceptibility of rams are at odds with what I found in my kea strike injury prevalence study (see chapter 3). However, my results for rams in that study were based on one station, and may not reflect the overall experiences of farmers that encounter kea strike, although there are several historical reports of kea attacking rams (see chapter 3). Respondents' perceptions of lambs' low susceptibility to kea strike are consistent with those amongst the farmers included in my prevalence study (see chapter 3), and with several accounts in the kea strike literature (e.g. Aspinall, 1990; Marriner, 1908). Although kea strike has been reported to occur most frequently in winter, it has also been reported throughout the rest of the year, including spring (Aspinall, 1990; Marriner, 1908; Thomas, 1972). One historical account describes young, live lambs being found alongside dead, kea-struck ewes in the months of September and October (Austral spring) (Aspinall, 1990).

The survey respondents in my study reported that Merinos were very susceptible to kea strike, but that Merino crossbreds and New Zealand Halfbreds were only moderately susceptible, and that Perendales were not at all susceptible. However, breed susceptibility may also be affected by farming practices. For example, in my study of kea strike injury prevalence, one farmer reported that the Perendales on his station, which he ran at low altitude, had never been attacked by kea, but that the Merino wethers he ran on the back blocks did get attacked (see chapter 3). In the same study, I found that on another station there was a higher prevalence of wounds attributed to kea strike in Perendales than in Merinos. One survey respondent that ran Romneys indicated that they were not susceptible, but there is at least one historical record of Romney rams being attacked ('The Murderous Kea', 1909). There is another historical report that kea preferentially attack some breeds over others: one farmer reported that only "Halfbreds" were attacked when run with Merinos ('News of the Day', 1902). "Halfbreds" in this context could have been any of a number of crossbreeds, as New Zealand Halfbreds were not officially recognised until 1911 (Eastwood et al. 1978). There are also a number of historical reports that kea preferentially attack sheep that are in good condition (e.g. Benham, 1906; Marriner, 1908), and this was also reported by one of the farmers in my prevalence study. If this is the case, breeds that have more flesh and subcutaneous fat may provide more attractive targets to kea (see chapter 3).

Kea strike mitigation

Farm practices that mitigate kea strike, whether or not that was the intention behind introducing them on the stations in question, were used to varying degrees by the respondents in this study (Table 4.5). The respondents' ratings of these practices appear to be consistent with observations noted elsewhere. For example, keeping stock below ~700m a.s.l. was a common feature of stations that did not have kea strike in the Whakatipu area, where kea strike is an ongoing problem (B. Lawrence, DOC, personal communication, 2011), and has been recommended for mitigating losses due to large kea strike wounds (Campbell, 1976). Campbell (1976) reported from his questionnaire that "very few" kea were sighted below 700m a.s.l., and that the majority of sightings were near the top of the station range, 1200 m and higher.

Moving sheep around regularly was regarded as either highly or moderately effective by those respondents using this practice. It has been recommended that sheep set-stocked (i.e. grazed continually in the conventional manner, as opposed to being regularly moved through different pastures as in rotational grazing) on blocks that kea are known to frequent should be checked regularly for signs of kea strike, and that it may be practical to muster the sheep to another part of the station to stop the outbreak (Scott, 2012). Rotational grazing, moving sheep when kea strike is detected, keeping sheep below 700m a.s.l. in winter, and retiring areas where kea strike has been problematic may reduce the encounter rate between kea and sheep by reducing the spatial and temporal overlap between them. In other studies of human-wildlife conflict, overlap of livestock and predators in seasonally high risk areas (e.g. carnivore dens and rendezvous sites) have been correlated to predation vulnerability of livestock, and these findings suggested that land managers could mitigate predation of stock by minimising spatial overlap with areas of intense predator activity (e.g. Bradley & Pletscher, 2005; Breck et al. 2011; Nelson et al. 2012; Oakleaf et al. 2003).

One survey respondent that had not experienced kea strike made the following comment, which seems to dovetail with the responses of the farmers in Table 4.5:

> "In my experience the extent of kea strike on sheep is negligible especially under more modern grazing systems such as rotational grazing and winter de-stocking of higher altitude land. There are many other things that account for sheep deaths on an annual basis."

One respondent reported that changing the time of year that shearing occurred (e.g. making it earlier or later than usual) was very effective. This may be explained by the fact that kea are reported to attack sheep most frequently in winter (e.g. Aspinall, 1972; Marriner, 1908; Potts, 1882) prior to pre-lambing shearing and, when attacking sheep, kea cling to the fleece to stay with the sheep as it moves around (e.g. Scott, 2012). Benham (1906) reported that kea apparently always attacked sheep with long wool, and never attacked newly shorn sheep, and Potts (1882) posited that the shortness of the wool post-shearing afforded a less secure hold for kea than a full fleece. Shearing early where possible may preclude kea from attacking sheep, provided the sheep are closely shorn (e.g. machine shorn) and have some mobility (e.g. they aren't snow-bound).

Vaccination against *Clostridium* spp. is recommended by DOC to mitigate the effects of kea strike, although it does not guarantee complete protection from kea strike losses (e.g. Grant, 1993). Two respondents indicated that vaccination was very effective and one that it was moderately effective. This is consistent with the perception that a number of farmers have reported in the literature that it is an effective measure to prevent mortality associated with kea strike (e.g. Aspinall, 1967; Jessep, 1965; Scott, 2012; Thomas, 1972; see also chapter 3).

Lethal control of kea

Farmers that experience problems with kea strike on their stations may consult DOC for a permit to kill kea on a case-by-case basis (B. Lawrence, DOC, personal communication, 2011). One respondent indicated in their answers to several questions that they had used lethal control (carried out by DOC staff under permit), and that it was effective at stopping kea strike, sometimes for years. Another respondent reported that they had used lethal control in the past (30+ years ago), but would not use it now. The latter respondent also stated that they would be proactive in finding a way to stop kea strike so that they could co-exist with them. This may reflect a gradual shift in farmer attitudes towards kea, as indicated by several farmers in the literature who expressed an appreciation for them, even if they saw a need for lethal control to protect their stock (see for example Aspinall, 1990; McLeod, 1974; Newton, 1983; Scott, 2012).

Of the respondents who had not experienced kea strike on their stations, one commented that they had previously worked on stations where lethal control (i.e. shooting) was used when kea were a problem. Two commented that they were not in favour of lethal control to mitigate kea strike, one indicating that kea strike was only engaged in by certain individuals and, although disposing of those individuals would stop the problem, the respondent did not support shooting kea because of their current low numbers, and hoped that a different technique would be used. Another farmer said that in the case of rogue birds, they should be translocated (and, if necessary, into a wildlife sanctuary). The respondent also indicated that, although dismayed by kea strike as witnessed by fellow station owners, because of kea's conservation status they did not believe that people had the right to kill kea, and that anyone caught killing them should face severe repercussions. In addition to the consideration of lethal control in light of kea's endangered status, it should be noted that in other cases of human-wildlife conflict that the use of non-lethal methods instead of lethal ones can both reduce depredation and be economically advantageous (McManus et al. 2015).

The possibility that a few individuals may use lethal control illegally should also be considered. It has been suspected that a few farmers may kill kea illegally either by shooting or use of poisons or otherwise hazardous substances (B. Lawrence, DOC, personal communication, 2011). If this is the case, then for every targeted individual killed under permit, there may be an unknown number of kea killed indiscriminately.

A few farmers may not be aware that they can apply for a permit to use lethal control to mitigate kea strike, as indicated by one farmer that I spoke to as part of my prevalence study (chapter 3). Others may have a poor relationship with DOC, or consider applying for a permit impractical, and therefore undertake lethal control illegally in the form of shooting and/or poisoning. Human-wildlife conflict studies of stakeholder attitudes have found a preference for illegal lethal actions in groups that distrusted authorities (Højberg et al. 2017; Pohja-Mykrä 2017). Kea are still illegally killed in other contexts, but the annual toll is unknown (Elliott & Kemp 2004; Steffens & Gasson 2009). Of 109 dead wild kea submitted to Massey University for necropsy between 1991 and 2017, the cause of death for 15 (14%) birds was confirmed as deliberate killing by either gunshot or poisoning (B. D. Gartrell, unpublished data).

Farmer perceptions of kea

Of the respondents that had experienced kea strike on their stations, one considered kea strike to be a rogue behaviour and reported that when the individual kea involved were removed (i.e. shot under permit), then the problem stopped on their station, sometimes for years. They also regarded the key to stopping kea strike was to stop the behaviour as soon as it began by removing the rogue individuals before other kea could learn the behaviour. The concept of kea strike as a rogue behaviour is consistent with reports from farmers that I spoke to as part of my prevalence study (see chapter 3), and reports from farmers in the literature (Campbell, 1976; Macnicol, 1967; McLeod, 1974; Newton, 1983; Thomas, 1972; see also chapter 5).

Of farmers that hadn’t experienced kea strike on their stations, one expressed an awareness of other bird species that attacked live sheep (e.g. kāhu/harrier hawks (*Circus approximans*), and karoro/black-backed gulls (*Larus dominicanus*) picking the eyes out of sick, cast, or snowbound sheep – a problem that is often mentioned by farmers alongside kea strike (e.g. Marriner, 1908; McLeod, 1974; Scott, 2012). This farmer also commented that kea were in serious decline, and welcomed research into the matter. The respondent simultaneously expressed concern regarding sheep welfare issues arising from kea strike, and that kea were their favourite bird.

Survey engagement

The low survey response rate and small sample size in this study may have been influenced by the use of email as a contact medium instead of other methods (e.g. postal or telephone) (Couper, 2000; Matsuo et al. 2004). Concerns about privacy and/or confidentiality of online surveys may result in higher nonresponse (or less honest reporting) on surveys that include sensitive topics (Couper, 2000) – in the case of this study, the use of lethal control, legal or otherwise. Farming communities can also be especially challenging to survey because a large proportion usually do not respond (Pennings et al. 2002). Several other recent studies of human-wildlife conflict using online surveys have also had low response rates (e.g. Jacobs et al. 2015; Kreye et al. 2017), and the authors of one study verified that some of the anonymous survey recipients did not respond because of concerns about confidentiality (Kreye et al. 2017).

It is possible that there were biases in my results, such as nonresponse bias (i.e. the respondents to the survey differed from those that did not respond in a way that is important to the study), and self-selection bias (where some individuals, including those with an interest in the topic, are more likely to participate (Dillman et al. 2007)). Responses may have been biased towards farmers that have a positive attitude towards kea. Although I did not specifically measure respondents' attitudes, it may be that farmers with a negative attitude towards kea are more likely to use lethal control (legal or otherwise), and that those individuals would have been less inclined to participate in the survey. Illegal killing of wildlife is a sensitive subject and is notoriously difficult to study directly because those who engage in it are usually unwilling to disclose their activities due to concerns about retribution (see for example Cross et al. 2013). St John et al. (2012) found that farmers in South Africa with the attitude that carnivores are pests and should be killed on farms are more likely to have illegally killed carnivores. Cross et al. (2013) reported that farmers in Wales who had a negative attitude towards badgers (*Meles meles*) were more likely to have killed them illegally.

The survey participants in my study represent approximately 7.4% of South Island high country sheep farmers, and due to this small sample size I cannot draw any strong conclusions about how representative the responses are of the target population. However, this study presents a limited but valuable insight into the range in high country farmers' experiences and perceptions of kea strike and its associated human-wildlife conflict, and provides an important contribution to the limited kea strike literature.

Kea strike in the future

Although farmer-kea conflict appears to have declined (see for example Aspinall, 1990), the potential for the problem to increase in future, at least in some areas, should be considered. In a number of places human-wildlife conflicts are increasing as some species recolonise parts of their ranges (Skogen et al. 2008; Woodroffe et al. 2005). While kea numbers overall have declined and continue to do so rapidly (BirdLife International, 2017; Robertson et al. 2017), the possibility of future recolonization of parts of their range should be taken into account in relation to kea strike. As high altitude pasture is retired and subalpine scrub consequently regenerates (see for example Hunt et al. 2011), kea numbers may consequently increase in the vicinity of high country stations because of an increase in food sources in these areas. Also, kea numbers may increase on stations in or near areas where coordinated predator control occurs – especially that of stoats (*Mustela erminea*) and possums (*Trichosurus vulpecula*), which are known nest predators of kea, with stoats having been shown to have a significant impact on kea nesting success and survival (Brown et al. 2015; Kemp et al. 2018).

Effective mitigation plans are urgently needed to resolve human-wildlife conflict, but technical approaches alone are unlikely the complete answer (Dickman, 2010). Although the resolution of human-wildlife conflicts may at first appear to be relatively straightforward, the psychology involved in human-wildlife conflict is complex (see for example Wieczorek Hudenko, 2012), and a broader, multidisciplinary approach is required to mitigate such conflict fully in the long term (Dickman, 2010). Human-kea conflict also occurs in other areas where these species overlap – for example in forestry and alpine recreation areas and settlements (T. Orr-Walker, Kea Conservation Trust, personal communication, 2017; Peat, 1995; C. Reid, personal observation), therefore focussing on the high country farming/kea interface alone will not resolve all human-kea conflict. However, investigating this area of conflict can contribute to overall efforts, and help to build a larger picture of where work needs to be done to promote peaceful human/kea coexistence.

Conclusions

This small study presents a limited but valuable insight into the range of high country farmers' experiences and perceptions of kea strike and its associated human-wildlife conflict. Less than half of the farmers reported having experienced kea strike on their stations, with low estimates of sheep injuries (≤ 10%) and losses (≤ 1%), and that it had decreased on several stations over the past 25+ years, which may be a result of both decreasing kea numbers on high country stations and changes to the management and size of sheep flocks, especially in high altitude pastures. More than half of the respondents, and the majority of respondents with experience of kea strike, thought that only some kea attack sheep, which is consistent with the long-standing concept that kea strike is initiated by 'rogue' kea (problem individuals). Equal numbers of respondents that either had or had not experienced kea strike on their stations reported seeing kea at least occasionally (once or twice a year) on their stations, which may indicate that kea presence on a station in itself is not a predictor of kea strike. Station management practices that were considered at least moderately effective for mitigating kea strike were, where possible, keeping stock below ~700m a.s.l. and/or retiring kea strike hot spots (e.g. winter de-stocking of high elevation pasture, or retiring the 'tops'), moving stock regularly (e.g. rotational grazing), vaccinating against *Clostridium* spp., approaching DOC for advice and/or assistance, and even changing the timing of shearing. In terms of perceived susceptibility to kea strike, wethers and purebred Merinos scored highest. Recent and ongoing changes in high country farming practices, such as retiring high altitude pasture and shifting towards breeds more suitable to meat production (Hunt et al. 2011), may continue to contribute to kea strike mitigation. Lethal control (carried out under permit) was considered effective by at least one respondent, although several other respondents did not favour its use because of kea's conservation status. Several respondents indicated an awareness of kea's threatened status, which may reflect a shift over the past few decades in high country farmers' attitudes towards kea, and is timely considering the IUCN's recent uplisting of kea from vulnerable to endangered (BirdLife International, 2017). In view of kea's endangered status and rapid decline, and the impacts of kea strike on individual high country sheep farmers, an improved understanding of farmer's experiences with kea strike is necessary for planning mitigation efforts. Mitigating kea strike will benefit farmers and their stock by reducing financial losses to farmers and harm to their sheep, and will benefit kea by reducing lethal control, and limiting potential illegal retaliation against them.

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Chapter 5

The role of personality, social rank and innovative problem solving in responses of kea (*Nestor notabilis)* to a mechanical analogue of a sheep (*Ovis aries*)

Abstract

There is often a disproportionate contribution of 'problem individuals' to a species' impacts on human livelihoods, and consequently human-wildlife conflict, which highlights the need to study the behavioural characteristics of these individuals. Generalist species with a high degree of behavioural flexibility produce the best examples of problem individuals, and at the individual level certain behavioural characteristics such as a propensity for innovation, high exploration tendency and low neophobia are thought to put individuals at an increased risk of lethal encounters with humans. Kea (*Nestor notabilis*) are a prime candidate species for such study because of their behavioural makeup and the intermittent development of predatory behaviour on sheep (*Ovis aries*) (referred to as 'kea strike') on high country stations, which has resulted in a long-standing conflict with high country sheep farmers. Here I measured behavioural factors (innovative problem solving performance, neophobia, exploration tendency and social rank) in kea using voluntary experimental tasks presented to wild kea. I employed novel object tasks to measure neophobia and exploration tendency, and a mechanical sheep analogue task paired with a multi-access box (MAB) task to examine innovative problem solving performance. The mechanical sheep analogue task was also used as a proxy for the development of kea strike. I predicted that high ranking males with high exploration tendency and low neophobia would exhibit the best innovative problem solving performance, and that only some kea would solve the tasks. Five of 18 (28%) subjects solved the mechanical sheep analogue task, and in the MAB task three of six subjects passed level 1 (all retrieval methods available) and two passed level 2 (string method of retrieval blocked). Exploration tendency was positively associated with innovative problem solving performance, but neophobia and innovative problem solving performance were not related. However, kea exhibiting high exploration tendency had low neophobia, suggesting the two traits may be linked. Only males solved the innovative problem solving tasks, and high ranking individuals demonstrated better performance than low ranking ones. My results indicate that exploration tendency and social rank underpin innovative problem solving in kea, and exploration tendency may act in conjunction with neophobia. I propose that only a few individuals (i.e. innovative, exploratory, high ranking males) may initiate kea strike. The responses of kea that solved the mechanical sheep analogue task demonstrated exploratory behaviours that may be associated with the development of kea strike behaviour. Once these kea discovered the food reward, they consistently displayed foraging behaviour that may cause the kea strike wounds seen in live sheep. In light of the kea's endangered status and the potential importance of these individuals to this species' survival, I recommend that lethal control of kea to mitigate kea strike should not be considered in isolation of other threats to this species.

Introduction

Human-wildlife conflict is a global phenomenon with widespread impacts that can be especially difficult to address where human livelihoods are directly affected (e.g. Woodroffe et al. 2005). The existence of 'problem individuals' – those responsible for a disproportionately large negative impact on human interests – is gaining recognition, as is the importance of understanding the behaviours of these individuals as a requirement for successfully addressing and mitigating such conflicts and their impacts in the long-term (Swan et al. 2017). Problem individuals have been identified in a number of wild animal populations, the best examples being found in generalist species with high behavioural plasticity (see Swan et al. 2017 for a review).

At the individual level, too, it has been hypothesised that animals showing certain behavioural characteristics – such as high exploration tendency and/or low neophobia, as well as a propensity for innovation and behavioural flexibility – may also be at a greatest risk of lethal encounters with humans (Barrett et al. 2019). Exploration tendency and neophobia are both recognised personality traits in animals (Forss et al. 2017; Réale et al. 2007). Animal personality is defined as stable, long-term behavioural, emotional, and physiological differences in suites of traits between individuals of the same species (Carere & Locurto, 2011). Neophobia is the avoidance of novelty (Greenberg, 2003), and exploration tendency is defined here as the attraction toward novel objects or places and a strong tendency to explore them (Forss et al. 2017). Exploration tendency may also be referred to as neophilia, but as such is it often treated as being paired with neophobia as the endpoints of a single personality trait, although they have been demonstrated to be independently regulated motivations (see Forss et al. 2017 for a review). Here I follow Forss et al.'s (2017) treatment of neophobia and neophilia as separate, independent traits, and employ their term 'exploration tendency' to refer to neophilia. The definition of the term 'behavioural flexibility' also varies in the literature: in this study I define it as a distinct type of behavioural plasticity in which the rules governing behavioural expression, and therefore the behaviours themselves, can be modified in accordance with environmental input throughout development (Audet & Lefebvre, 2017; Godfrey-Smith, 1996; Mikhalevich et al. 2017).

With increasing recognition of problem individuals and the importance of the characteristics underlying their problem behaviours, understanding intraspecific variation in animal personality and cognitive propensities such as innovation should be a primary focus of human-wildlife conflict studies. This is especially important from a conservation perspective, as conflict often results in wildlife mortality (Woodroffe et al. 2005). It should also be noted here that the individual animals and their behaviours that trigger conflict with humans are only ‘problematic’ in the context of increasing human-wildlife conflict. The facets of behaviour that predispose species and individuals to conflict with humans – especially behavioural flexibility, innovation and exploration – are key to enabling species to exploit new and changing environments, and are essential for finding food, shelter and mates (Moretti et al. 2015; Reid, 2007). In other words, these behaviours, and especially the intraspecific variation therein – are essential to species survival, especially in light of increasing anthropogenic environmental change (Dall et al. 2004). Conflict-related mortality risks impacting species’ adaptability by removing the very individuals that may be key to their continued existence, especially in the case of endangered species.

Innovation – the solution of a novel problem or discovery of a new solution to an existing one (but see Ramsey et al. 2007 and Reader & Laland, 2003 for discussions of the definition of innovation) – is key to the study of behaviour and human-wildlife conflict (Barrett et al. 2019). More specifically, inter-individual differences in innovation and its relationship with traits such as neophobia and exploration tendency are fundamental to the study of problem individuals. Studies quantifying variation in innovative propensity between individuals have revealed that some are more inclined to solve problems than others (Benson-Amram & Holekamp, 2012; Cole et al. 2011; Morand-Ferron et al. 2011; Overington et al. 2011; Sol et al. 2012; Thornton & Samson, 2012). Studies have also demonstrated a link between innovation, neophobia and exploration tendency (Benson-Amram & Holekamp, 2012; Massen et al. 2013). Specifically, high exploration tendency and low neophobia have been demonstrated to be related to the propensity for innovation (Benson-Amram & Holekamp, 2012; Bouchard et al. 2007; Miller et al. 2016; Overington et al. 2011; Reader, 2003; Webster & Lefebvre, 2001).

Other individual factors such as social rank, age and sex are important to the study of problem individuals. For example, it is now being recognised that the trend towards selective wildlife management (which targets and removes problem individuals rather than focussing on conflict at the population level), as well as being logistically challenging, may have indirect negative impacts on populations by disproportionately affecting correlated traits such as sex or social position (Swan et al. 2017). These factors are also important to consider in relation to personality and cognitive characteristics of interest in the context of problem individuals. A number of studies of the interplay between personality traits and social rank, for example, have demonstrated such links. In a study of wild coyotes (*Canis latrans*), it was found that dominant individuals were the first to feed in the presence of novel stimuli (a fladry barrier – a series of hanging flags attached to a rope suspended a short distance from the ground, a tool used in wildlife management to deter carnivores) placed around familiar food, and eventually crossed the barrier, whereas subordinates did not (in other words, the subordinates were more neophobic) (Mettler & Shivik, 2007). Greenberg & Holekamp (2017) found that high ranking juvenile hyaenas (*Crocuta crocuta*) were less neophobic and more exploratory than low ranking ones. In a study of carrion crows (*Corvus corone corone*), dominant males were the fastest to approach novel food (i.e. had lower neophobia) than subordinates (Chiarati et al. 2012). However, the nature of the relationship between novelty response, which includes neophobia and exploration tendency, and social rank is not consistent between, or even within, species, and can be context dependent (Boogert et al. 2006; Greenberg & Holekamp, 2017; Greenberg & Mettke-Hofmann, 2001; Stöwe et al. 2006). The results of studies of innovation and social rank are also mixed: in some taxa, dominant individuals are more likely to succeed in problem solving tasks than subordinate ones (Boogert et al. 2008; Keynan et al. 2015; Langley et al. 2018), whereas in others subordinate individuals are more likely to solve the tasks presented (Aplin et al. 2013; Thornton & Samson, 2012). In yet other taxa, no relationship has been found between problem solving performance and social rank (Benson-Amram & Holekamp, 2012; Miller et al. 2016; Zandberg et al. 2017).

Innovation is another behavioural characteristic that can be affected by age and sex in a number of taxa. For example, most innovators in a study of meerkats (*Suricata suricatta*) were adult males (Thornton & Samson, 2012), and in a large review of primate studies, the reported incidence of innovation was higher in males and adults (Reader & Laland, 2001). However, the results of studies in other taxa are varied: in blue tits (*Cyanistes caeruleus*) juvenile females were most likely to solve an innovative problem solving task (Aplin et al. 2013); in a study of red-fronted lemurs (*Eulemur rufifrons*), adults were the only age group that successfully solved, but there was no difference between sexes (Huebner & Fichtel, 2015); and in a study of Arabian babblers

(*Turdoides squamiceps*) no effect of age or sex was found in task solving (Keynan et al. 2016).

The kea (*Nestor notabilis),* an endangered parrot endemic to New Zealand, is an exemplary species for the study of problem individuals. The behavioural characteristics underlying kea attacks on sheep (*Ovis aries*) (hereafter 'kea strike') have not previously been investigated, and kea's behavioural and cognitive milieu provides a compelling example of the interplay between innovation, personality, and sociality. Kea have both a broad generalist strategy and a high degree of behavioural flexibility (Diamond & Bond, 1999), and have demonstrated excellent problem solving skills (O'Hara et al. 2012), including complex problem solving (Miyata et al. 2010), spontaneous assessment of spatial means-end (cause-effect) relationships in captivity (Auersperg et al. 2009; Huber & Gajdon, 2006; Werdenich & Huber, 2006) and the wild (Johnston, 1999), tool use in captivity (Auersperg et al. 2010, 2011a, 2011b) and the wild (Goodman et al. 2018), and innovative problem solving, also in captivity (e.g. Auersperg et al. 2011a & 2012) and the wild (Gajdon et al. 2006). Kea are also highly social, forming dominance hierarchies via agonistic interactions (Diamond & Bond, 1999).

Kea have also demonstrated inter-individual differences in innovative problem solving (Gajdon et al. 2006) and neophobia (Reid, 2008). Relationships have also been found between social rank and both neophobia and exploration tendency, where dominant kea showed low neophobia and high exploration tendency (Reid, 2008). It has been hypothesised that the kea that initiate attacks on sheep may have a particular personality type – e.g. exploratory, innovative, bold (i.e. risk-taking) with low neophobia – and consequently may have been, and continue to be, targeted for culling (Fidler, 2011; Reid, 2008). Anecdotal reports indicate that kea strike is initiated by 'rogue' kea (i.e.

problem individuals), typically thought to be only a few older birds, and that removal of those individuals stops kea strike at least in the short- to medium-term (Aspinall, 1990; Campbell, 1976; McLeod, 1974; Marriner, 1908; Newton, 1983; Thomas, 1972; see also chapter 4).

In this study, I used an experimental approach to examine the potential relationships of two personality traits – neophobia and exploration tendency – with innovation in wild kea. To investigate innovation I used a novel problem solving task designed to emulate stimuli that kea might experience when interacting directly with sheep, as it has been shown that problem solving tasks are valid experimental assays for studying innovation (Griffin & Guez, 2014). To examine problem solving performance more closely, I tested kea in a multi-access box (MAB) task. My aim in exploring these relationships was to gain a better understanding of some of the behavioural factors that potentially underpin kea strike, i.e. innovation, neophobia, exploration tendency, and social rank. I predicted that individual kea would differ in their innovative problem solving performance, and that problem solving kea would be less neophobic, more exploratory and of higher social rank than non-solvers. Because of kea's highly social nature, I also investigated the role that social rank might play in innovative problem solving, and predicted that dominant kea would be better problem solvers. Also, based on a previous study of innovation in wild kea (Gajdon et al. 2006), I predicted that males would perform better than females in the task.

Methods

Subjects and study site

The study subjects were wild kea visiting the area of the Otira Viaduct lookout in Arthur's Pass National Park in the South Island, New Zealand. The study was conducted under Massey University Animal Ethics permit MUAEC Protocol #14/93, and Department of Conservation/Te Papa Atawhai (DOC) permit number #39741-FAU. Birds were caught and banded under permit #2013/023 from the DOC Banding Office. Subjects that were not already banded as part of research by DOC or other researchers were captured and banded. All subjects were identifiable by their alphanumeric PMMA (multi-layered impact acrylic) leg bands (Interrex, Poland). An unknown number of unbanded birds were also present, but not included in my analyses. All subjects were free-living and their participation in the tasks used in this study was voluntary, as they were free to come and go during the experiments. Observations were conducted in the morning, usually for the first 3–4 h after dawn, and evening, for approx. 2 h before sunset, between Jan. 4, 2015 and Feb. 27, 2015. Thirty-two birds were subjects in the novel object tests, 20 in the mechanical sheep analogue test, seven in the multi-access box (MAB) test, and seven in all three tests. The exact ages of the subjects were unknown, but their age classes ranged from fledgling to adult. Fledglings are classified as birds in the summer of their emergence from the nest, juveniles are birds in their second summer, sub-adults are in their third or fourth summer, and adults are older than four years of age. Age class and sex of subjects were determined by a combination of bill measurements, facial and plumage colouration, moult stage, and weight (Bond et al. 1991; Diamond & Bond, 1999).

Novel object task (neophobia and exploration tendency)

I used a novel object task (e.g. Greenberg & Holekamp, 2017; Reid, 2008; Stöwe et al. 2006) (Figure 5.1) to test neophobia (measured as the latency to contact a novel object in seconds) and exploration tendency (measured as the number of different behaviours an individual exhibits towards a novel object when interacting with it, also referred to as exploration/exploratory diversity (e.g. Benson-Amram & Holekamp, 2012). I chose exploration diversity as a measure for exploration tendency because it is a gauge of motor diversity (the total number of different motor techniques, which I refer to here as object-related exploratory behaviours, such as grasp, lever, or probe – see Appendix 2) which has been suggested may facilitate innovation by increasing the ways in which objects can be handled (Griffin et al. 2014), and is considered a measure of exploration tendency (Forss et al. 2017). Subjects, tested either alone or with others present, were presented with one novel object at a time, secured to a wooden platform with a length of light stainless steel chain (see Visalberghi et al. 2003), and the wooden platform was anchored with large rocks to prevent the kea from moving it. Objects that were not constructed in a way that allowed the chain to be threaded through them were fitted with one or two coloured cable ties to allow attachment to the platform via the chain (Figure 5.1). Seventeen different objects were used (e.g. Stöwe & Kotrschal, 2007) and chosen pseudorandomly for presentation (half of the objects would be taken into the field each day in an opaque container, and a single object was chosen blindly out of the container for presentation. Once all of the objects in the container had been presented, the other half of the object sample would be deployed). This number of objects offered a range of textures, shapes, colours and other characteristics (e.g. weight, density, etc.) to provide an accurate measure of general novelty responses (Greggor et al. 2015). Also, kea's latencies to first contact have been found to be completely independent of any physical properties of novel objects, both in the wild and captivity (Johnston, 1999; Stamm, 2007), and kea have exhibited differences in exploratory behaviour that are dependent on the characteristics of those objects (Diamond & Bond, 1999; Kubat, 1992; Stamm, 2007). Trials were video recorded and ended two minutes after the last kea departed the test area, or when 10 minutes had passed, whichever came first.

Figure 5.1 Setup and items used in the novel object task for measuring neophobia and exploration tendency in kea (*Nestor notabilis*) at Arthur's Pass, New Zealand: (a) the seventeen objects used for the task. The objects included toys made for domestic dogs, birds, cats, and humans, as well as household items. Objects were made of various plastics, cotton rope, stainless steel and wood. (b) The novel object task apparatus, showing the wooden platform and chain for securing novel objects; (c) the apparatus in use during a trial, showing a fledgling kea interacting with the novel object. (NB The ruler shown in photos 'a' and 'b' is 30 cm long.)

Mechanical sheep analogue task

The mechanical sheep analogue (Figures 5.2 and 5.3) consisted of a wooden base with two metal springs supporting a moveable ‘body’ made of wood and covered with carpet (glued onto the wood), with a removable synthetic fleece cover. Coloured synthetic fleece was used rather than a sheep’s fleece to reduce the likelihood of kea associating real sheep with food rewards as a consequence of participating in this task. In a hidden pocket in the fleece cover located on the top rear surface of the analogue, a small food reward (half a peanut in the shell) was placed, and replaced once retrieved from the pocket by a subject. Placement of the food reward was hidden from view of subjects by shielding the action with a hand. Movement of the top platform of the analogue – built so that, when activated, its movements were analogous to that of a sheep – was enacted remotely by two nylon cords attached to the apparatus via a pulley system. The portion of each cord that protruded from the apparatus was covered with a section of PVC tubing to prevent entanglement of the cords and damage by kea. A length of carpet was glued to the base of the apparatus, to which the fleece cover was attached with Velcro. This was to protect the inner workings of the analogue (i.e. the nylon cord pulley system) and the subjects, and helped to keep the cover in place while the apparatus was in motion. The apparatus was attached with screws to a plywood baseboard, which was anchored with large rocks to prevent the apparatus from moving when in operation. Trials were video recorded and ended when the target kea retrieved the food reward, or until two minutes after the last kea departed the test area and the reward had not been retrieved, or when 20 min had passed, whichever came first. At the beginning of each trial, the kea were allowed enough time to approach and make contact with the apparatus before it was activated. I enacted movement of the analogue’s body when any kea present in the test area visibly began to chew on the cover. The analogue’s movements were small at first, and then increased in intensity once kea visibly became more vigorous in their chewing. The speed and rhythm of the movements were enacted to try to emulate the possible responses of a real sheep. Kea were tested in a group setting to emulate the conditions likely to be found on high country sheep stations.

Subjects were considered successful if they discovered the food reward in at least one trial. After their initial discovery of the food reward, successful kea were tested in nine subsequent consecutive trials (ten in total per kea) to gauge their performance, and then prevented from retrieving the food reward in further trials to give other individuals the opportunity to access the apparatus. Subjects that had completed ten successful consecutive trials were blocked from the apparatus by research assistant(s), who prevented that bird from approaching the apparatus by placing themselves between it and the bird in question and maintaining their position relative to both. Alternatively, novel objects that were not used in the novel object trials were used as lures to keep non-target subjects away from the apparatus.

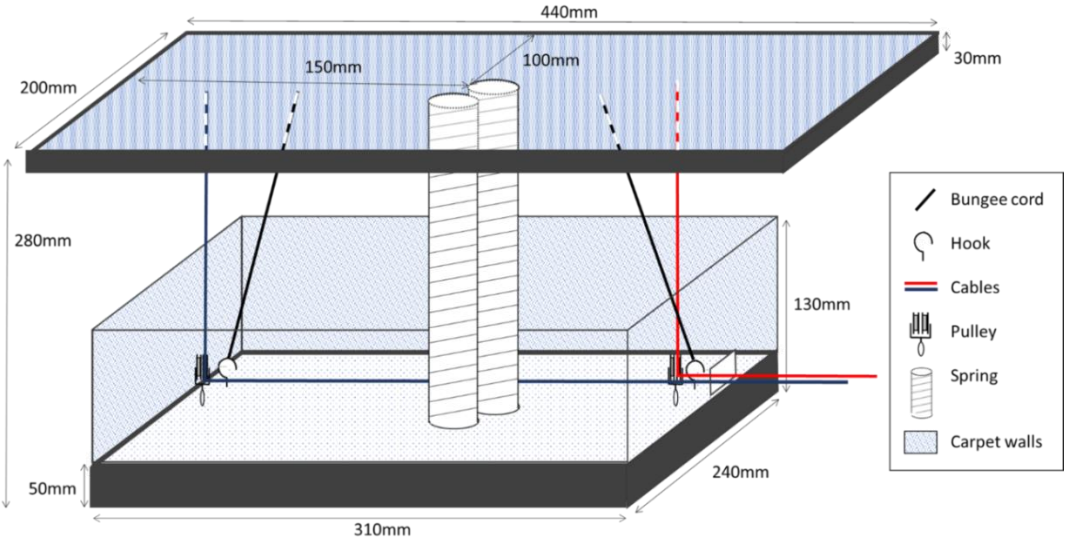

Figure 5.2 Diagram of the mechanical sheep analogue apparatus used for measuring innovative problem solving performance and behavioural responses of kea (*Nestor notabilis*) at Arthur's Pass, New Zealand.

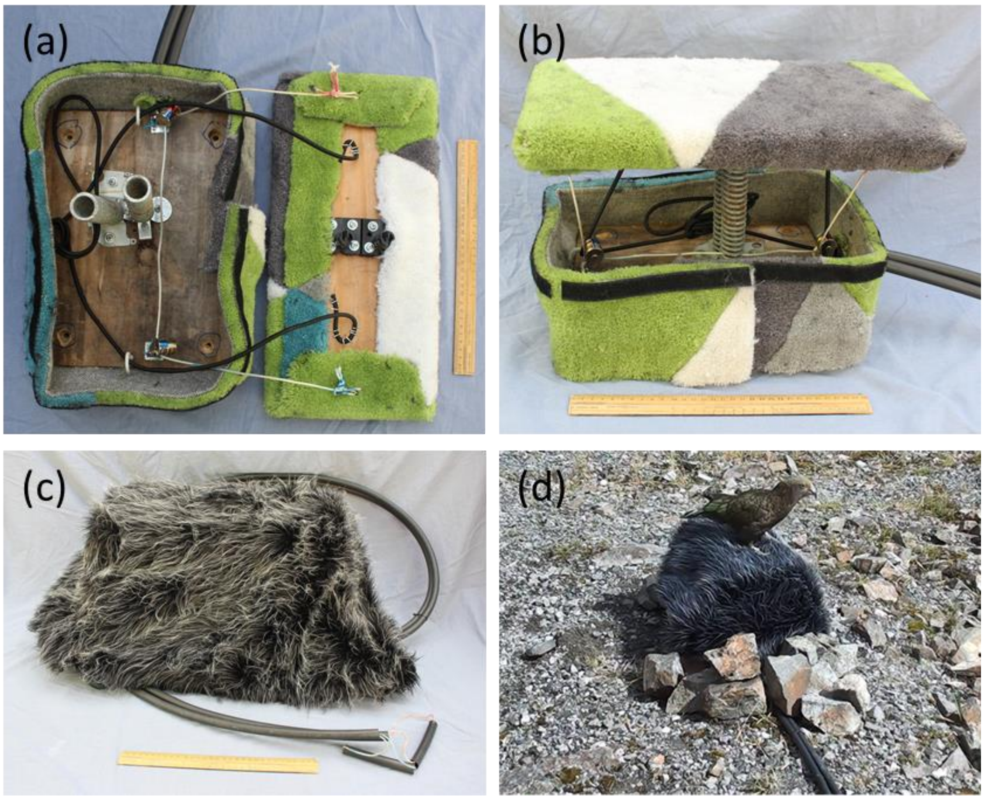

Figure 5.3 The mechanical sheep analogue apparatus used for measuring innovative problem solving performance and behavioural responses of kea (*Nestor notabilis*) at Arthur's Pass, New Zealand: (a) view of the apparatus from above with the top of the apparatus removed to show the inner workings; (b) side view of the apparatus with the top fitted, but before the cover is attached; (c) side view of the apparatus with the cover in place and the operating cable visible; (d) front view of the apparatus in use during a trial with a fledgling kea on top of it. (NB The ruler shown in the photos is 30 cm long.)

Multi-access box (MAB)

The subjects' innovative problem solving ability was also tested using a multi-access box apparatus (MAB, figures 5.4 and 5.5) after Auersperg et al. (2011a & 2012). My experiments followed Auersperg et al.'s methodology, with the following modifications: the MAB frame was constructed of wood rather than metal, and the apparatus was mounted on a plywood base and large rocks (one on each corner) used to anchor the apparatus to prevent the kea from moving it. The walls of the apparatus were not interchangeable, so instead of switching the walls between trials the whole apparatus was rotated pseudorandomly. The marbles used as ball tools were all the same size and unpainted, and natural sticks (*Nothofagus* spp.) were used to reduce the likelihood and impact of kea removing them from the test site. Tests were usually conducted in a group setting. Individuals were not prevented from participating in a test unless they had already successfully solved the task (i.e. they passed to the next level of testing) via one of the available solutions, in which case they were blocked from participating by the research assistant(s) via the same methods as used during the mechanical sheep analogue task. This was done to enable other kea the opportunity to engage with the apparatus without interference from a previously successful bird. Two sticks and two marbles were supplied during each trial, placed on alternating corners of the MAB (marbles were placed diagonally opposite each other in the wells of the plywood base of the MAB where screws mounted it to the larger main plywood base, and sticks were placed in the same orientation. Kea were not given familiarisation trials (i.e. where a wall was removed from the MAB to allow subjects to freely retrieve the food reward) prior to the start of actual tests, with the exception of Arthur, a fledgling male, whose results are not included (see results). Subjects had, however, been familiarised with the food reward itself by being given half a peanut in the shell prior to the task. If a kea did not retrieve the food reward after ten minutes, another trial was started, and trials continued until the target bird failed two trails in a row, or reached the criteria for passing (two successful sessions), or left the test area. Trials ended when the peanut was retrieved, or when 10 min had passed, whichever came first. If a subject (i.e. one that was eligible for testing in that trial) was absent from the test area for >2 min during a trial, the trial was not included in its overall trial count. After each trial, the marbles, sticks and string (where applicable) were retrieved and replaced in their original positions.

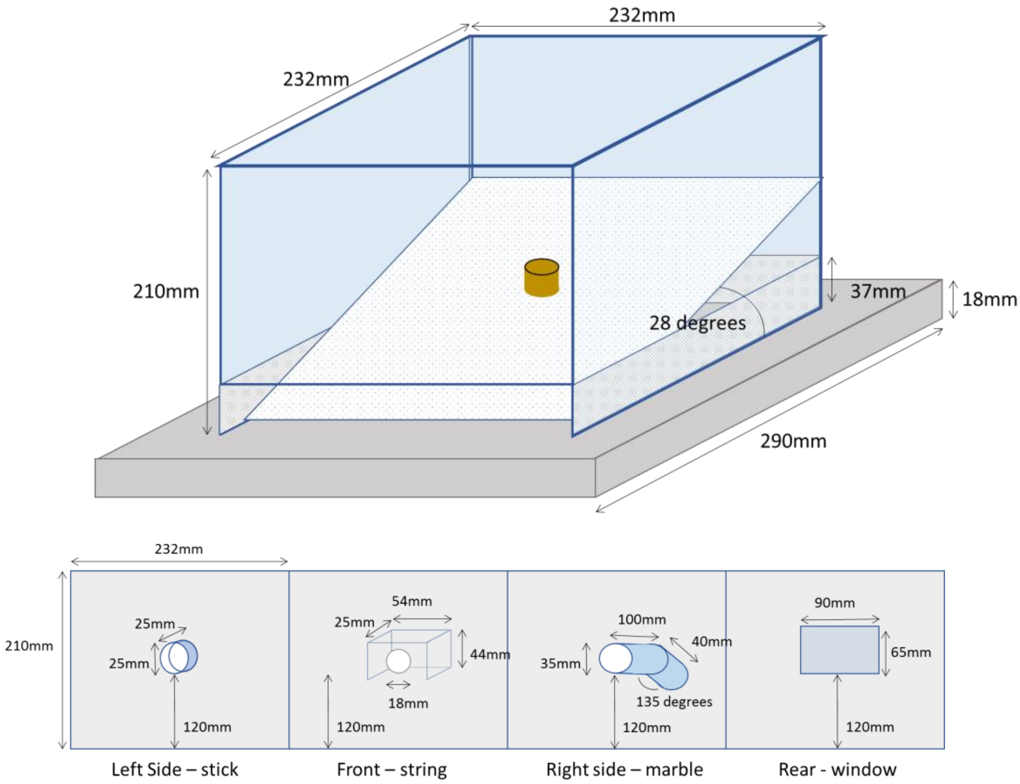

Figure 5.4 Multi-access box apparatus (MAB, after Auersperg et al. 2011) used to test innovative problem solving in kea (*Nestor notabilis*) at Arthur's Pass, New Zealand. The apparatus used in my study consisted of a wooden frame with four Plexiglas walls with openings corresponding to the 4 possible solutions: stick, string, marble, and window. A food reward (half a peanut in the shell) presented on the wooden pedestal in the centre the MAB could be retrieved by one of four possible methods: opening the window, pulling a string via the corresponding opening, inserting a marble into the appropriate opening, or inserting as stick tool through the appropriate opening.

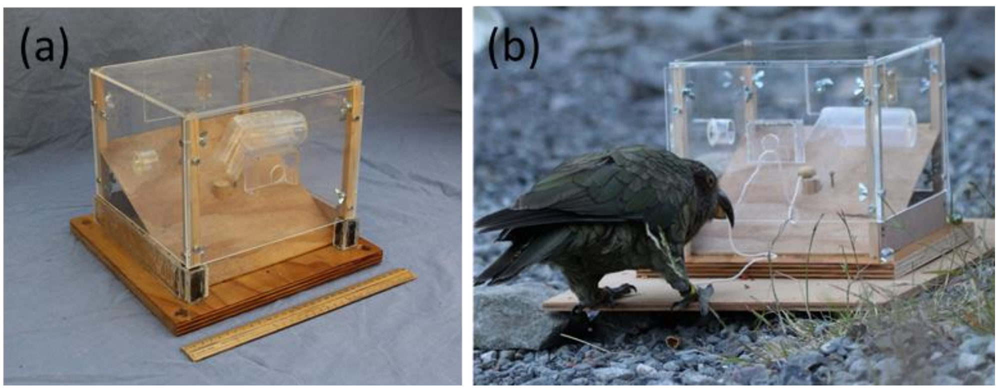

Figure 5.5 Multi-access box apparatus (MAB, after Auersperg et al. 2011) used to test innovative problem solving in kea (*Nestor notabilis*) at Arthur's Pass, New Zealand: (a) the apparatus, showing the stick opening on the left, window at the back left, marble opening at back right, and string opening at front right; (b) the apparatus in use during a trial showing a juvenile kea in front of the string access wall. (NB The ruler shown in the image on the left is 30 cm long.)

Data collection

I conducted experiments opportunistically during my twice daily observation periods. All experimental trials were recorded on a video camera mounted on a tripod. Trials were terminated when no target individuals were present within a 2 m radius of the apparatus for 2 min, or because of other logistical constraints (e.g. darkness, or to prevent an individual from damaging the apparatus). Behavioural data for each subject were extracted from the video footage using BehaView version 0.0.11c (Boguszewski, 2011). In each trial, any individual approaching within 2 m of the apparatus was considered a subject. For each subject I measured latency to contact (in seconds) and the number of different object-related exploratory behaviours. I used the mean number of distinct exploratory behaviours from each of an individual's trials to assign their exploration score (e.g. Benson-Amram & Holekamp, 2012). Subjects with means ranging from 3 to 4.5 behaviours were assigned to category 1; those with means ranging from 4.6 to 6.1 were assigned to category 2; those with means ranging from 6.2 to 7.7 were assigned to category 3; and those with means ranging from 7.8 to 9.3 were assigned to category 4. Subjects exhibited up to 15 object-related behaviours per trial. Based on my observations and the literature (Diamond & Bond, 1991; Gajdon & Voelkl, 2002; Johnston, 1999; Keller, 1974, 1975; Potts, 1969; Reid, 2008), I identified a total of 25 object-related behaviours as applicable to the novel object trials in this study (Appendix 2). I used the mean latency to contact the novel objects (in seconds) across all trials that a subject participated in to assign their neophobia score (Stöwe & Kotrschal, 2007; Reid, 2008). Subjects with mean latencies ranging from 1 to 2 s were assigned to category 1; those with means ranging from 2.1 to 3 s were assigned to category 2; those with means ranging from 3.1 to 4 s were assigned to category 3; and those with means ranging from 4.1 to 5 were assigned to category 4. Each kea that participated in both the mechanical sheep analogue trials and the novel object trials was given both a neophobia and exploration score. Each kea that was given scores for neophobia and exploration participated in a minimum of three novel object trials. Repeat exposures to a particular object (e.g. resulting from an individual participating in a trial in which another subject was being presented with that object) were not included in the individual's score calculations.

Social rank

To assess social rank, I noted dyadic agonistic interactions between banded individuals from the video recordings of experimental trials. Social hierarchy in kea is determinable by noting instances of displacement, i.e. where a bird moves away from an approaching individual (Diamond & Bond, 1999). I appointed social ranks from the recorded interactions for the 20 banded individuals that participated in the mechanical sheep analogue trials by using a David's score (David, 1987; Gammell et al. 2003). Each individual had interacted with at least three other banded kea. David's scores (DS) were calculated by following the methodology from Gammell et al. (2003): the proportion of 'wins' by individual *i* in its interactions with another individual *j* (P_{ij}) is the number of times that *i* 'defeats' *j* (α_{ij}) divided by the total number of interactions between *i* and *j* (n_{ij}), i.e. $P_{ij} = \alpha_{ij}/n_{ij}$. The proportion of 'losses' by *i* in interactions with *j* is calculated as $P_{ji} = 1 - P_{ij}$. If $n_{ij} = 0$, then $P_{ij} = 0$ and $P_{ji} = 0$ (David 1988; de Vries 1998). David's score for each member, *i*, of a group is calculated with the formula:

$$\text{DS} = w + w_2 - l - l_2,$$

where *w* represents the sum of *i*'s P_{ij} values, w_2 represents the summed *w* values (weighted by the appropriate P_{ij} values) of those individuals with which *i* interacted, *l* represents the sum of i's P_{ji} values and l_2 represents the summed l values (weighted by the appropriate P_{ji} values) of those individuals with which i interacted (David, 1988; de Vries, 1998; Gammell et al. 2003). I used the simplified correction developed by de Vries (2006) for cases where interaction frequency varies substantially between dyads (de Vries, 1998), as it did in my study, where P_{ij} is calculated as: $d_{ij} = (\alpha_{ij} + 0.5)/(n_{ij} + 1)$.

Statistical analyses

Neophobia, exploration tendency, and social rank were compared between kea that discovered the food hidden in the mechanical sheep analogue ('successful') and those that did not ('unsuccessful'), and between females and males using Wilcoxon rank sum tests. Relationships between exploration tendency, neophobia and social rank were compared using Pearson correlation tests. All statistical tests were conducted using the R Commander package from the R program for statistical computing, version 3.3.3 (Fox & Bouchet-Valat, 2017; R Core Team, 2017).

Results

Novel object experiments (neophobia and exploration tendency)

I conducted a total of 226 novel object trials, from which 18 kea were scored for neophobia and exploration tendency. These kea also participated in the mechanical sheep analogue task. All 18 kea made contact with the novel objects during those trials. Neophobia scores varied from 1 to 4. Three subjects received a score of 1 (17%), 10 subjects received a score of 2 (55%), three received a score of 3 (17%), and two received a score of 4 (11%; Figure 5.6). Exploration scores varied from 1 to 4. Three subjects received a score of 1 (17%), two subjects received a score of 2 (11%), eight received a score of 3 (44%), and five received a score of 4 (28%; Figure 5.7). The number of trials per individual ranged from 3 to 17, and the mean number of trials per individual was 9 ± 4.87 SD. Females had lower exploration scores, exhibiting fewer exploratory behaviours towards the novel objects (Wilcoxon rank sum test: W = 12.5; n = 5; n = 13; p = 0.041; 95% CI -2.00–0) (Figure 5.7), but there was insufficient evidence that they differed from males in their neophobia scores (Wilcoxon rank sum test: W = 47; n = 5; n = 13; p = 0.128; 95% CI 0–1.00) (Figure 5.6). Neophobic kea showed lower exploration tendency; i.e. those that were slower to approach novel objects also exhibited a smaller range of exploratory behaviours towards them (Pearson correlation: r = -0.66; n = 18; P = 0.003; 95% CI -0.86 – -0.28) (Figure 5.8).

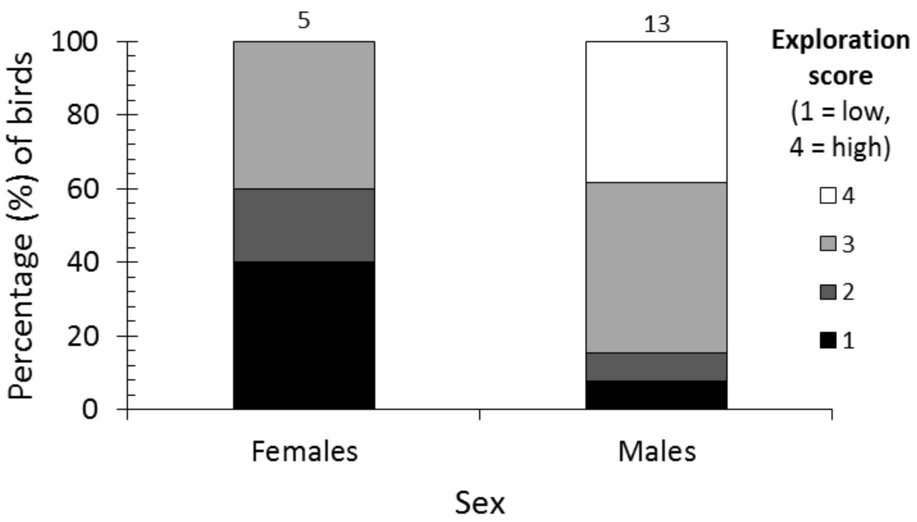

Figure 5.6 Exploration scores (based on mean exploratory behaviours across all novel object trials) in the novel object task for female and male kea (*Nestor notabilis*) at Arthur's Pass, New Zealand. Numbers above bars denote sample sizes.

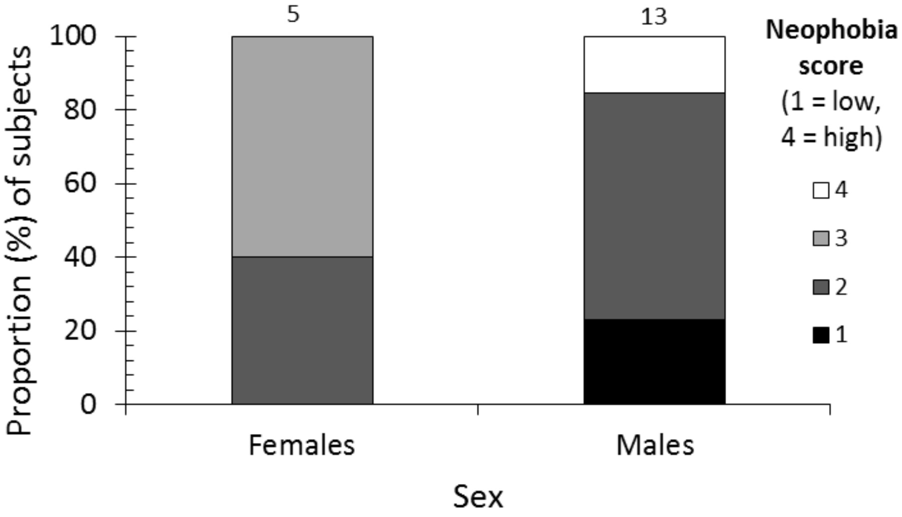

Figure 5.7 Neophobia scores (based on mean latency to contact in seconds across all trials) in the novel object task for female and male kea (*Nestor notabilis*) at Arthur's Pass, New Zealand. Numbers above bars denote sample sizes.

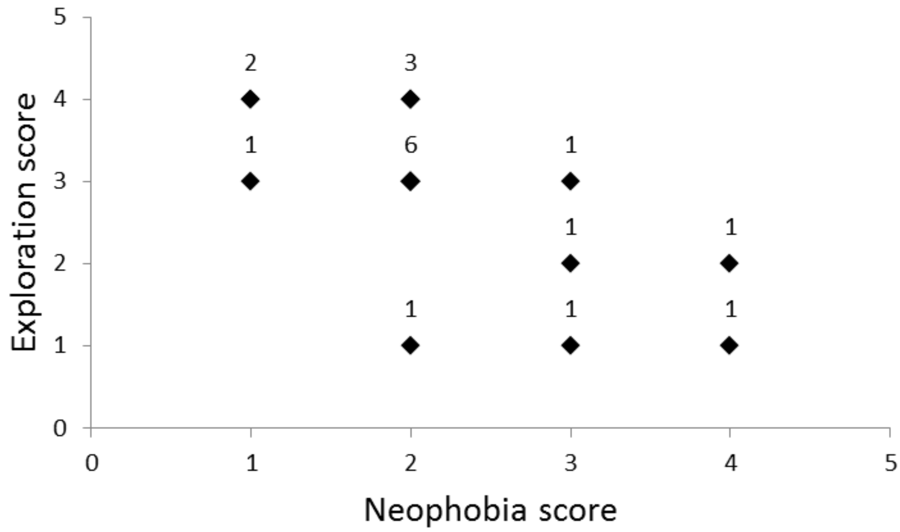

Figure 5.8 Exploration scores (based on mean exploratory behaviours across all trials) versus neophobia scores (mean latency to contact in seconds across all trials) in a novel object task for kea (*Nestor notabilis*) at Arthur's Pass, New Zealand. Numbers above diamonds denote number of birds in each category.

Social rank was calculated for the 20 kea that participated in the mechanical sheep analogue experiment. Social rank did not differ between females and males (Wilcoxon rank sum test: W = 21; n = 6; n = 14; p = 0.091; 95% CI -62.17–4.46) (Figure 5.9). Although social rank had a moderate positive relationship with exploration tendency, there was insufficient evidence for this (Pearson correlation: r = 0.39; n = 18; P = 0.110; 95% CI -0.09–0.72) (Figure 5.10). There was also insufficient evidence for the moderate negative relationship with neophobia (Pearson correlation: r = -0.35; n = 18; P = 0.150; 95% CI -0.70 – 0.14) (Figure 5.11).

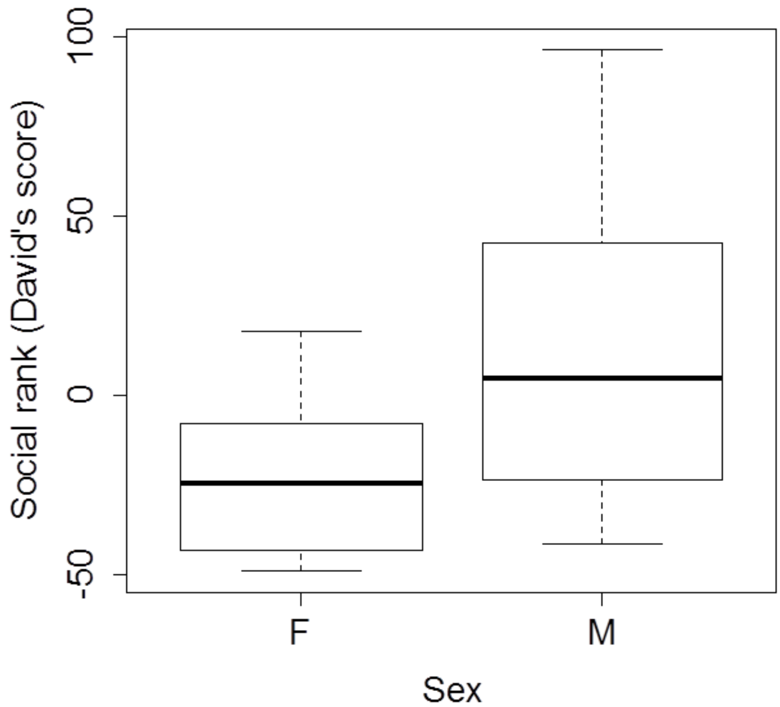

Figure 5.9 Social rank (David's Score) for female (n = 6) and male (n = 14) kea (*Nestor notabilis*) participating in the mechanical sheep analogue task at Arthur's Pass, New Zealand.

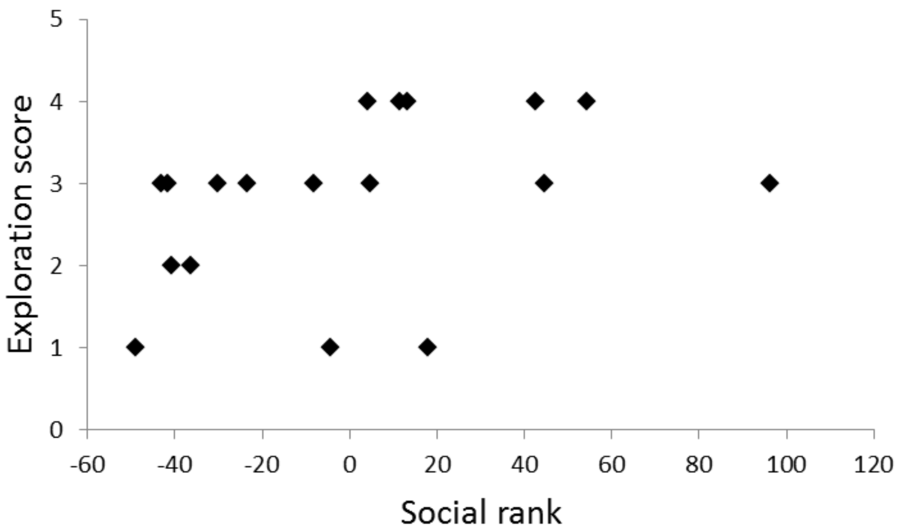

Figure 5.10 Social rank (David's Score) versus exploration scores (mean number of exploratory behaviours across all trials) in the novel object task for kea (*Nestor notabilis*) at Arthur's Pass, New Zealand.

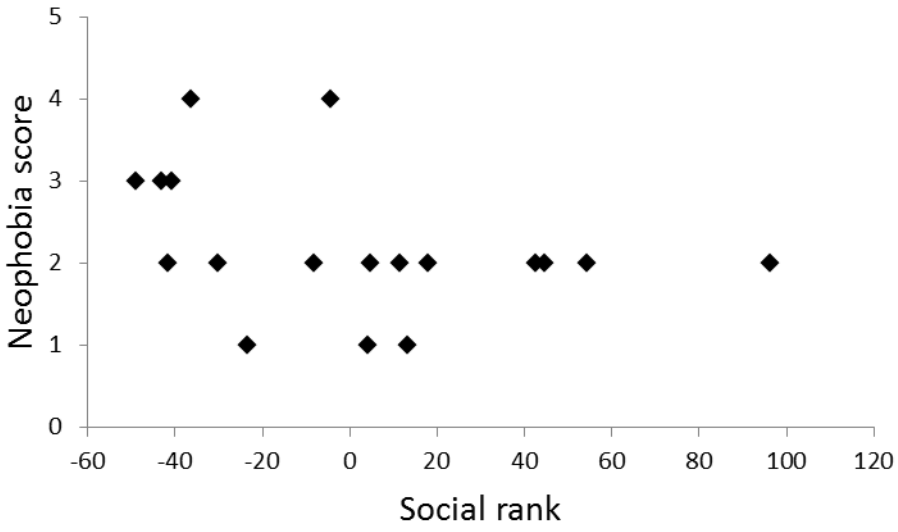

Figure 5.11 Neophobia scores (based on mean latency to contact in seconds across all trials) in the novel object task versus social rank (David's Score) for kea (*Nestor notabilis*) at Arthur's Pass, New Zealand.

Mechanical sheep analogue

Of the 20 kea that participated in the mechanical sheep analogue task (i.e. were present in the test area) across 82 trials, five (25% of subjects) were successful and only four birds did not interact with the apparatus (Table 5.1). All successful individuals also retrieved the food reward in ten consecutive trials (i.e. their first successful trial followed by nine consecutive trials). Eighteen of the 20 kea that participated in the mechanical sheep analogue experiment were given neophobia and exploration scores from their novel object trials (the remaining two did not participate in any novel object trials, and therefore could not be given scores and were excluded from analyses of neophobia and exploration tendency). Neophobia scores did not differ between successful and unsuccessful kea (Wilcoxon rank sum test: $W = 44$; $n = 5$; $n = 13$; $p = 0.231$; 95% CI 0–2.00) (Figure 5.12). Exploration tendency was higher for successful birds (Wilcoxon rank sum test: $W = 13$; $n = 5$; $n = 13$; $p = 0.047$; 95% CI -2.00–0) (Figure 5.13). Successful kea were of higher social rank than unsuccessful ones (Wilcoxon rank sum test: $W = 4$; $n = 5$; $n = 15$; $p = 0.002$; 95% CI -95.24 – -33.07) (Figure 5.14).

Of the kea that were successful in the mechanical sheep analogue task, Wadda was the fastest solver (3 trials) (Table 5.1). Dobbie was the next fastest solver (9 trials), followed by Arthur (17 trials), Matu (19 trials), and Marvin (30 trials). Wadda made contact with the apparatus most often (100% of trials), followed by Dobbie (94%), Arthur (85%), Matu (77%) and Marvin (72%).

Table 5.1 Details of kea (*Nestor notabilis*) that participated in the mechanical sheep analogue task at Arthur's Pass, New Zealand.

Kea ID	Age	Sex	Social rank	Success with MSA	No. MSA trials present†	No. MSA trials until success	Contact with MSA	No. MSA trials in which contact was made	Tested in novel object trials	Tested in MAB trials
Dobbie	Juvenile	Male	1	Yes	9	9	Yes	17 (94%)	Yes	Yes
Arthur	Fledgling	Male	2	Yes	17	17	Yes	22 (85%)	Yes	Yes*
Marvin	Juvenile	Male	3	Yes	30	30	Yes	28 (72%)	Yes	Yes
Wadda	Juvenile	Male	4	Yes	3	3	Yes	12 (100%)	Yes	Yes
Eva	Adult	Female	5	No	3	-	No	0 (0%)	Yes	Yes
Ford	Juvenile	Male	6	No	7	-	Yes	7 100%)	Yes	Yes
Romano	Fledgling	Male	7	No	10	-	Yes	8 (80%)	Yes	No
David	Fledgling	Male	8	No	6	-	Yes	6 (100%)	Yes	No
Matu	Sub-adult	Male	9	Yes	19	19	Yes	24 (77%)	Yes	Yes
Freya	Sub-adult	Female	10	No	1	-	Yes	1 (100%)	Yes	No
Hoheria	Fledgling	Female	11	No	1	-	Yes	1 (100%)	No	No
Lance	Adult	Male	12	No	2	-	Yes	1 (50%)	Yes	No
Saul	Sub-adult	Male	13	No	4	-	No	0 (0%)	No	No
Totara	Fledgling	Male	14	No	9	-	Yes	7 (78%)	Yes	No
Rata	Fledgling	Male	15	No	2	-	No	0 (0%)	Yes	No
Tane	Fledgling	Male	16	No	4	-	Yes	4 (100%)	Yes	No
Michelle	Fledgling	Female	17	No	2	-	Yes	1 (50%)	Yes	No
Kaua	Fledgling	Female	18	No	2	-	No	0 (0%)	Yes	No
Malcolm	Fledgling	Male	19	No	1	-	Yes	1 (100%)	Yes	No
Trillian	Fledgling	Female	20	No	4	-	Yes	4 (100%)	Yes	No

*Data for this individual are not presented in Table 5.1 because he was tested out of sequential order due to experimenter error.

†Trials in which successful kea were present after their first successful trial are not included

MSA: mechanical sheep analogue

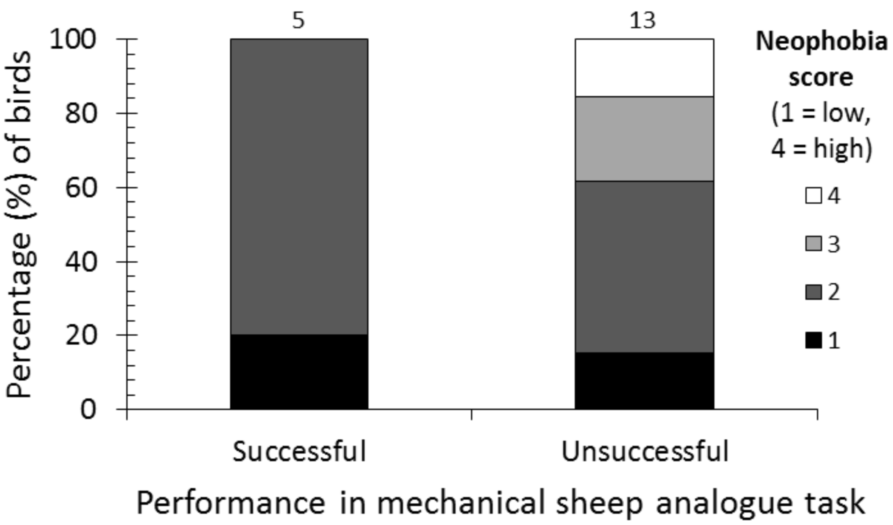

Figure 5.12 Neophobia scores (based on mean latency to contact in seconds across all novel object trials) for kea (*Nestor notabilis*) that solved versus those that did not solve the mechanical sheep analogue task at Arthur's Pass, New Zealand. Numbers above bars denote sample sizes.

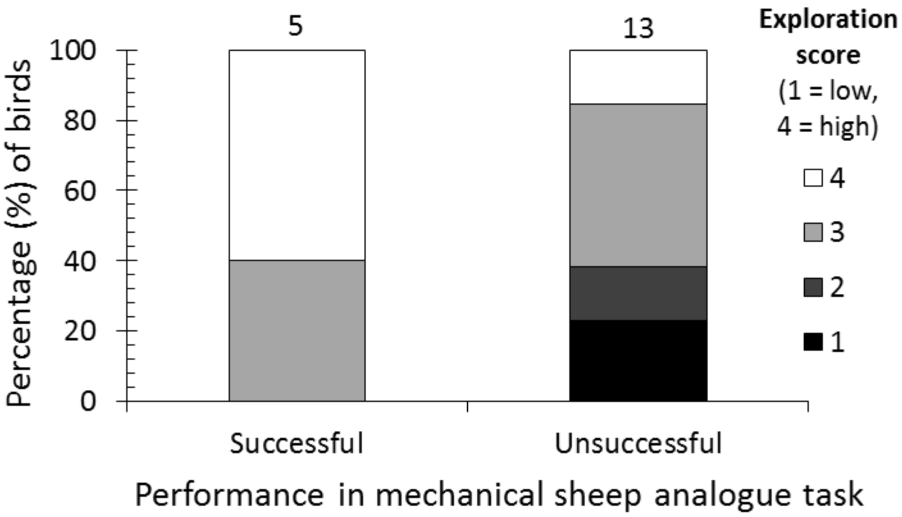

Figure 5.13 Exploration scores (based on mean number of exploratory behaviours across all novel object trials) for kea (*Nestor notabilis*) that solved versus those that did not solve the mechanical sheep analogue task at Arthur's Pass, New Zealand. Numbers above bars denote sample sizes.

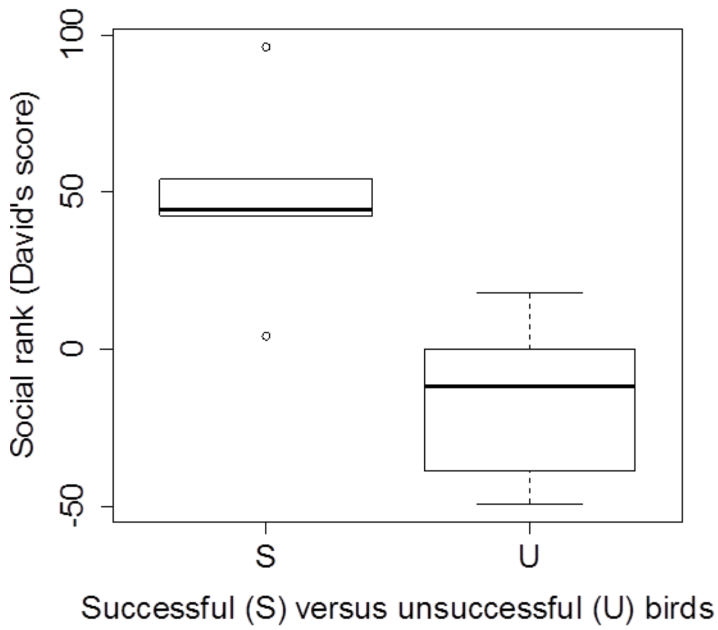

Figure 5.14 Social rank (David's Score) of kea (*Nestor notabilis*) that solved (n = 5) versus those that did not solve (n = 15) the mechanical sheep analogue task at Arthur's Pass, New Zealand. Outliers are denoted by open circles.

Multi-access box (MAB)

Seven kea that were tested in the mechanical sheep analogue task were also tested for problem solving performance in the multi-access box (MAB) task across 507 trials (Table 5.1), and data for six of those kea were valid for further analysis (Table 5.2). The test results for one kea (Arthur, a fledgling male) are not included because he was tested out of session sequence due to experimenter error. Because of the small sample size of birds tested in this experiment, I did not include the results in the overall analyses with the mechanical sheep analogue and novel object experiments.

All subjects tested in the MAB task also participated in the mechanical sheep analogue task, and five of them were also successful in the mechanical sheep analogue task (Table 5.2). Three of the kea that were successful in the sheep analogue task also passed level 1 of the MAB task (all food retrieval methods available), and two of those birds passed level 2 (string access blocked). No kea passed level three (string and window access blocked) (Appendix 2). Of the two kea that were tested in the MAB task that were unsuccessful in the mechanical sheep analogue task, neither passed level 1. All kea that were tested demonstrated successful use of the string and window to retrieve the food, but only one of the two kea tested at level three discovered a third technique (Wadda, a juvenile male, using the marble in his fifth session). No kea tested discovered the stick method of retrieval.

Table 5.2 Results of multi-access box (MAB) task presented to kea (*Nestor notabilis*) at Arthur's Pass, New Zealand.

Kea ID	**Level 1 (4-way access)**							
	Session 1		**Session 2**		**Session 3**		**Session 4**	
	Result	Pass	Result	Pass	Result	Pass	Results	Pass
Dobbie	1 D, 2 IC, 7 S	No	2 IC, 8 Con S	Yes	1 IC, 9 S	Yes	NA	NA
Eva	1 D, 4 IC, 3 S, 2 W	No	1 IC, 6 S, 3 W	No	2 IC, 8 Con S	Yes	-	-
Ford	1 IC, 5 S, 4 W	No	2 IC, 6 S, 2 W	No	1 IC, 6 S, 3 W	No	1 IC, 7 S, 2 W	No
Marvin	1 D, 1 IC, 8 Con S	Yes	1 IC, 9 S	Yes	NA	NA	NA	NA
Matu	1 D, 1 IC, 8 S	No	1 IC, 9 S	Yes	4 IC, 6 S	No	2 IC, 8 S	No
Wadda	1 IC, 9 S	Yes	1 IC, 9 S	Yes	NA	NA	NA	NA

Kea ID	**Level 2 (3-way access, no string)**											
	Session 1		**Session 2**		**Session 3**		**Session 4**		**Session 5**		**Session 6**	
	Results	Pass	Results	Pass	Results	Pass	Results	Pass	Results	Pass	Results	Pass
Dobbie	1 D, 5 IC, 4 W	No	10 W	Yes	10 W	Yes	NA	NA	NA	NA	NA	NA
Eva	-	-	-	-	-	-	-	-	-	-	-	-
Ford	-	-	-	-	-	-	-	-	-	-	-	-
Marvin	NR10	No	NR10	No	NR10	No	NR10	No	6 IC, 4 W	No	10 W	Yes
Matu	-	-	-	-	-	-	-	-	-	-	-	-
Wadda	NR10	No	1 IC, 9 W	Yes	10 W	Yes	NA	NA	NA	NA	NA	NA

Kea ID	**Level 3 (2-way access, no string or window)**													
	Session 1		**Session 3**		**Session 4**		**Session 5**		**Session 6**		**Session 7**		**Session 8**	
	Results	Pass	Results	Pass	Results	Pass	Results	Pass	Results	Pass	Results	Pass	Results	Pass
Dobbie	NR10	No	NR10	No	NR10	No	NR10	No	NR10	No	NR10	No	NR10	No
Eva	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ford	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Marvin	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Matu	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Wadda	NR10	No	NR10	No	NR10	No	NR10	No	1 D (M) (T #1), NR10 (T #2)	No	NR10	No	6 IC, 4 M	No

Key: '-' = Individual was not tested in this session/level; NR10 = No retrieval in 10 minutes; D = Discovery; IC = Incorrect; S = String; W = Window; M = Marble; T = Trial; Con = Consecutive.

Discussion

My results indicate that some kea exhibit better problem solving performance than others, with only 28% of subjects solving the mechanical sheep analogue task, and 33% of subjects tested in the MAB task advancing beyond level 2. These findings are consistent with those of other studies of problem solving in wild kea: Johnston (1999) found that only 37% of subjects in a string-pulling task successfully solved it; Gajdon et al. (2004) found that only three of 15 (20%) participants solved a tube-lifting task; and Gajdon et al. (2006) found that only five of 36 (14%) successfully opened rubbish bins with hinged lids. These results are also consistent with those of studies in other taxa, such as and kākā (*Nestor meridionalis*, a close relative of kea; Loepelt et al. 2016), hyaenas (Benson-Amram & Holekamp, 2012), common mynas (*Sturnus tristis*) (Sol et al. 2012), meerkats (Thornton & Samson, 2012), great tits (Cole et al. 2011), and corvids (Miller et al. 2016). There was also inter-individual variation between the performances of individuals that successfully solved the mechanical sheep analogue task, with the fastest solver (Wadda) succeeding in his third trial, and the slowest (Marvin) in his 30th. These subjects also varied in their performance in the MAB task, with only two kea advancing beyond level 2, and only one kea discovering a third technique (the marble) of the four available techniques. I also found that kea that were successful problem solvers were more exploratory, which is consistent with those of other studies of exploration tendency in kākā (Loepelt et al. 2016), hyaenas (Benson-Amram & Holekamp, 2012), and urban birds (Diquelou et al. 2016; Griffin et al. 2014). Such findings demonstrate that exploration tendency (as measured by exploration diversity) plays a central role of variation in exploratory behaviour in innovation (Diquelou et al. 2016; Griffin et al. 2014), and indicate that exploration tendency and innovation may also be key behavioural characteristics underlying kea strike. The responses of the kea that were successful in the mechanical sheep analogue task demonstrated exploratory behaviours that may be associated with the development of kea strike behaviour. Once these kea discovered the food reward, they consistently displayed foraging behaviour that may cause the kea strike wounds in live sheep characterised in chapter 3. If the successful kea demonstrate the potential of problem individuals, their behavioural characteristics (i.e. problem solving performance and high exploration tendency) could indicate that a particular personality type or suite of traits underlie their propensity for kea strike and other behaviours that contribute to conflict scenarios with humans. The role of innovative propensity in the context of 'problem' kea elsewhere has arguably been demonstrated by Gajdon et al. (2006), in that only a handful of individuals were capable of solving a complex task (opening rubbish bins with hinged lids) – in this context a behaviour that is often a source of conflict with humans (Peat, 1995; C. Reid, personal observation).

I did not find evidence that neophobia differed between kea that successfully solved the task and those that did not, which suggests that neophobia may not play an important role in innovation in kea, and therefore may not have a primary influence on kea strike behaviour. This finding is consistent with a number of other avian studies, i.e. corvids (Miller et al. 2016), house sparrows (*Passer domesticus*; Liker & Bókony, 2009), great tits (*Parus major*; Cole et al. 2011), Indian mynas (*Acridotheres tristis*) and noisy miners (*Manorina melanocephala*; Griffin et al. 2014; Griffin & Diquelou, 2015), and starlings (*Sturnus vulgaris*; Boogert et al. 2006). A review by Griffin & Guez (2014) revealed that although neophobia represents a contextual factor, it does not co-vary with problem solving ability and the two were not linked across species. Neophobia may be linked to problem solving because both are influenced by one or more underlying processes, such as feeding motivation (Sol et al., 2012; Webster & Lefebvre, 2001) or stress (Griffin & Guez, 2014).

I found strong evidence that exploratory kea also have low neophobia, which indicates that the two traits may be linked in kea. This result is consistent with the findings for fledgling males in my previous study of wild kea (Reid, 2008), and in a study of captive spotted hyaenas (Johnson-Ulrich et al. 2018), which showed a correlation between the two traits. Although I did not find that problem solvers were less neophobic, neophobia may nevertheless interact with other personality traits such as exploration tendency to influence innovation. In Johnson-Ulrich et al. (2018)'s study, high exploration tendency and low neophobia were found to act as part of a proactive suite of personality traits to influence innovation. A growing number of studies have linked suites of personality traits to cognition (Carere & Locurto, 2011; Guillette et al. 2017; Johnson-Ulrich et al. 2018; Sih & Del Giudice, 2012), and I propose that neophobia and exploration tendency may work together as driving factors in kea strike behaviour.

Unlike my previous study (Reid, 2008), I did not find a difference in exploration tendency or neophobia between high and low ranking individuals. However, the confidence intervals for my analyses of these relationships spanned zero, indicating that these results should be read with some caution. These differences between the two studies may be due a number of factors, including differing age and sex ratios between the study samples, differences between the study populations, or methodology (different indices for social rank were used, for example). However, the relationship between novelty response (including neophobia and exploration tendency) and social rank has been shown to be inconsistent within other species, and can be context dependent

(Boogert et al. 2006; Greenberg & Holekamp, 2017; Greenberg & Mettke-Hofmann, 2001; Stöwe et al. 2006), which may also be the case with kea. My results indicate that social rank may not interact strongly with neophobia or exploration tendency to influence kea strike behaviour.

The association between higher social rank and success in the mechanical sheep analogue task is inconsistent with the finding of Gajdon et al (2006)'s study of innovative problem solving in wild kea. Gajdon et al. (2006) found that social rank did not differ between males that successfully opened rubbish bins and males that did not. The differences between the two studies could be a result of methodological differences (the two studies used different indices to calculate social rank, for instance), differences in age ratios, or other factors. Social rank is related to age in kea (Diamond & Bond, 1999), and Gajdon et al. (2006)'s study sample included more adult and sub-adult males than ours. Studies in hyaenas found that although social rank was related to problem solving success in juvenile hyaenas (Greenberg & Holekamp, 2017), no such relationship was found in mixed-age samples (Benson-Amram & Holekamp, 2012). The large proportion of young kea in my sample may therefore have had an influence on my results. The relationship between social rank and problem solving may also be context dependent in kea, and my results suggest that in the context of kea strike behaviour, high ranking individuals may be more likely to initiate it.

My finding that females were less exploratory than males is consistent with the results of my previous study (Reid, 2008), and may be related to the sex differences in problem solving performance reported in other studies of wild kea (Gajdon et al. 2004, 2006). If females are less exploratory than males, they may be less motivated to engage in innovative feeding such as opening rubbish bins and attacking sheep. Although two females attempted to open bins in Gajdon et al.'s (2006) study, neither were successful. One adult female (Eva) was tested in the MAB task of my study, but did not pass level 1. However, unlike my previous study (Reid, 2008), I did not find a difference in neophobia between the sexes. Although my results indicate that neophobia may not play an important role in sex differences in kea strike behaviour, the differences in the results of these two studies indicate that no strong conclusions can be drawn in this regard.

The difference in problem solving performance between the sexes in my study is consistent with Gajdon et al.'s (2006) study, where only males solved the task. However, other factors such as age and social rank may also be involved. Although I did not find a difference between social rank between the sexes in my study, other studies of wild kea have found a relationship between them, with female kea being of lower rank than males (Diamond & Bond, 1999; Gajdon et al. 2006). As age is also related to social rank in kea (Diamond & Bond, 1999), it may be that the large proportion of younger birds in my study masked this relationship and its effect on the opportunities that females had to interact with the apparatus. Studies of kea in captivity have demonstrated that female kea are capable of various different types of problem solving (Auersperg et al. 2009, 2010; Gajdon et al. 2013; O'Hara et al. 2015, 2016; Werdenich & Huber, 2006). Although males may be more likely to initiate kea strike behaviour, this does not exclude the possibility that females may subsequently join in this behaviour. Although I did not examine social effects in this study, social facilitation is an important aspect of kea sociality, especially in object related behaviours (Diamond & Bond, 1999). I found in my previous study (Reid, 2008) that social context has been shown to influence behaviour towards novel objects, and this may also extend to novelties such as sheep in the high country.

Although I was not able to examine age in my analyses, it should be noted that the majority (80%) of solvers in the mechanical sheep analogue task were juveniles, as were all of the kea that advanced beyond level 1 of the MAB task. This is consistent with Johnston (1999)'s study of problem solving in wild kea, where five of seven (71%) successful problem solvers were juveniles, and the remainder were adults. Gajdon et al. (2004) found that in another problem solving test of wild kea, only three males (a fledgling, juvenile and young adult) of at least 15 kea solved the task. This is in contrast with Gajdon et al. (2006)'s findings, where only older (sub-adult and adult) males were able to solve the task. These varying results suggest that the role of age in kea's problem solving performance may be context dependent, and could be due to a number of factors such as complexity of the tasks, or motivational states. The process of opening a hinged rubbish bin lid is challenging for kea, involving a series of difficult movements that must be performed with coordination in a set order (Gajdon et al. 2006). The difficulty of this process is highlighted by the fact that only 14% of subjects in Gajdon et al. (2006)'s study successfully opened the bins, and that they had only a 9% success rate. The results of the MAB task in my study may also point to context dependence in problem solving performance: one kea (Matu, a sub-adult male) was successful in the mechanical sheep analogue task, but did not pass level 1 of the MAB task. Also, only two kea passed the second level of the MAB task, and only one of those kea (Wadda) discovered a third technique (using the marble) for solving it (Table 5.2). This success ratio (i.e. one bird, or 20% of subjects, discovering a third technique) is similar to that of Gajdon et al.'s (2006) study (14% of subjects), again providing evidence for inter-individual differences in behavioural traits within kea populations. Innovative propensity has been shown to be context dependent in other avian species (Bókony et al. 2014; Loepelt et al. 2016; Morand-Ferron et al. 2011; Sol et al. 2012). Motivation, a factor that has been shown to influence innovative propensity (e.g. Sol et al. 2012), may also have been involved in the differences between my study and Gajdon et al.'s (2006): bin opening was studied in winter, when kea nest and food is scarce, whereas my study was done in summer, when food is more plentiful and most nestling kea have fledged (Elliott & Kemp, 1999; Greer et al. 2015). Although not mentioned in their paper, during Gajdon et al. (2006)'s study one subject – a breeding adult male – was tracked via VHF radio telemetry directly back to his nesting territory after a foraging session at the bins in the study site (C. Reid, personal observation). Food scarcity and nest provisioning may also play a role in kea strike. The scarcity of natural food in winter may be a local trigger for kea strike as a foraging innovation, as has been suggested for other taxa such as primates (Reader & Laland, 2001). One farmer who reported on kea that he had shot and dissected on his station over several years found that in summer they had berries in their crops and good levels of subcutaneous body fat, whereas in winter they had no detectable body fat and no fruit in their crops, but sometimes had strands of wool (Aspinall, 1990). If food scarcity and nest provisioning are a driver for kea strike, this may explain consistent observations (both historical and recent) that the problem individuals involved in kea strike tend to be older birds (e.g. Aspinall, 1990; Campbell, 1976; Marriner, 1908), and that attacks are also reported to be the worst in winter (Aspinall, 1972; Marriner, 1908). The scarcity of natural food has been linked to conflict behaviour in a variety of species, such as grizzly bears (*Ursus arctos horribilis*) (Artelle et al. 2016), snow leopards (*Panthera uncia*) (Bagchi & Mishra, 2005) and primates (Hockings et al. 2009; Siex & Struhsaker, 1999; Strum, 1994).

The results of this study highlight how behavioural traits that often promote survival – innovativeness and exploration – may incur a cost to kea where their habitats overlap with those of humans. In anthropogenically altered environments innovative, exploratory kea may face an increased risk of mortality via exposure to toxins such as lead (Pb), entrapment, and lethal control as a result of conflict. One of the subjects in this study (Matu, a sub-adult male) that was successful in the mechanical sheep analogue task died during the same season in an incident unrelated to this study, likely as a result of vehicle strike (C. Reid, personal observation). Vehicle strike is an occurrence not uncommon at the Otira Viaduct, where people congregate and often feed kea (T. Orr-Walker, Kea Conservation Trust, personal communication, 2015; C. Reid, personal observation). Similarly, an adult male that was a subject in Gajdon et al.'s (2006) bin-opening study was subsequently killed in a predator trap (Reid, 2008). The potentially heightened risk of mortality that innovative, exploratory kea face may also spread via social facilitation to individuals with other personality types. In my previous study (Reid, 2008), social context was found to influence kea behaviour towards novel objects, and I posited that less exploratory kea were exposed to lead (Pb) via social facilitation, which plays a role in object-related behaviours in kea (Diamond & Bond, 1999). The importance of maintaining a range of personality types is important from a wildlife conservation perspective. Because environmental change from anthropogenic influences is expected to be a key factor in determining the future of many species, a primary issue in conservation biology is their adaptability and the various personality types that determine an individual's ability to survive (Dall et al. 2004). If the majority of individuals in a species are not the appropriate behavioural type for coping with an environmental change – including anthropogenic change – the species can still persist if it has large inter-individual variation in behaviour, so that at least some individuals respond appropriately (Bolnick et al. 2003; Sih et al. 2004). In the case of kea, if the individuals with personality types that promote survival in contexts outside of human-wildlife conflict – such as evading nest predators or finding food resources – are being removed by lethal control and other human-wildlife conflict-related mortality events, this may have an unforeseen impact on kea survivability at the local population or species level. The removal of these individuals in an already threatened species may skew the ratio of personality types in such a way as to reduce the adaptability of local populations, which in turn could impact on the species overall. In this light, lethal control of kea that engage in kea strike or other behaviours that result in conflict with humans should not be considered in isolation. If innovative, exploratory kea are at higher risk of mortality overall, lethal control risks removing individuals that the species cannot afford to lose. The very traits that have enabled kea to survive through myriad natural and anthropogenic environmental impacts, such as habitat destruction and the introduction of mammalian predators and competitors (see chapter 2), may no longer be enough to ensure their survival in the face of numerous current and future threats. The ranges of some predator species such as possums continue to expand (Cowan, 2005), and as human populations continue to increase, so too do their impacts – climate change and biodiversity loss being perhaps chief among them.

Conclusions

My results indicate that exploration tendency, social rank and sex are related to innovative problem solving performance in kea. Although neophobia did not appear to directly influence problem solving, it may interact with other factors such as exploration tendency to influence problem solving in this species. The results of both the mechanical sheep analogue and MAB tasks are consistent with previous studies of problem solving in wild kea showing that some individuals exhibit better problem solving performance than others. My findings, when considered alongside those of other studies in wild kea, lend support to the idea that ‘problem’ kea exist in the context of human-kea conflict, and that innovative, exploratory kea may be the most likely to initiate kea strike. I recommend that the removal of these individuals from the population via lethal control should be considered in light of the role that they may play in the survivability of this endangered species.

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Chapter 6

General Discussion

The central aim of this thesis was to document the conflict between high country sheep farmers and kea (*Nestor notabilis*). The work presented here represents the first scientific attempt since Marriner and Benham's work (Benham 1906; Marriner 1906, 1907, 1908) in the early 20th century to document this conflict. Chapter 2 outlined the historical literature about the conflict, providing context for the current state of the conflict and reporting that an estimated 116,869 kea were killed for bounty during the period of open persecution of kea (1868 to 1970), although this likely underrepresents the number of kea actually culled. The impact of the conflict on the kea population is estimated to have been unsustainable and contributed substantially to their extinction risk (Elliott & Kemp, 2004). Data on historical impacts on endangered populations is useful in performing population analyses and modelling (e.g. Dussex et al. 2015; Elliott & Kemp, 2004), and detailed reporting of historical data can therefore contribute towards these analyses and help to inform conservation management decisions. Chapter 3 reported the first formal characterisation of wounds in sheep attributed to kea attacks (kea strike), and the prevalence of wounds on high country sheep stations in an area with a history of kea strike. The results demonstrated that the majority of wounds (80%) are in the loin (lumbar) region, and the prevalence on the stations in this study was low (0–1.25%), which was consistent with what the farmers reported for these stations. However, it should be noted that in some years and some stations the prevalence reported by farmers can be higher, which is consistent with reports in the historical literature (e.g. Marriner, 1908), and that this can cause considerable economic costs for some farmers, and welfare costs for the attacked sheep. The logistic regression analyses to identify risk factors for the presence of wounds that were attributed to kea strike on these stations highlighted certain classes in the categories of location (two particular stations, 4 and 5), breed (Perendale), sheep class (rams), and age (>1 year). However, given the small number of stations and the opportunistic nature of this study, it is recommended that the results of these logistic regression models should be further validated. Chapter 4 reported on the results of an anonymous online survey of high country sheep farmers. Although the sample size was low (n = 16; representing ~7.4% of South Island high country sheep stations), the results of this study present a limited but valuable insight into the range of high country farmers' experiences and perceptions of kea strike and its associated human-kea conflict. The results presented in chapter 5 indicate that individual kea differ in innovative problem solving performance, and that exploration tendency and social rank are linked with innovative problem solving performance in kea. These results build on and are supported by previous work in wild kea (Gajdon et al. 2006; Reid, 2008). I propose that high ranking males that are innovative and exploratory may be responsible for initiating kea strike. The response of the kea that solved the mechanical sheep analogue task demonstrated exploratory behaviours that may be associated with the development of kea strike behaviour. Once these kea discovered the food reward, they consistently displayed foraging behaviour that may cause the kea strike wounds in live sheep characterised in chapter 3.

The findings presented in this thesis provide data that can be used to inform kea conservation policy. The continued use of lethal control as a kea strike mitigation tool should be considered in the wider context of overall anthropogenic impacts on kea and their current endangered status. Although the use of lethal control as a mitigation tool for kea strike may initially appear to have an insignificant impact by removing only a few problem individuals from the population, this may not be the case for kea. Kea are long-lived and slow to reproduce, leading to slow recovery from even small mortality events (Diamond & Bond, 1999; Spurr, 1979). Lethal control may skew the ratio of personality types in local populations by removing highly exploratory and innovative problem solvers, affecting the adaptability of populations in an environment that has already been considerably altered by human activities. It may cause local extinctions, declines or population suppression, and the effects of such control can be magnified by social factors, affecting group dynamics and consequently group function and survival (Woodroffe et al. 2005). During the bounty period, Marriner (1908) noted that in some districts, where kea were once to be seen in large flocks, the persecution had already greatly reduced their numbers. Outcomes of human-wildlife conflicts may also extend beyond populations to the ecosystem level – many ‘conflict’ species are also keystone species whose removal affects the structure of whole ecosystems, causing trophic cascades (Woodroffe et al. 2005). Kea have been identified as an important seed disperser of alpine species, which may depend largely on kea for long distance dispersal, and therefore kea play a role in maintaining vital ecosystem processes (Young et al. 2012). The continued decline in the kea population therefore has potential ramifications at the ecosystem level.

Just as the impact of lethal control and other causes of mortality arising from human-kea conflict should not be considered in isolation, but rather alongside the cumulative effects of the range of other anthropogenic threats to kea, decisions regarding kea conservation can no longer be made by the Crown alone. The nature of the relationship between Māori and the Crown, including the Department of Conservation/Te Papa Atawhai, is that of a partnership as recognised by The Treaty of Waitangi/Te Tiriti o

Waitangi (Ministry of Justice, 2011; Waitangi Tribunal, 2011). As kea are taonga (treasures) to Ngāi Tahu, and because Māori retain tino rangatiratanga (full authority) over their taonga (Department of Conservation, 2006; Waitangi Tribunal, 2011), future conservation decisions regarding kea, including human-kea conflict, will need to be reached via this partnership, marking a considerable departure from the decision-making processes of government agencies during the kea bounty period.

Relevance to other human-wildlife conflict scenarios

This study is, to the best of my knowledge, the first to scientifically document the occurrence of human-wildlife conflict involving predation of livestock by a parrot species. On a broader scale, it fits within the study of human-avian conflict, specifically human-parrot conflict (e.g. conflict stemming from crop-raiding and property damage by parrots), human-corvid and human-raptor conflict (e.g. corvid and raptor attacks on livestock). Importantly, the results of this study contribute to the growing body of work on human-wildlife conflict involving endangered species. The bounty data presented in chapter 2 contribute to the literature on the scale of historical bounties and harvests, and their potential impacts on wildlife populations. The results of the kea strike injury prevalence study (chapter 3) and the behavioural study (chapter 5) demonstrate how documenting a human-wildlife conflict scenario can serve to verify anecdotal information where there is a gap in scientific data. These chapters also emphasise that compromise may be the best approach to such scenarios that involve endangered species – i.e. employing effective mitigation techniques other than lethal control. The results of the farmer survey (chapter 4) demonstrate how engaging with stakeholders can provide information on the extent of human-wildlife conflict scenarios, and techniques useful for mitigation. The low response rate to the survey also lends support the assertion that stakeholders may be reluctant to engage in sensitive topics related to human-wildlife conflict, such as lethal control, and highlights the need for careful study design to address potential biases stemming from this. The survey results may also reflect a shift in stakeholder attitudes towards conservation, which has been detected elsewhere (e.g. Manfredo et al. 2018). As stakeholder attitudes gradually move away from the acceptance of lethal control as a mitigation tactic, the adoption of non-lethal techniques that fit in with routine management practices (e.g. farming/husbandry techniques) may be ideal, especially in scenarios involving endangered species. The recommendations regarding human-wildlife conflict mitigation in the context of this study (see below) may also prove to be useful in addressing similar conflicts elsewhere (e.g., corvid and raptor predation of livestock, as well as other instances of farmer/wildlife conflict). The results of my kea strike behaviour study (chapter five) make an important contribution to the fledgling field of animal personality in the context of human-wildlife conflict, especially the study of problem individuals. The investigation of wildlife behaviours that underpin human-wildlife conflict may prove to be important in gauging potential impacts of mitigation practices (e.g. lethal control), especially on threatened wildlife species.

Recommendations for mitigating kea strike

Based on the results of the farmer survey (chapter 4), my discussions with farmers visited as part of my kea strike injury prevalence study (chapter 3), and the kea strike literature, the following practices have been found to be useful in mitigating kea strike:

(i) Employing a Clostridium vaccination programme to reduce sheep losses from infections stemming from kea strike injuries

(ii) Regularly monitoring sheep in areas that kea are known to visit and moving sheep as soon as kea strike is detected, preferably to a safer part of the station

(iii) Employing rotational grazing instead of set-stocking

(iv) Avoiding use of high altitude pasture (i.e. 'the tops'), and known kea strike 'hot spots'

(v) Keeping sheep below ~700m a.s.l. where possible, especially in winter

(vi) Changing sheep breeds (e.g. crossbreeding Merinos with other breeds)

(vii) Approaching the Department of Conservation (DOC) for advice and assistance

(viii) Changing the timing of shearing

Future directions

This study examined prevalence of suspected kea strike wounds on five high country stations in the Whakatipu area and reported a low prevalence. Future studies investigating the current extent of kea strike could add to this preliminary data by examining the prevalence of wounds on affected stations in other districts. It is recommended that any future research in this area should be designed as a case control study, given the low prevalence of wounds I attributed to kea strike (both at the station and at the individual animal level). Also, the sample size of the farmer survey conducted for this study was small, and any future studies should attempt to survey a larger proportion of the high country sheep farming community, perhaps via a mixed-methods approach including direct interviews.

For in-situ studies of kea strike and other human-kea conflict scenarios, the use of satellite telemetry may prove to be a valuable tool. Such a spatio-temporal approach has already been demonstrated as a useful technique for collecting data on the movements and behaviours of individual kea (Kennedy et al. 2015). This method has been recommended as a tool in addressing cases of ongoing human-kea conflict by identifying potential spatial 'hot-spots' of conflict, specific time periods during which conflicts are most likely to occur, population sub-groups that are more vulnerable to conflict, the potential influence of human activity on animal behaviour, and the effect of human-induced mortality on long-term population dynamics (Kennedy, 2017). This method could prove to be especially useful in the context of farmer-kea conflict, given the size of high country stations and their remote and difficult terrain.

Kea behaviour was only one part of this study, and future studies of kea behaviour in contexts of human-kea conflict would benefit from larger sample sizes, preferably attained over multiple field seasons, which would enable the use of an information theoretic approach (e.g. Benson-Amram & Holekamp, 2012; Greenberg & Holekamp, 2017; Loepelt et al. 2016). Including a larger sample of females and older (i.e. sub-adult and adult) individuals will also enable a closer analysis of the interactions of sex with behaviours of interest, and the analysis of how age interplays with these as well. Other behavioural measures of interest include risk-taking (boldness) and persistence, which have been linked to innovative problem solving in other species (e.g. Benson-Amram & Holekamp, 2012; Greenberg & Holekamp, 2017). Play and social facilitation are also behaviours of interest in terms of conflict. It has been suggested by some farmers that I interviewed as part of my prevalence study (chapter 3), for example, that play behaviour may be a precursor to kea strike. In a previous study, I also posited that social facilitation may be a contributor towards factors such as lead (Pb) exposure in kea (Reid, 2008), and I also propose that it may influence conflict-related behaviours such as kea strike. Comparing kea populations at different sites and examining kea behaviour in more remote areas, as well as using a variety of problem solving tasks would also allow investigation of behavioural consistency across contexts.

Concluding remarks

Documenting human-wildlife conflict is key to understanding the underlying causes and building appropriate mitigation strategies. My research indicates that farmer-kea conflict likely had a marked historical impact on the kea population, and although kea are now legally protected, this conflict continues to have an impact on kea, high country sheep farmers and their stock. Although the severity of the problem appears to have diminished since historical times as a consequence of kea population decline and changes to farming management, and kea strike now generally occurs at a low prevalence, it is still a welfare issue for sheep and can impose an economic burden on farmers. Although farmer perspectives of kea have changed over the years, lethal control can still be legally used as a mitigation tool. But the culling of even a limited number of kea should be considered in light of the host of other anthropogenic pressures on this endangered and rapidly declining species. My research demonstrates that, just as farmers have suspected for years, a few ‘problem’ individuals are likely responsible for initiating kea strike – i.e. socially high ranking males that are both innovative and exploratory. The impact of removing these individuals from local populations could have far-reaching impacts for this species, and mitigation strategies for kea strike should be considered carefully with this in mind.

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Appendix 1: Online survey of high country sheep farmers in the South Island of New Zealand

I'm asking for your help in a study of sheep and kea that I'm conducting as part of my PhD through the Institute of Veterinary, Animal and Biomedical Sciences (IVABS) at Massey University. Its purpose is to find out the extent of kea strike – incidents where kea attack sheep – on high country sheep stations. The information from this survey will be used to help high country sheep farmers reduce harm to sheep caused by kea.

This survey is anonymous and the information from individual surveys will be seen only by myself (Clio Reid). The overall results from this survey will later be made available to South Island high country sheep farmers via the regional Merino organisations. The results will also be made available to conservation managers and published in a scientific journal. If you would like to discuss this matter personally I can be contacted by email at clio.reid.1@uni.massey.ac.nz.

I really appreciate your help in filling out this survey. I need completed surveys from as many South Island high country sheep farmers as possible to get the most accurate idea of the current kea strike situation. So even if you do not see kea on your station, or they are present but do not cause problems on your station, it is very important to complete this survey.

Thank you for taking the time to participate in this survey. The survey contains 23 questions and should take about 10 to 15 minutes to complete.

This project has been reviewed and approved by the Massey University Human Ethics Committee: Southern A Application 14/82. If you have any concerns about the conduct of this research, please contact Dr Brian Finch, Chair, Massey University Human Ethics Committee: Southern A, telephone 06 350 5799 x 84459, email humanethicsoutha@massey.ac.nz.

Q1 In which district is your station located?

- ○ Nelson/Marlborough (1)
- ○ West Coast (2)
- ○ Canterbury (3)
- ○ Otago (4)
- ○ Southland (5)

Q2 How many years have you been on your station?

____

Q3 What is the size of your station in hectares?

____

Q4 How many hectares of land on your station would you classify as high country (more than 700 metres above sea level)?

____

Q5 How many sheep do you have on your station in winter?

____

Q6 What breeds do you have on your station? Please enter the number of sheep of each breed you have on your station.

- ○ Merino (1) ____
- ○ Merino crossbred (2) ____
- ○ New Zealand Halfbred (3) ____
- ○ Corriedale (4) ____
- ○ Perendale (5) ____
- ○ Other (6) ____

Display This Question:

If What breeds do you have on your station? Please enter the number of sheep of each breed you have... Is Not Empty

Q6a If “Other” was selected for the previous question, please specify which breed(s).

____

Q7 What is the composition of your flock (i.e., how many ewes, wethers, etc.)?

- ○ Ewes (1) ____
- ○ Wethers (2) ____
- ○ Hoggets (3) ____
- ○ Rams (4) ____

Q8 How often do you see kea on your station?

- ○ Frequently (daily; weekly; at least once every 3 months) (1)
- ○ Occasionally (about once or twice a year) (2)
- ○ Rarely (about once every few years) (3)
- ○ Never (4)

Q9 Have you seen kea scavenging sheep carcasses on your station?

- ○ Yes (1)
- ○ No (2)

Q10 Please choose one statement that best describes your view of kea's capacity to attack sheep.

- ○ All kea would attack sheep if given the chance (1)
- ○ Only some kea would attack sheep if given the chance (2)
- ○ No kea attack sheep (3)
- ○ Don't know (4)

Q11 Which of the following statements best describes the rate of kea attacks on sheep on your station?

- ○ It has happened, but not within the past 10 years (1)
- ○ It happens about once every 5–10 years (2)
- ○ It happens about once every 2–5 years (3)
- ○ It happens every year (4)
- ○ It has not happened on my station (5)
- ○ Don't know (6)

Skip To: Q22 If Q11= It has not happened on my station (5)

Skip To: Q22 If Q11 = Don't know (6)

Q12 What signs of attack by kea (a.k.a. "kea strike") have you seen in your flock?

- ▢ Wool flagging (tufts of wool pulled up above the lie of the fleece) (1)
- ▢ Survivable injuries (e.g. live sheep with wounds that heal) (2)
- ▢ Fatal injuries (e.g. live sheep with severe wounds that don't heal) (3)
- ▢ Kea attacking live sheep (i.e., you have witnessed kea attacking your sheep) (4)
- ▢ Dead sheep with signs of kea strike (5)
- ▢ Kea wounds seen at shearing time (6)

Q13 In the years that you have encountered kea strike on your station, what was the estimated yearly average number of sheep killed by kea strike?

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Q14 In the years that you have encountered kea strike on your station, what was the estimated yearly average number of sheep affected, but not killed, by kea strike? (Signs of kea strike include wool flagging and injuries.)

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Q15 In the years that you have encountered kea strike on your station, what were the estimated yearly average annual financial losses in NZ$ due to kea strike on your station?

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Q16 Are some classes of sheep (e.g., ewes, wethers, etc.) more prone to kea strike than others?

- ○ Yes (1)
- ○ No (2)
- ○ Don't know (3)

Q17 Please indicate how susceptible each group is to kea strike by ticking the appropriate box for each group.

	Highly susceptible (1)	Moderately susceptible (2)	Not at all susceptible (3)
Ewes (1)	○	○	○
Wethers (2)	○	○	○
Hoggets (3)	○	○	○
Rams (4)	○	○	○
Lambs (5)	○	○	○

Q18 If you have or had different sheep breeds on your station, are some of them more prone to kea strike than others?

- ○ Yes (1)
- ○ No (2)
- ○ Don't Know (3)

Q19 Please indicate how susceptible each breed is to kea strike by ticking the appropriate box for each breed that you have had on your station. Please tick the box for NA ("not applicable") for any breeds below that you have not had on your station.

	Highly susceptible (1)	Moderately susceptible (2)	Not at all susceptible (3)	NA (4)
Merino purebred (1)	○	○	○	○
Merino crossbred (2)	○	○	○	○
New Zealand Halfbred (3)	○	○	○	○
Corriedale (4)	○	○	○	○
Perendale (5)	○	○	○	○
Other breed (please specify) (6)	○	○	○	○

Q20 Are there practices that you have adopted on your station that have helped to reduce kea strike and/or mortality from kea strike, even if the original purpose of adopting that practice was not related to kea strike? Please rank the effectiveness of the practices you have used by ticking the appropriate box. Please tick the box for NA ("not applicable") for the practices that you have not used.

	Very effective (1)	Moderately effective (2)	Not at all effective (3)	NA (4)
No longer using areas where kea strike has occurred (1)	○	○	○	○
In winter, keeping sheep where they are less likely to be attacked by kea (e.g., below 700 m above sea level) (2)	○	○	○	○
Moving stock around regularly, especially in winter (3)	○	○	○	○
No longer stocking the tops (i.e., the highest elevation pastures) (4)	○	○	○	○
Changing the timing of shearing (i.e., shearing earlier or later than previously) (5)	○	○	○	○
Changing breed of sheep (this includes crossing merino with other breeds) (6)	○	○	○	○
Approaching the Dept. of Conservation (DOC) for advice and/or assistance (7)	○	○	○	○
Approaching other farmers or organisations for advice and/or assistance (8)	○	○	○	○
Vaccinating against blood poisoning (i.e., annual application of 5-in-1 *Clostridium* vaccine) (9)	○	○	○	○
Other (please specify) (10)	○	○	○	○

Q21 If you have approached DOC, other organisations, and/or other farmers for advice and/or assistance, what advice did you receive?

____
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____
____
____

Q22 Do you think that shooting and/or poisoning problem kea is an effective technique to stop or reduce kea strike?

- ○ Yes (1)
- ○ No (2)
- ○ Don't know (3)

Q23 If you have any comments about kea on high country sheep stations, please write them in the space provided below.

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Appendix 2: Object-related exploratory behaviours in kea (*Nestor notabilis*)

Table A.1 Object-related exploratory behaviours observed during novel object trials with free-ranging kea (*Nestor notabilis*) at Arthur's Pass, New Zealand. These behavioural classifications were based on my observations and the literature (Diamond & Bond, 1991; Gajdon & Voelkl, 2002; Johnston, 1999; Keller, 1974, 1975; Potts, 1969; Reid, 2008). (See below for full references.)

Behaviour	Description
Carry	Once grasped in the bill and lifted, an object is transported by the bird, typically by carrying it in the bill while the bird runs or walks.
Chew	An object is held in the bill and repeatedly pressed between the maxilla and mandible.
Flick	With an object grasped in the bill, a kea jerks its head vertically so that part of the object is lifted into the air, but the object does not break contact with the ground as in Toss. The kea may do this repeatedly, and be stationary or moving.
Hold Down with Foot	An object is held against the substrate with a foot while the bird manipulates it with the bill.
Grasps with Bill	An object is held without manipulation between the maxilla and mandible while the animal is stationary.
Grasps with Foot	An object is grasped with a foot and held while being manipulated with the bill.
Lever	The tip of the maxilla is inserted into a hole or crevice, then pulled and twisted. The force is exerted mainly with the head and neck. The tip of the mandible may be used as a fulcrum, or the bird may pry against the curved upper surface of the maxilla or twist the maxilla laterally.
Lick	An object is repeatedly touched with the tongue as it is grasped with the bill. As opposed to Nibbling, the maxilla and mandible are not moved.
Lifts with Bill	An object, having been grasped with the bill, is lifted until it is no longer in contact with the substrate.
Lifts with Foot	An object, having been grasped with the foot, is lifted until it is no longer in contact with the substrate.
Lying on Back with Object	The bird rolls onto its back or side with wings closed and feet extended, sometimes making wrestling movements. Its head is oriented towards the object.
Nibble	A forceps-like movement of the bill, opposing tips of the mandible and maxilla, often accompanied by in-and-out movements of the tongue.
Probe	The maxilla is inserted vertically into any crevices or grooves in an object and may also be dragged along a groove.

Appendix 2 Continued

Behaviour	Description
Probe Under	The bill is inserted laterally between the substrate and the object.
Pull with Bill	Once grasped in the bill, the object is pulled towards the body.
Pull with Foot	Once grasped with the foot, the object is pulled towards the body.
Pushes with Bill	The maxilla is pressed against an object, causing the object to move.
Pushes with Foot	The foot is pressed against an object, causing the object to move.
Scrape	An object is held in position with the maxilla while the mandible is scraped over the surface of the object.
Scratch with Bill	The tip of the maxilla is moved over the surface of an object.
Shake	Once the bill has been inserted in the object, it is shaken in situ via a rapid back-and-forth motion of the head and bill towards the body.
Stand on Object	Both feet are placed on the object, stable or otherwise, and the bird maintains its balance for at least a few seconds.
Toss	While an object is held in the bill, the head is jerked vertically or laterally and the object is released, causing it to be tossed into the air.
Touch with Bill	A stationary object on the ground is briefly touched with the tip of the maxilla.
Wrestle with Object	Once grasped with the bill, the bird pulls vigorously at the object in a repeated back-and-forth or side-to-side motion. The object moves but remains in contact with the ground.

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