Ship rat, stoat and possum control on mainland New Zealand

An overview of techniques, successes and challenges

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Abstract

Ship rats (*Rattus rattus*), stoats (*Mustela erminea*) and possums (*Trichosurus vulpecula*) are the most significant predators in the mainland forests of New Zealand. These mammals were first introduced to New Zealand in the 1800s and have had a large impact on our native fauna ever since, being implicated in the extinction of at least nine bird species. Over the past 30 years, attempts have been made to control these pests both on offshore islands and, more ambitiously, on the mainland, with varying success. In this report, we provide an overview of mainland control efforts. First, we assess the historic and current impacts of these three species on native wildlife in New Zealand. We then discuss the types of control that are currently available and consider under which circumstances each is of most use. We then consider what pest control has achieved to date, both in terms of reducing the abundance of pest species and increasing the abundance of our native fauna. Finally, we discuss what we have learned from pest control efforts to date and use this information to formulate some recommendations for future research and management in this field. It is hoped that by collating this information, we will provide pest control managers and practitioners with better insight into ways to improve and optimise control efforts in the future.

Keywords: ship rat, *Rattus rattus*, stoat, *Mustela erminea*, possum, *Trichosurus vulpecula*, pest control, adaptive management, ground control, aerial 1080

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1. Introduction

New Zealand is home to plant and animal species that are not found anywhere else in the world. These species evolved in the absence of mammalian predators. Consequently, the introduction of mammals, including ship rats (*Rattus rattus*), stoats (*Mustela erminea*) and possums (*Trichosurus vulpecula*), to New Zealand has resulted in declines and extinctions of native species (Brown et al. 2015).

Fifty-eight species of birds have become extinct since humans first arrived in the New Zealand bio-geographic region (including Norfolk and Macquarie Islands) 800 years ago (Tennyson & Martinson 2006). In total, 32 species of mammals have been introduced since then (Wodzicki & Wright 1984), of which ship rats, stoats and possums are the most significant predators in the mainland forests of New Zealand (Innes et al. 2010). Tennyson & Martinson (2006) implicated these three species in the extinction of at least nine New Zealand bird species and it is now clear that unless they are effectively controlled, many more native species will continue to decline to extinction (Elliott et al. 2010; Innes et al. 2010; Barnett 2011).

The importance and feasibility of controlling introduced predators has been the subject of debate among New Zealand ecologists. King (1984, p. 190) voiced the widely held view that '… the processes of nature are repopulating New Zealand with birds that are able to live with predators, while the rest are either adapting or have already gone'. However, Innes & Hay (1990, p. 2528) concluded that '… at least twelve endemic forest bird species or subspecies have yet neither adapted nor gone, but are declining'; and more recently, Innes et al. (2010, p. 86) concluded that 'predation by introduced pest mammals continues to be responsible for current declines and limitation of New Zealand forest birds'.

The effectiveness of predator control methods has improved dramatically over the last three decades (Innes et al. 1999; Saunders & Norton 2001; Greene et al. 2012; O'Donnell & Hoare 2012). The Department of Conservation (DOC), TBfree New Zealand (formerly the Animal Health Board), Landcare Research, local authorities and, more recently, community groups have all invested large amounts of money and time on predator management and research (Parkes & Murphy 2003), as a result of which there are many success stories. For example, in 2008 the threat status of the North Island kōkako (*Callaeas wilsoni*) was downgraded from 'Nationally Endangered' to 'Nationally Vulnerable' (Miskelly et al. 2008) as a result of a predator control regime that was developed via adaptive management (Innes et al. 1999). However, Green & Clarkson's (2005) review of the New Zealand Biodiversity Strategy (DOC & MfE 2000) showed that although the effectiveness of biodiversity management has improved, New Zealand native species are continuing to decline, with introduced predators being the main cause.

This report provides an overview of the historic and current impacts of mammalian pests on our native fauna, outlines pest control techniques, and assesses what is and is not working. This information was compiled from published and unpublished literature, as well as the authors' own data and observations. This overview covers the impacts and control of mammalian predators in forests of the New Zealand mainland (which includes the North and South Islands, and Stewart Island/Rakiura) that have challenges different from island eradications due to ongoing predator reinvasion. It specifically focuses on ship rats, stoats and possums because these three species currently pose the greatest threat to our native wildlife in mainland forests (Innes et al. 2010), and are known to have caused the extinction of native animal species, currently suppress native animal populations and will cause further extinctions if not controlled. It should be noted, however, that cats (*Felis catus*) and ferrets (*Mustela putorius* furo) can also be important predators in forests.

We hope that the information provided will help to improve the control of ship rats, stoats and possums on the New Zealand mainland, and will stimulate further management, applied research and development to increase the protection of New Zealand's biodiversity. Improvements in control of these three predators will make a significant conservation difference.

2. Why do mammalian predators need to be controlled?

Ship rats, stoats and possums were introduced to New Zealand (stoats and possums intentionally) in the 1800s, with little understanding of the immense impact that they would have on our native fauna. In this section, we begin by outlining the historic impacts that these species had when first introduced and then discuss their ongoing impacts, despite the numerous attempts to control them. We then consider the relative threat of these three species to native wildlife.

2.1 Historic impacts

2.1.1 Ship rats

Ship rats probably travelled to New Zealand on board European ships in the 1800s; they then spread through the North Island sometime after 1860 and through the South Island after 1890 (Atkinson 1973). Historically, ship rats, Norway rats (*Rattus norvegicus*) and kiore (*Rattus exulans*) were all important predators of native wildlife; however, ship rats are currently by far the most widespread, common and significant of these three species of rat. They are also agile climbers and are ubiquitous in forests on mainland New Zealand, where they can reach plague numbers following beech (*Lophozonia* spp.)and rimu (*Dacrydium cupressinum*) mast events (Harper 2005; Innes 2005). As arboreal and omnivorous predators, ship rats prey on the eggs, nestlings and adults of native birds, as well as lizards, bats, frogs and land snails.

The literature on the impacts of rats on island biodiversity is both extensive and damning (Atkinson 1985, 1989, 1996; Towns et al. 2006; Gibbs 2009; Towns 2009). The spread of ship rats through the North Island was 'more or less coincidental with declines of the bellbird [*Anthornis melanura*], robin [*Petroica australis*], stitchbird (*Notiomystis cincta*), saddleback [*Philesturnus carunculatus*] and [native] thrush (*Turnagra capensis*)' (Atkinson 1973 p. 468); and, during the 1890s and early 1900s, declines in all of these species[1] were also recorded in the South Island, alongside reductions in populations of mohua (*Mohoua ochrocephala*), South Island kōkako (*Callaeas cinerea*), and red- and yellow-crowned parakeets (*Cyanoramphus novaezealandiae* and *C. auriceps*).

In more recent times, several bird species have been driven to extinction largely due to predation by ship rats. For example, Tennyson & Martinson (2006) identified predation by ship rats as one of the primary causes of extinction of the bush wren (*Xenicus longipes*), Chatham Island bellbird (*Anthornis melanocephala*), huia (*Heteralocha acutirostris*), laughing owl (*Sceloglaux albifacies*), New Zealand little bitten (*Ixobrychus novaezelandiae*), North Island and South Island piopio/thrush (*Turnagra tanagra* and *T. capensis*, respectively), South Island kōkako and South Island snipe (*Coenocorypha iredalei*) (Table 1). Harper (2009) also suggested that ship rats and possums were responsible for the local extinction of brown teal (*Anas aucklandica*), rifleman (*Acanthisitta chloris*), mohua, South Island kōkako, New Zealand falcon (*Falco novaeseelandiae*), Stewart Island weka (*Gallirallus australis*) and, probably, yellow-crowned parakeet, and for the local decline of kererū (*Hemiphaga novaeseelandiae*), kākā (*Nestor meridionalis*), kākāpō (*Strigops habroptilus*) and Stewart Island robin (*Petroica australis rakiura*) on Stewart Island/Rakiura—although cats are also known predators of birds, particularly kākāpō (Powlesland et al. 1995).

The impact of ship rats on native fauna was graphically illustrated by their arrival on Taukihepa/Big South Cape Island near Stewart Island/Rakiura in 1962 (Bell 1978). Rather prophetically, Herbert Guthrie-Smith wrote in 1936 that although the South Island snipe was safe on Big South

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[1] With the exception of the stitchbird, which was only recorded in the North Island.

Table 1. Extinctions of native forest birds that were likely contributed to by ship rat, stoat and possum predation (adapted from Tennyson & Martinson 2006).

BIRD SPECIES		ESTIMATED EXTINCTION DATE	PREDATOR(S)
COMMON NAME	SCIENTIFIC NAME		
Bush wren	*Xenicus longipes*	1972	Ship rats
Chatham Island bellbird	*Anthornis melanocephala*	1906	Ship rats
Huia	*Heteralocha acutirostris*	Mid-1920s	Ship rats and stoats
Laughing owl	*Sceloglaux albifacies*	1914	Ship rats and stoats
New Zealand little bittern	*Ixobrychus novaezelandiae*	1890s	Ship rats and stoats
North Island piopio	*Turnagra tanagra*	1902	Ship rats
South Island kōkako	*Callaeas cinerea cinerea*	1967	Ship rats, stoats and possums
South Island piopio	*Turnagra capensis*	1905	Ship rats and stoats
South Island snipe	*Coenocorypha iredalei*	1964	Ship rats

Cape, '… always hangs overhead the sword of Damocles: should rats obtain a footing, farewell to Snipe, Robin, Bush Wren and Saddleback' (Guthrie-Smith 1936, p. 183). As predicted, within 4 years of the arrival of ship rats on the island, five bird species or subspecies and one bat species became extinct, including Stead's bush wren (*Xenicus longipes variabilis*), South Island snipe and greater short-tailed bat (*Mystacina robusta*). These multiple extinctions following invasion of the island by ship rats is a seminal story that calls New Zealand conservationists to action.

2.1.2 Stoats

Stoats were introduced to New Zealand in 1884 to control rabbits (*Oryctolagus cuniculus*) (King & Murphy 2005), and are now ubiquitous in North and South Island forests and other habitats (Smith et al. 2007). Although stoats do not reach the same densities as ship rats, they are highly mobile with large home ranges (males often > 200 ha and females often > 100 ha) and, unlike ship rats, are obligate predators rather than generalist omnivores (King & Murphy 2005). They are also semi-arboreal and capable of killing prey many times their own weight.

The dramatic reduction in native bird numbers following the introduction and spread of stoats was noted by many early observers, including Guthrie-Smith (Guthrie-Smith 1936), Charles Douglas (Langton 2000), Andreas Reischek (King 1981), Sir Walter Buller (Galbreath 1989) and Richard Henry (Hill & Hill 1987). Tennyson & Martinson (2006) identified stoat predation as one of the primary causes of the extinction of the huia (*Heteralocha acutirostris*), laughing owl (*Sceloglaux albifacies*), New Zealand little bittern (*Ixobrychus novaezelandiae*), South Island kōkako and South Island piopio (Table 1).

It is generally not easy to definitively attribute species extinctions to specific causes, let alone specific predators. Nonetheless, King & Murphy (2005, p. 284) stated that stoats and ship rats certainly contributed 'to the final disappearance of the South Island subspecies of the bush wren (*Xenicus l. longipes*), New Zealand thrush (*Turnagra c. capensis*), laughing owl (*Sceloglaux a. albifacies)*, saddleback (*Philesturnus c. carunculatus*) [on the South Island mainland], and kokako (*Callaeas c. cinerea*), and aided the already advanced decline of the kakapo (*Strigops habroptilus*), South Island takahe (*Porphyrio mantelli hochstetteri*), and little spotted kiwi (*Apteryx owenii*)'.

2.1.3 Possums

Brushtail possums were intentionally introduced to New Zealand to establish a fur trade and were successfully established by 1858 (Cowan 2005). They now occur throughout the main islands, although they have only recently colonised Northland and south western Fiordland. Like ship rats, possums are ubiquitous in forests, are agile climbers and can reach high densities (e.g. 10–12/ha) (Cowan 2005). Although possums are primarily herbivorous, they opportunistically prey on native wildlife (Brown et al. 1993; Innes 1995; Sadleir 2000) and evidence of the impact of such predation on native species has increased dramatically in the last two decades (O'Donnell 1995; Montague 2000). Tennyson & Martinson (2006) suggested that possums possibly contributed to the extinction of South Island kōkako.

2.2 Current impacts

2.2.1 Ship rats

Direct and indirect evidence for the impact of ship rats on native forest animals continues to accumulate, and remote cameras have now confirmed that ship rats are important predators of the adults, chicks and eggs of kōkako (Innes et al. 1996), kererū (Innes et al. 2004), robins (Brown 1997; Moira Pryde, DOC, unpubl. data), mohua (Dilks et al. 2003) and rifleman (G. Elliott, DOC, unpubl. data).

Brown (1997) found that 82% of North Island robin (*Petroica longipes*) and North Island tomtit (*Petroica macrocephala toitoi*) nests were preyed on, and that ship rats were responsible for at least 72% of these events. Nine of 24 North Island robin pairs also lost breeding females, mainly to ship rats, which significantly impacted on population productivity. Similarly, Armstrong et al. (2006) found that the nesting success, fecundity, adult female survival and juvenile survival of North Island robins in the Paengaroa Mainland Island declined as rat tracking rates increased; although 40 robins were reintroduced to Paengaroa in 1999, none of these were found in 2010—likely as a result of rat predation. South Island robin (*Petroica australis*) numbers have also been found to be strongly correlated with rat abundance in the Rotoiti Nature Recovery Project, Nelson Lakes (Harper 2012), and robin numbers have declined dramatically following rat irruptions in the Eglinton Valley (T. Greene, DOC, unpubl. data).

It is also now clear that ship rats pose at least as great a threat to mohua as stoats (O'Donnell et al. 2002). Many mohua populations dramatically declined during a South Island-wide rat irruption in 2000 (O'Donnell et al. 1992; Dilks et al. 2003), and a mohua population on Mt Stokes in the Marlborough Sounds was driven to extinction (Gaze 2001).

Orange-fronted parakeet (*Cyanoramphus malherbi*) declined dramatically following a rat and stoat plague in the South Branch of the Hurunui in 2000 (Elliott & Suggate 2007). During this time, stoat trapping occurred on the valley floor but there was no rat control, suggesting that this decline was largely due to rat predation.

Ship rats also have significant impacts on our native bats, snails and frogs: significant declines in populations of both long-tailed bats (*Chalinolobus tuberculatus*) and lesser short-tailed bats (*Mystacina tuberculata*) in the Eglinton Valley were strongly correlated with irruptions of ship rats (Pryde et al. 2005; O'Donnell et al. 2011); ship rats are significant predators of *Powelliphanta* snails in lowland forests (Walker 2003) and *Placostylus* flax snails in northern coastal forests (Sherley et al. 1998); and native frogs (*Leiopelma* spp.) have been found preyed upon by ship rats in Whareorino Forest (Thurley & Bell 1994; T. Thurley, DOC, unpubl. data).

2.2.2 Stoats

Stoats pose a serious threat to the continued survival of many endangered or threatened native bird species. Remote cameras have identified stoats as significant predators of robin, rifleman, kea (*Nestor notabilis*) and kākā nests (Moorhouse et al. 2003; G. Elliott & J. Kemp, DOC, unpubl. data). For example, J. Kemp (unpubl. data) found that kea nesting success fell from 79% with stoat control to 37% without stoat control in a non-mast year to 3% during stoat plague years; and Wilson et al. (1998) and Moorhouse et al. (2003) showed that predation by stoats on nesting females is primarily responsible for the decline and, in many instances, local extinction of kākā on the New Zealand mainland.

Video monitoring has also confirmed significant stoat predation on the eggs, chicks and/or nesting females of whio (*Hymenolaimus malacorhynchos*) (Whitehead et al. 2007), rock wren (*Xenicus gilviventris*) (J. Monks & C. O'Donnell, DOC, unpubl. data), kākāriki (G. Elliott, DOC, unpubl. data), kōkako (Flux et al. 2006) and bellbird (Kelly et al. 2005).

Stoats also impact on kiwi (*Apteryx* spp.), mohua and takahē (*Porphyrio hochstetteri*) populations: stoats are responsible for approximately half of the deaths of kiwi chicks in the North and South Islands (Holzapfel et al. 2008), and it has been estimated that kiwi populations decline by 2.5% per annum in the absence of predator (particularly stoat) control (Robertson et al. 2011); periodic intense episodes of stoat and rat predation follow beech masts and ongoing stoat predation has led to the decline of mohua across the South Island (Elliott & O'Donnell 1988; Elliott et al. 1996; O'Donnell et al. 1996); and stoat predation is considered a major impediment to the recovery of takahē in the Murchison Mountains (Clout & Craig 1994; Hamilton 2005; Wickes et al. 2009; Hegg et al. 2012, 2013).

2.2.3 Possums

Remote cameras have shown that possums prey on the eggs and chicks of a variety of forest birds (Brown et al. 1993), including kererū (Innes et al. 2004), kōkako (Innes et al. 1999), robins, yellow-crowned kākāriki (G. Elliott, DOC, unpubl. data), tūī (*Prosthemadera novaeseelandiae*) (J. Innes et al., Landcare Research, unpubl. data) and kea (J. Kemp, DOC, unpubl. data). They also prey on kiwi eggs and occasionally kill adult kiwi (Robertson et al. 1999). Possums are particularly damaging to kākā populations, as they not only prey on the eggs and chicks of this species, but also nesting females (Moorhouse et al. 2003; Greene et al. 2004), and have been strongly implicated in the decline of kākā in South Westland (Rose et al. 1990).

In addition, possums are important predators of *Powelliphanta* land snails in upland beech forests (Walker 2003) and have even been seen attempting to catch bats in their roosts (O'Donnell 2000).

2.3 The relative threat of ship rats, stoats and possums to native fauna

Ship rat, stoat and possum impacts differ by native fauna species and life stage. Ship rats and/or stoats generally have the greatest effect, on the widest range of species. However, pest mammal guilds differ greatly in composition and dynamics depending on forest composition, mast events and altitude. For example, lowland mixed broadleaved forests maintain high ship rat numbers while their numbers 'boom and bust' in response to seed mast in beech forests (see, for example, section 6.1.2). Therefore, it is important that we understand which predator is of greatest threat to a particular species in a particular habitat at a particular time so that we know where and when to target our control efforts. Controlling less-important predators may be of little benefit if the main predator remains uncontrolled. Table 2 summarises the main predators of various native New Zealand animal species, the life stages that are vulnerable to predation and key references.

It should be noted that feral cats probably also have a significant negative impact on native forest birds at certain times and places (e.g. Powlesland et al. 2003). For example, on Stewart Island/Rakiura, cats are more common than in most forests of the North and South Islands, and stoats are also absent from Rakiura, which may result in cats having a greater impact on forest birds there than they do elsewhere (Harper 2009). However, cats are probably of much less importance than rats, stoats and possums nationally.

Table 2. Relative threat of ship rats (*Rattus rattus*), stoats (*Mustela erminea*) and possums (*Trichosurus vulpecula*) to native forest animals.

SPECIES		MAIN PREDATOR(S)	ADDITIONAL PREDATOR(S)	LIFE STAGE(S) AT RISK	REFERENCES
COMMON NAME	SCIENTIFIC NAME				
Birds					
Bellbird	*Anthornis melanura*	Ship rats	Stoats*	Eggs and chicks	Kelly et al. 2005; Elliott et al. 2010; Harper 2010
Kākā	*Nestor meridionalis*	Stoats	Possums	Eggs, chicks and incubating females	Moorhouse et al. 2003; Greene et al. 2004; Taylor et al. 2009
Kākāriki	*Cyanoramphus* spp.	Ship rats and stoats	Possums	Eggs, chicks and incubating females	Elliott et al. 1996
Kea	*Nestor notabilis*	Stoats	Possums	Eggs, chicks and incubating females	J. Kemp, DOC, unpubl. data
Kererū	*Hemiphaga novaeseelandiae*	Ship rats	Possums and stoats	Eggs and chicks	Clout et al. 1995; Innes et al. 2004
Kiwi	*Apteryx* spp.	Stoats	Ferrets†	Chicks and adults	McLennan et al. 1996; Robertson & de Monchy 2012
Mohua	*Mohoua ochrocephala*	Ship rats and stoats‡		Eggs, chicks, incubating females and roosting adults	Elliott 1996; O'Donnell et al. 1996; Dilks et al. 2003
North Island kōkako	*Callaeas wilsoni*	Ship rats	Possums and stoats	Eggs, chicks and incubating females	Innes et al. 1999; Flux et al. 2006
Rifleman	*Acanthisitta chloris*	Ship rats and stoats		Eggs, chicks and incubating females	Elliott et al. 2010; G. Elliott, DOC, unpubl. data
Robin	*Petroica* spp.	Ship rats and stoats	Possums	Eggs, chicks and incubating females	Brown 1997; Brown et al. 1998b; Armstrong et al. 2006; G. Elliott, DOC, unpubl. data; M. Pryde, DOC, unpubl. data
Rock wren	*Xenicus gilviventris*	Stoats		Eggs, chicks and incubating females	J. Monks & C. O'Donnell, DOC, unpubl. data
Takahē	*Porphyrio hochstetteri*	Stoats		Eggs, chicks and adults	Wickes et al. 2009; Hegg et al. 2012
Tūī	*Prosthemadera novaeseelandiae*	Ship rats	Possums	Eggs and chicks	J. Innes, Landcare Research, unpubl. data
Whio	*Hymenolaimus malacorhynchos*	Stoats		Eggs, chicks and incubating females	Whitehead et al. 2007, 2010; Glaser et al. 2010
Bats					
Long and lesser short-tailed bats	*Chalinolobus tuberculatus* *Mystacina tuberculata*	Ship rats	Stoats and possums	Roosting adults and young	Pryde et al. 2005; O'Donnell et al. 2011
Frogs					
Archey's frog	*Leiopelma archeyi*	Ship rats		Unknown	Thurley & Bell 1994; Haigh et al. 2010
Hochstetter's frog	*Leiopelma hochstetteri*	Ship rats	Stoats	Juveniles	Thurley & Bell 1994; Baber et al. 2008
Snails					
Powelliphanta snails	*Powelliphanta* spp.	Ship rats	Possums	Adults	Walker 2003

* Stoats are the main predator of bellbirds in beech forest in the absence of ship rats, but ship rats are likely the most important predator in non-beech forests.

† Ferrets (*Mustela putorius furo*) can have a catastrophic effect on kiwi populations, as they invade forests and kill adults as well as chicks following rabbit (*Oryctolagus cuniculus*) population crashes in surrounding farmlands.

‡ Stoats are the most important predator of mohua in most years. However, in beech mast years ship rat impacts can be drastic, including causing local extinction.

3. How can we control mammalian predators on the mainland?

Much has been learnt from attempts to control ship rats, stoats and possums on the New Zealand mainland in the last 25 years. Pest management options span a broad spectrum from localised nest protection, to pulsed or press control using intensive grids of traps or bait stations, to pulsed control using aerially applied toxic baits, to exclusion using fences and islands. The most widespread mainland techniques are traps and/or toxic baits applied at ground level, or aerial application of 1080 baits. It is critical that accurate measures of cost, effort and outcome are recorded if meaningful comparisons are to be made between the uses of different methods in different circumstances. The main factors influencing the choice of mammal control techniques are the target species, the desired residual abundance, scale, cost, topography, available expertise, and community acceptance of the proposed actions.

3.1 Ground control

3.1.1 Traps

In the last 10 years, there have been significant developments in trap design and in our understanding of what can be achieved by trapping, both in isolation and in conjunction with the use of toxins (see section 3.1.2). In the past, the humaneness of trapping has been of particular concern, and so DOC now only uses traps that have passed the National Animal Welfare Advisory Committee (NAWAC) guidelines (MAFBNZ 2010). The use of traps is preferable over the use of toxins because it removes the risk of secondary poisoning, and is generally more acceptable to communities. That is not to say that traps have no non-target effects, because they can kill native birds unless the latter are excluded. Trapping is still the major tool for large-scale stoat control, is widely used to target possums in conjunction with toxins, but is rarely used as a main tool for ship rat control.

Ship rats

Controlling ship rats with single-kill traps is generally ineffective at scales beyond tens of hectares because traps need to be closely spaced and regularly checked and trapping is therefore expensive. New Zealand projects that have attempted to maintain control of rats using traps alone, such as in Urewera, at Rotoiti (Nelson Lakes National Park) and at Windy Hill (Great Barrier Island), have all ended up using toxins in addition to or instead of traps because occasional population peaks and constant reinvasion overwhelm affordable trap-checking.

It is still a valuable objective to maximise the use of traps and so minimise the use of toxins, if biodiversity targets can be met. For example, in Te Urewera Mainland Island, Victor® professional snapback traps have been used as the main control tool against ship rats for many years, but cost-effective control now uses cholecalciferol baits alongside trapping. Ship rats are maintained generally below 5% tracking rates all year round in the Otamatuna 'core area' (557 ha) by using cholecalciferol and trapping together, while at Mangaone (232 ha), Pakoakoa (212 ha) and Waikokopu (200 ha) rat populations are initially 'knocked down' with cholecalciferol before being maintained near or below 5% tracking rates over the kōkako breeding season by trapping (Moorcroft et al. 2010).—Trapping in Te Urewera is undertaken on altitudinal contour lines along and below ridge crests, which is an effective and adaptive technique for that topography, but this is a nationally unconventional approach and, predictably, rat populations remain substantial 50–150 m outside the outer line of traps (Fergusson 2005). Trapping was ineffective at suppressing ship rat numbers and protecting robins in a beech mast year at Rotoiti (Harper 2012), and trapping failed to adequately suppress rats during a mast year at Hawdon (Elliott & Suggate 2007).

Initial rat control results from efficacy trials for Goodnature® A24 self-resetting rat and stoat traps are promising for rats. Rats have been controlled to 0% tracking at Harts Hill, Fiordland (200 ha) using 467 traps on a 100 × 50 m grid, but at a cost of $169 per trap plus the ongoing cost of lure and gas cartridges (DOC 2015a; www.goodnature.co.nz). Rats have also been eradicated from Native Island (63 ha) using 142 A24 traps (DOC 2015b). Long-term mechanical reliability of these traps has been an issue (Gillies et al. 2013, 2014) that appears to have been resolved (DOC 2015c).

There is an urgent need to publish scientific accounts of projects that have trialled trapping ship rats in New Zealand, so that effectiveness, full costs over time, and affordable scales of different techniques can be reasonably compared with common and standard metrics.

DOC best practice recommends that rat traps are placed in grids on tracks along 100 m contours at a spacing of 25–50 m to ensure that at least one trap occurs within each rat home range (refer to DOC 2011a). Peanut butter is the most commonly used bait in snap traps and long-life lures are being developed for use in self-setting traps.

Stoats

Stoat trapping advanced in 2007 when Fenn traps, which did not meet the humane standards of the Animal Welfare Act 1999, were replaced by DOC series traps in DOC predator control operations. The DOC series now includes the DOC 200 and smaller DOC 150 traps for killing stoats and rats—as well as the bigger DOC 250 for killing ferrets—and standardised trap boxes that exclude non-target species have been developed. DOC series traps can effectively control stoats over large areas (e.g. Project Janszoon controls stoats over 14 300 ha), and the combination of traps and aerial 1080 can suppress stoats to even lower levels (Sutton et al. 2012). Spitfire traps, which squirt toxin onto stoats as they pass through the tunnels, also show promise as a stoat control tool (E. Murphy, DOC, unpubl. data), and both these and self re-setting A24s (which are currently being trialled for their efficacy; Gillies et al. 2013, 2014) have the potential to make stoat trapping more cost-effective at the landscape scale—although a recent trial of A24s at Rotoiti resulted in high stoat tracking rates and kākā mortality (Gillies et al. 2014). Mechanical reliability was an issue when this work was carried out and the efficacy of the Goodnature Ltd. long-life stoat lure has yet to be demonstrated.

The biggest current issue with stoat trapping is that not all stoats enter the traps, especially when alternative food is plentiful. There have been few significant advances in bait for stoat traps, with eggs still being most commonly used because they last longer than meat. Fresh rabbit is the most effective bait for stoats, however, and so Erayz® rabbit-based bait, which is long-lasting, is also commonly used—although both this and fresh rabbit are vulnerable to removal by wasps (*Vespula* spp.). The development of a lure that will entice all stoats to enter traps is the 'Holy Grail' of stoat trapping.

DOC best practice recommends that stoat traps are placed no more than 200 m apart on lines no more than 1 km apart, while making use of ridges, tracks, roads, contours and waterways (refer to DOC 2013a).

Possums

Possums can be maintained at a low abundance using traps with periodic applications of cyanide (D. Baigent, DOC, unpubl. data). Leg-hold trapping using Victor leg-hold traps (which have replaced gin traps; MAFBNZ 2010) is the preferred method when fur or skins are being recovered, but is labour intensive and expensive because leg hold traps are required to be checked daily. When no recovery is required, Sentinel possum kill traps have proven to be both very efficient (Warburton & Orchard 1996) and cost effective compared with leg hold trapping

(Moorcroft et al. 2010) in controlling possums; and other possum kill traps are also available on the market (e.g. Trapinator). Possums were maintained below 5% Residual Trap Catch over 11 350 ha using Sentinel traps (and cyanide) at 75 m intervals on lines along prominent features such as ridges, spurs and valley bottoms (0.4 to > 0.7 traps/ha) in Te Urewera (Moorcroft et al. 2010). A12 self-resetting possum traps, which are currently being trialled for their efficacy (Gillies et al. 2013, 2014), appear to be a useful possum control tool, especially for community groups whose members might be reluctant to handle dead possums. Visual lures, such as a flour blaze placed on a tree, are used to attract possums to traps and specific rat-resistant possum paste baits can be purchased for use in Sentinel traps.

There is **no DOC best practice** for possum trapping, but the best practice for bait stations targeting possums recommends that they are placed no more than 150 m apart, preferably on ridges and spurs, and along pasture boundaries (refer to DOC 2011b).

3.1.2 Toxins

There have also been significant developments in the last 15 years in toxins for targeting ship rats, possums and stoats.

A number of toxins have been registered for use in controlling rats and possums in New Zealand. Brodifacoum was widely used on mainland New Zealand in the 1990s, where it proved very effective for controlling these pest species through primary poisoning (Gillies et al. 2003). The use of brodifacoum had measured benefits to populations of kōkako, kererū, North Island robin, morepork (*Ninox novaeseelandiae*) and land snails (Innes 2005; Fraser & Hauber 2008); and the successful recovery of the Chatham Island parea from near extinction (Flux et al. 2001) was attributed to its use. However, concerns about the persistence of brodifacoum in living animals (Innes & Barker 1999; Broome et al. 2012) led to DOC regulating its use on the mainland. In January 2000, DOC moved to limit brodifacoum use to sites where there would be minimal exposure to pigs (*Sus scrofa*) and deer, and to target only rodents, with baits fixed inside bait stations. Then, in 2002, following an internal risk assessment, DOC's Pesticides Advisory Group recommended that brodifacoum should only be used sparingly, i.e. restricted to one or two operations per lifespan for the longest lived native animal species that were likely to be exposed to avoid the build up of the toxin within native species through repeated doses.

Other toxins that have been registered to control rats and possums include diphacinone (RatAbate Paste in 2006, Pestoff Rat Bait 50D in 2009 and D-Block in 2011), cholecalciferol (Feracol® in 2000, Pestoff Decal Possum Bait and NO Possums Cholecalciferol Gel Bait in 2006), coumatetralyl (Racumin® Paste in 1999), pindone (Pindone pellets in 1992), cyanide (Feratox® in 1995), zinc phosphide (ZaP Possum Paste in 2011) and sodium nitrite (in 2013). First generation anticoagulants (multiple-dose as opposed to single-dose, second generation anticoagulants like brodifacoum) can also cause non-target mortality (e.g. Dennis & Gartrell 2015), and there are concerns about their environmental fate (Fisher et al. 2004, Spurr et al. 2005, Crowell et al. 2013), as there are for brodifacoum.

DOC best practice recommends that toxins be hand laid or deployed in bait stations or in bait bags, depending on the toxin and circumstance (DOC 2015d). The effectiveness of deploying toxin in bait stations for controlling ship rats during a beech mast rat irruption was tested in the Catlins and Eglinton Valley in 2006 with variable results (Elliott & Suggate 2007). In the Catlins, rats were controlled to acceptably low levels using bait stations at a density of 1/1.25 ha over about 800 ha and loaded with pre-feed, 1080 and then brodifacoum. Rats have been controlled successfully to at or near undetectable levels, using 1 bait station per hectare containing Pindone pellets, through seven beech mast events between 2009 and 2015 at several sites in Fiordland: Eglinton (4800 ha), Iris Burn (500 ha) and Kepler (450 ha) (Hill 2015).

By contrast, in 2006 in the Eglinton Valley, using bait stations with a combination of 1080, coumatetralyl and then diphacinone, rat numbers were suppressed but then recovered to unacceptable levels using bait stations at a density of 1/ha in three blocks of 200 ha, 300 ha and 450 ha. Also, at Nelson Lakes, pindone in bait stations at 100 × 100 m spacings failed to control rats (Long et al. 2015). Bait stations are suitable for use in situations of limited scale (e.g. < 5000 ha), and moderate topography with good access. Elsewhere, they are more expensive.

Up until 2011, no poison was registered for ground-based control of stoats[2]. However, stoats are vulnerable to secondary poisoning, which means that their abundance can be significantly reduced by a variety of toxins that are intended for rats and/or possums (Alterio 1996; Alterio et al. 1997; Brown et al. 1998a; Murphy et al. 1999; Alterio 2000; Alterio & Moller 2000; Gillies et al. 2003). In April 2011, PAPP (para-aminopropiophenone) became the first toxin to be registered for stoat control in New Zealand and the first new toxin to be registered for mammalian pest control anywhere in the world for at least 20 years. Compared with most other toxins, PAPP is relatively humane, as stoats become unconscious within about 15 minutes and die shortly afterwards (Eason et al. 2014). Therefore, if PAPP proves effective, it could provide a very cost-effective alternative to stoat trapping—particularly if it can be registered for aerial use in the future (see below).

3.2 Aerial control

The aerial application of 1080 is currently the only tool we have that can simultaneously control ship rats, possums and stoats on a large scale (i.e. > 10 000 ha). It is affordable, at approximately $17–$27 per hectare (Terry Farrell, DOC, unpubl. data), but faces some opposition, primarily from the hunting lobby.

Landscape-scale aerial application of 1080 to protect forests from possums commenced in 1962. In the late 1970s, the goalposts changed from forest protection to the control of bovine tuberculosis (Tb), but the goal of forest protection recommenced when DOC took over possum control from the New Zealand Forest Service in 1987 (while the Ministry of Agriculture and Forestry (eventually becoming the Animal Health Board and now TBfree New Zealand) continued with the Tb goal). In 1993, DOC developed a National Possum Control Plan (DOC 1994), which identified the strategic direction, priorities and operational guidelines for possum control on DOC-managed lands nationally. However, this plan is now out of date and no strategic plans exist for rodent or stoat control. Today, site-based operational plans that identify outcome and result targets are used.

Over the years, there has been considerable effort to refine the efficiency and environmental safety of aerial 1080 (Morgan & Hickling 2000; Morgan et al. 2006; Fisher et al. 2011; J. Kemp, DOC, unpubl. data). While **individual** native animals of some species (e.g. kea habituated to novel foods at ski fields and rubbish dumps when young) can be at risk from 1080 poisoning, overall **populations** tend to benefit (J. Kemp, DOC, unpubl. data; Fairweather et al. 2015). The main improvements have been greatly reduced sowing rates, recognition of the importance of pre-feeding non-toxic baits, the use of global positioning systems (GPS) for more accurate bait delivery, and improved operational standards and monitoring (Cowan 2005; Fisher et al. 2011; Nugent et al. 2011, 2012; see Box 1). However, this tool still meets with some opposition. A more informed public opinion could likely be achieved through better transfer of the known benefits, costs and risks of 1080 compared with those of alternative control methods or doing nothing.

The effective aerial application of 1080 requires legal consents, complex operations, community consultation, public awareness and high-quality monitoring. Different parts of DOC manage different aspects of aerial 1080 use, often to varying standards, which decreases efficiency,

2 1080 legally applied aerially to control possums and rats also kills stoats.

and increases operational and social risk. Rationalisation of consent processing, monitoring, consultation, public awareness and the management of operations could be best achieved by adopting a single programme approach to the use of aerial 1080. Such an integrated management approach using a dedicated team of legal, public awareness, operational and science staff, would likely increase operational effectiveness, reduce cost and risk, and increase biodiversity outcomes and public support.

PAPP offers a new possibility for the aerial control of stoats at different scales and in rough terrain. This toxin is extremely humane (see section 3.1.2) with low risk of secondary poisoning. If it can be registered for aerial application, PAPP is likely to be a much cheaper alternative than ground-based stoat trapping. PAPP could be as little as < 50 cents per ha per application (G. Elliott, DOC, unpubl. data) compared with, for example, $24.40 per ha per year (C. Golding, DOC, unpubl. data) for trapping. However, due to its specificity to stoats and cats (Eason et al. 2014), PAPP will not replace 1080 for rat and possum control but complement it.

Box 1. How can we optimise the aerial application of 1080 for rat control?

Rat plagues are major contributors to the decline and extinction of native fauna in upland beech forests, as highlighted by the plagues that occurred in the South Island in the 1999/2000 season (e.g. resulting in local mohua population extinction (Gaze 2001)). To date, such rat irruptions had only been able to be suppressed by the aerial application of poison, but these operations had met with varying success on the New Zealand mainland (Gillies 2002; Murphy 2003; Murphy et al. 2004). Consequently, the optimisation of aerial 1080 operations for rat control was considered a top priority during a Rodent Research Workshop held in 2006 (Murphy 2006).

In response to this, in 2006 DOC commenced research to improve the consistency of rat kills using aerially applied 1080 by developing a best practice with regard to weather conditions, pre-baiting, sowing rates and bait characteristics (e.g. type, size, freshness, hardness, lures and masks). It also sought to refine the timing of operations with respect to mast seeding and to identify factors determining the rate of post-control increases in pest numbers (J. Kemp, unpubl. data).

Brown & Urlich (2005) and Brown (2006) found that rat control using aerial 1080 was more effective when non-toxic pre-baiting (pre-feeding) was used, and rat monitoring data from routine (non-experimental) control operations in 2006 and 2007 also indicated consistently high levels of rat control when pre-baiting was undertaken. The same outcomes were later apparent in TBfree NZ-funded research by Landcare Research staff (Nugent et al. 2012). Consequently, by 2009 pre-baiting was standard practice for both DOC and TBfree. By contrast, all other factors mentioned above appear to have little effect on the outcome of 1080 operations to control rats, including sowing rates—extremely effective rat control was consistently achieved at the minimum available sowing rates (1 kg/ha for 6 g pellets and 2 kg/ha for 12 g pellets). However, Landcare Research is currently investigating the feasibility of trickle sowing bait in lines rather than broadcasting bait, which would reduce the sowing rate enabling further cost savings (Sweetapple & Nugent 2007; Nugent et al. 2011)—and the results of initial trials look promising (Nugent & Morris 2013). Though likely effective against possums and rats at low density this method is unlikely to be effective against ship rats at high densities because of smaller home ranges when density rises.

Having established a new practice to control rats as cheaply as possible, the project's emphasis shifted to measuring re-population by rats. This has primarily involved the creation of a large database of tracking tunnel data based on thousands of tracking tunnel transects from a large number of sites across New Zealand that have had dozens of rat control operations (or no control) and in which dozens of mast seeding events have occurred (J. Kemp, unpubl. data). Variability in the size, shape, natural boundaries, forest types and mast seeding events in the managed sites was then examined to estimate the range of re-population times, identify factors that influence re-population time and develop computer models of re-population.

Recent trials that used pre-feed and were carried out over very large areas (10 000–30 000 ha) suppressed rat populations for 6–18 months, depending on the forest type (J. Kemp, unpubl. data). New Zealand forests appear to cluster into four different types with respect to re-population by rats:

Continued on next page

\` 1. Fertile podocarp/hardwood forests
2. Infertile rimu forests of the South Island
3. Upland beech forests
4. Mixed beech-podocarp forests.

Rats recover to high levels in about 6 months in fertile podocarp/hardwood forests, regardless of the size of the operation, whereas recovery takes longer in less diverse forests—and may take longer still in forests dominated by beech and rimu, where rats are naturally at a low abundance except in plague years (G. Elliott & J. Kemp, DOC, unpubl. data).

The optimal timing of rat control depends very strongly on the time until a beech mast (see section 5.1.2 for discussion of mast) is likely to occur, which may not be for several years. A rudimentary non-spatial model has been developed to assess the optimal time for aerial 1080 baiting in strongly masting forests (e.g. upland beech and infertile rimu) (J. Kemp & G. Elliott, DOC, unpubl. data) and more sophisticated spatial models are currently being developed for all four forest types. The tracking tunnel database will be used to ensure that the models' predictions are realistic.

Further refinement of aerial application of bait is needed, as recently illustrated by the variability in rat kill results from DOC's large-scale 'Battle for our birds' response to the 2015 beech forest mast (J. Kemp & G. Elliott, DOC, unpubl. data). While all operations killed most rats present only 19 operations of 25 (76%) got the rats below 10% rat tracking, and 15 (60%) of the operations got the rats to 1% rat tracking or less. Many operations were carried out late in the season when rats had reached very high densities with likely small home ranges. It is likely that not all rats got access to bait due to variability in coverage. Testing this hypothesis is obviously a high priority research question. Stoat tracking rates were low compared to non-control sites suggesting high stoat kills.

Landscape-scale multi-species pest control has the following advantages over small-scale control of single species:

1. Economies of scale: The per-hectare and per-animal cost is reduced by targeting larger areas and several pest species.
2. Lower reinvasion rates: Large areas logically have lower pest reinvasion rates than small areas, allowing pest densities to be kept lower for longer in the central core. Furthermore, by conducting pest control over large areas, natural boundaries such as lakes, large rivers, coast and peninsulas can be used to further reduce pest reinvasion rates.
3. Increased protection of native species: Large areas can support genetically viable, sustainable populations of more native species than small areas, and large-scale control has a better chance of protecting valued native species even after natal dispersal takes young of the year many kilometres away from their nest sites. Effective pest control over large areas is essential for populations of native animals with large home ranges.

Landscape-scale species recovery doesn't necessarily mean controlling all pests over all the landscape. An alternative promising approach is being trialled at Te Urerwera Mainland Island to encourage species (e.g. kōkako) recovery over a large land area (Moorcroft et al. 2010). This approach uses a number of intensively managed 'core areas' distributed within a less-intensively managed matrix. The core areas have a high nesting success and perform as breeding areas from which kokako move out into the surrounding landscape where adult survival and nesting success is lower, but not zero. Birds move between the core areas, facilitating genetic flow and enabling a functioning kokako population over a large area, even though intensive rat control takes place over a relatively small area (Moorcroft et al. 2010).

Unless we routinely undertake pest control at a landscape scale in New Zealand, the bulk of public conservation land will receive no pest control and in the future will support only the most common and resilient species. Landscape-scale multi-species pest control is already carried out at some sites, including some Operation Ark sites and kiwi sanctuaries, and at more sites as part of the 'Battle for our Birds' project. However, at present the assessment of sites for landscape-scale pest control is somewhat ad hoc. An approach is needed to identify priority large-scale management sites that integrate prioritised Ecological Management Units and landscape-scale pest control.

3.3 Advantages and disadvantages of ground and aerial control

Ground-based pest control and aerial control are appropriate to use in different circumstances as both have advantages and disadvantages. Undoubtedly, aerial control is most appropriate in rugged back-country situations where large-scale control is required, although it can also be usefully applied at smaller (e.g. 1000 ha), more accessible sites. Advantages of aerial 1080 control are that it is cost-effective when compared with ground-based methods; is effective, as multiple target pests can be reduced to very low densities in one or two nights, even at high pest densities; can be applied in rugged terrain and at a large scale, reducing the effects of reinvasion; and non-target risks are low. Disadvantages are relatively high cost at small scales and mixed public acceptability of the tool.

Ground-based methods can be used for targeted control of ship rats and possums at smaller, more-accessible sites and control of stoats on a landscape scale (e.g. 14 300 ha by Project Janszoon). However, aerially applied PAPP has the potential to be significantly more cost-effective and trapping/aerial 1080 combined can currently be most effective. Advantages of ground-based methods include the cost effectiveness of being able to target pest control at specific small-scale sites (e.g. bat roosts); they are less weather dependent and more acceptable to some groups, particularly near populated areas. Disadvantages are that they are labour-intensive and consequently expensive; they typically target only one or two pests in favourable terrain, and are limited in the area they protect (with the exception of stoat trapping that can be carried out over large areas). Costs of ground-based control are also highly variable, depending on set-up and track maintenance costs, trap-checking and bait station-filling frequencies, and levels of contractor servicing. Such projects are more expensive when multiple fills are required to control pests (e.g. ship rats) at high abundance.

Therefore, it will inevitably cost more to control ship rats, stoats and possums using ground-based techniques rather than aerial operations at most moderate- to large-scale sites[3]. For example, as part of Project Janszoon, the cost estimate[4] for a 10 000-ha stoat trapping operation at Abel Tasman National Park is $24.40 per ha per year spread over 10 years, and for a 1500 ha possum and rat bait station operation at Falls River is $61.52 per ha per year spread over 5 years; by contrast, the cost of a recent 11 592 ha aerial 1080 operation targeting all three pests was about $27 per ha (including consent, consultation and administration costs) with benefits extending beyond one year (C. Golding, DOC, pers. comm.). On the other hand, trapping is the most publicly acceptable tool, while aerially applied poisons are the least (Russell 2014). Therefore, the feasibility and cost of using ground control needs to be weighed up against the acceptability of aerial poison control operations on a case-by-case basis.

3.4 Required scale and intensity of management

We currently do not know the minimum scale of pest control required to protect populations of many native species. To date, little work has been carried out to determine minimum areas required for species persistence (MASPs). Thus, we have MASPs for just a few of our native bird

[3] Average costs for ground-based trapping and toxin operations are difficult to obtain because they are not consistently recorded. Ideally, all contractor, travel, monitoring, administration and consultation costs should be captured alongside equipment and operational staff time (Karen Vincent, DOC, pers. comm.).

[4] These figures include staff and contractor costs.

species (see below). In general, species with large home ranges will require larger management areas. If these species are managed in smaller areas, they may require periodic transfers to maintain their genetic diversity and more intensive, and therefore expensive, pest control than would be required at a larger site. Current evidence suggests that New Zealand birds have approximate MASPs of:

- 1000 ha for kererū, tūī, fantail/pīwakawaka (*Rhipidura fuliginosa*), tomtit and silvereye (*Zosterops lateralis*) (Saunders & Norton 2001; Innes et al. 2004)
- 2000 ha for robin and North Island kōkako (Innes et al. 1999; Ramsey & Veltman 2005; Armstrong et al. 2006)
- 5000 ha for mohua and yellow-crowned parakeet (G. Elliott & J. Kemp, DOC, unpubl. data; T. Thurley, DOC, unpubl. data)
- 10 000 ha for kākā, kiwi and kea (Wilson et al. 1998; Basse & McLennan 2003; G. Elliott & J. Kemp, unpubl. data; H. Robertson, DOC, unpubl. data)
- 30 000 ha for whio (G. Elliott & J. Kemp, DOC, unpubl. data)

Likewise, we currently do not know the **intensity** of pest control or maximum allowable residual pest abundance targets for many native species. For pest control to be effective it is necessary that pest populations are maintained below levels that negatively impact on native animal populations. Few examples of such maximum pest abundance targets (e.g. < 10% rat tracking, < 20% stoat tracking and < 10% possum residual trap catch over the kōkako breeding season) are known. Knowledge of such targets allows for optimisation of the timing, frequency and intensity of control to protect native species.

3.5 Adaptive management to improve techniques and outcomes

Adaptive management uses the scientific method to learn from large-scale management operations (Holling 1978; Walters & Hilborn 1978). Examples where it has been used to improve efficiency and effectiveness include the kōkako research-by-management programme (Innes et al. 1999), Operation Ark (Elliott & Suggate 2007), some kiwi sanctuaries (Robertson & de Monchy 2012), in mainland islands (Saunders & Norton 2001; Gillies et al. 2003), an experimental deer control programme (Ramsey et al. 2012) and Battle for our Birds (G. Elliott, DOC, unpubl. data).

For it to work, adaptive management requires commitment from and good communication between managers and scientists. In a review of 100 attempts to apply adaptive management in various parts of the world over the past 30 years, Walters (2007, p. 304) found that most failed as a result of '1) lack of management resources for the expanded monitoring needed to carry out large-scale experiments; 2) unwillingness by decision makers to admit and embrace uncertainty in making policy choices; and 3) lack of leadership in the form of individuals willing to do all the hard work needed to plan and implement new and complex management programs'. For these reasons, adaptive management is seldom used. Because it offers a way to improve management techniques and conservation outcomes in the medium to long-term, its judicious use is encouraged.

4. What has pest control achieved to date?

4.1 Learning to control mammalian pests at mainland sites

New Zealand conservationists have led a worldwide movement of pest eradication from islands (Towns & Broome 2003; Howald et al. 2007; Keitt et al. 2011; <http://eradicationsdb.fos.auckland.ac.nz). Biodiversity gains from successful island eradications have inspired increasingly more ambitious island eradication attempts (Towns et al. 2013) and large-scale mainland control. While on islands eradication is feasible, control operations on the mainland aim to maintain pests below damage thresholds because of ongoing pest reinvasion. The scale and complexity of mainland predator control has increased dramatically in the last 25 years as we have learnt more and developed the confidence to act at larger scales. In the following text we discuss some initiatives that have been fundamental to increasing our pest management knowledge and capability.

The kōkako 'research by management' project, which was carried out from 1989 to 1997 in podocarp-broadleaved forests at different North Island sites, was the first to provide conclusive evidence that the management of ship rats and possums (to set targets) could reverse the decline of critically endangered forest bird populations (Innes et al. 1999). Simultaneously, stoat control in the Eglinton Valley in 1990/1991 and 1996 was shown to enhance mohua breeding success (O'Donnell et al. 1992; O'Donnell et al. 1996). Subsequent work has shown the importance of also controlling ship rats to protect mohua and other species in some mast years (Dilks et al. 2003; Elliott & Suggate 2007).

In 1995, six 'Mainland Islands' were established by DOC at Trounson Kauri Park, northern Te Urewera, Boundary Stream, Paengaroa Reserve, Hurunui and Lake Rotoiti. These are intensively managed multi-species pest control sites with ecosystem goals (Saunders & Norton 2001), and were inspired by the success of kōkako recovery, which led to calls for ecosystem and species recovery elsewhere on the mainland (Saunders 2000). They later evolved into sites that were primarily used for testing pest management tools, although they retained their biodiversity protection and community objectives (Brown & Gasson 2008). Much was learned and some species have benefited, but ecosystem restoration goals have not been clearly demonstrated.

In 1999, the first multi-species pest exclusion fence was built at Karori Sanctuary, Wellington (now Zealandia) (Campbell-Hunt 2002). Since then, a number of predator-exclusion fences have been constructed at various sites across New Zealand, the largest of which is at Maungatautari in the Waikato, where it encloses 3363 ha of native forest (Burns et al. 2012; Smuts-Kennedy & Parker 2013). Most pests (with the exception of mice) have been successfully excluded and many different native species have established inside the fence, although pest incursions requiring elimination are inevitable (Butler et al. 2014). There has also been considerable debate about the cost-effectiveness of multi-species pest exclusion fences (Scofield et al. 2011; Innes et al. 2012; Scofield & Cullen 2012).

In 2000, five kiwi sanctuaries were established by DOC to maintain viable kiwi populations. Overall, these have been successful, with four reporting a reversal in the decline of kiwi populations, with population growth rates of 2.9%–11.3% per year (Robertson & de Monchy 2012). These population increases have resulted from a combination of trapping, dog aversion training and the BNZ-sponsored Operation Nest Egg (BNZONE), in which eggs were removed to be hatched in captivity and the resultant chicks returned when they are large enough to be safe from stoats (Robertson & de Monchy 2012). For one kiwi population, it was estimated that the aerial application of 1080 alone would be sufficient to achieve an annual growth rate of 0.7% per annum, compared with a decline of 0.6% per annum without predator control (Robertson & de Monchy 2012).

Operation Ark was established by DOC in 2004 with the goal of protecting mohua, whio, orange-fronted parakeet and long-tailed and lesser short-tailed bat populations from ship rat, stoat and possum predation at ten sites (Elliott & Suggate 2007). A combination of ground-based pest control techniques and aerial application of 1080 were used, with aerial 1080 proving the most effective (Elliott & Suggate 2007). In 2010, the programme morphed into the South Island Pest Response Advisory Group (SIPRAG) that uses 1080 control to protect a range of biodiversity values at 28 sites covering 300 000 ha across the South Island and Stewart Island/Rakiura.

In 2011, the Parliamentary Commissioner for the Environment Jan Wright concluded that '… not only should the use of 1080 continue to protect our forests, but that we should use more of it' (Wright 2011). In accordance with this, the scale of aerial 1080 operations has increased in recent years. In 2014, DOC established 'Battle for our Birds', which aimed to protect native birds at 23 sites spread over approximately 700 000 ha of forest using aerially applied 1080 targeting ship rats, stoats and possums as a large-scale $11.5 million response to a major beech mast event.

Inspired by DOC initiatives, biodiversity sanctuaries (sites with multi-species pest control for ecosystem recovery) are now widespread across the country (www.sanctuariesnz.org; 1 February 2015). In a recent book, Butler et al. (2014) describes the successes, trials and tribulations, passion and huge investment of resources of these predominantly community-driven initiatives. For example, the Moehau Environment Group manages 13 500 ha of primarily private land on the Coromandel Peninsula in association with a large-scale DOC-led restoration project, and this work has resulted in a thriving brown teal/pāteke population—something that has rarely been achieved elsewhere, as most mainland brown teal translocations have failed due to insufficient predator control.

Today, ship rats, stoats and possums are being effectively controlled at several intensively managed sites on the New Zealand mainland, some of which cover hundreds to thousands of hectares of forest (Innes et al. 1999; Saunders & Norton 2001; O'Donnell & Hoare 2012; Hoare et al. 2013). More extensive management is also occurring (e.g. Battle for our Birds). These achievements have led to more ambitious proposals such as eradications from increasingly bigger islands (Towns et al. 2013)—and there has even been discussion around the feasibility of eradicating these pests from the mainland (Green 2011; Landcare Research 2013a, b; Bell & Bramley 2013; Russell et al. 2015).

4.2 Benefits to our native fauna

There is now considerable evidence that the control of ship rats, stoats and possums can benefit native species on the New Zealand mainland. For example, O'Donnell & Hoare (2012) found that stoat trapping and pulsed aerial application of 1080 targeting possums and ship rats resulted in significant population increases in nine bird species in the Landsborough Valley; Hoare et al. (2012) found that 9 of 18 bird populations responded positively to predator control at Kakahu Bush over a 10 year period; Barber et al. 2009 found that pest control to protect kōkako in the Hunua Ranges also benefited tūī, kererū and tomtit; and Miskelly et al. (2008) attributed the establishment of red-crowned parakeet, whitehead (*Mohoua albicilla*) and bellbird populations near Wellington city to the effective control of possums and rats.

A large number of native bird species have benefited from predator control, including:

- **Kōkako**: Kokako remain on the mainland only where predator control is undertaken. All unmanaged mainland populations are now locally extinct. The number of kōkako has increased at several sites as a result of predator control:
  - —Te Urewera has the second largest kokako population estimated at around 420 birds. At Otamatuna the population has increased from 6 pairs in 1996 to more than 120 pairs now.
  - —At Mapara, the kōkako population trebled in size following 8 years of pest control, including an eight-fold increase in the number of breeding pairs (Innes et al. 1999), with the latest census estimating an increase from less than 20 pairs in 1989 to at least 122 pairs (Thurley et al. 2013).

—At Kaharoa, the number of kōkako increased from 7 pairs and 8 singles in 1990 to 30 pairs in 2006 (Richardson et. al. 2006) and 58 pairs in 2010 following the implementation of predator control.

—In the Mangatutu Ecological Area, predator control led to an increase from 10 kōkako pairs in 1996 (Marsh 1996) to 102 pairs in 2012 (Smith et al. 2012); and the total northern Pureora kōkako population is now estimated at greater than 600 individuals as a result o ongoing ground and aerial 1080 pest control (McAulay & Thurley 2013).

At Mapara, predator control also improved population composition (changing it from predominantly old males to young birds with a nearly equal sex ratio; Innes et al. 1999) and increased the number of successful nesting attempts from 8% prior to control to 61% post control (Flux et al. 2006). Female mortality has also reduced, with no nesting female kōkako known to have been killed by predators when predator control was operating, but 12 of 31 banded females lost in three subsequent breeding seasons without predator control (Flux et al. 2006).

- **Bellbirds**: At Lake Rotoiti, bellbird numbers increased dramatically in response to intensive stoat trapping and the use of brodifacoum in bait stations to control ship rats, but decreased again when rat numbers increased in response to beech mast and once brodifacoum ceased to be used (Rotoiti Nature Restoration Project, unpubl. data).
- **Tūī**: Control of pest mammals by Waikato Regional Council ('Project Halo') in forest fragments around Hamilton reduced ship rats to an average 2.7% tracking rate and possums to an average 1.2% residual trap catch. This resulted in a more than eight-fold increase in tūī counts in Hamilton (J. Innes et al., Landcare Research, unpubl. data). A separate trial using artificial nests in blocks with and without pest control also suggested that this kind of pest control could increase tūī nesting success from 32% to 73%.
- **Mohua**: Mohua populations in The Catlins and Dart Valley were protected from rat irruptions in 2006 and 2009 through the aerial application of 1080 and various kinds of toxic baits in bait stations in combination with stoat trapping (Elliott & Suggate 2007; Hoare et al. 2013; G. Elliott, DOC, unpubl. data); and mohua in the Eglinton Valley enjoyed increased breeding success and female survivorship following stoat trapping (O'Donnell et al. 1996).
- **Robins**: Populations of North Island robins had positive growth rates in 19 forest fragments where rats were controlled, compared with marginally positive or negative rates in uncontrolled areas (Armstrong et al. 2014); and the productivity and nesting success of both North Island robins (Powlesland et al. 1999) and South Island robins (Etheridge & Powlesland 2001) increased following the effective control of ship rats, possums and, in the case of South Island robins, stoat control.
- **Kākā**: Kākā populations have responded extremely well to relatively low-intensity ground control and aerial control. For example, in the Eglinton Valley a single line of stoat traps was sufficient to protect the resident kākā population during several stoat irruptions, leading to 80% nesting success and 100% fledgling survival (Dilks et al. 2003); and in the Waipapa Ecological Area, Pureora, an aerial 1080 operation was followed by high kākā breeding success (78%), and high survival of fledglings (89%) and females (100%) (Henderson 2009). Nationally, nesting success at unmanaged sites is approximately 38% or less and 65% of radio-tagged nesting females were killed by predators at unmanaged sites (Moorhouse et al. 2003).
- **Kea**: Combined stoat, possum and rat control has greatly improved kea nesting success to an average of 79% from about 3% in a stoat plague year and 37% in a non-stoat plague year (Josh Kemp, DOC, unpubl. data). This has been achieved at Rotoiti and Hawdon Valley using integrated stoat trapping plus possum control by trapping and aerial 1080, and at Okarito using mast-timed aerial 1080 (H. Robertson & T. Makan, DOC, unpubl. data).

- **Kākāriki**: A combination of bait stations, the aerial application of 1080 and stoat trapping successfully protected a kākāriki population in the South Branch of the Hurunui during a stoat and rat plague in 2006, with 90% of nests being successful (G. Elliott, DOC, unpubl. data).
- **Kiwi**: The application of aerial 1080 at Okarito boosted rowi (*Apteryx rowi*) productivity to at least 38% over two breeding seasons—in the absence of pest control and/or Operation Nest Egg management, productivity is usually ≤5% (J. Kemp, DOC, unpubl. data).
- **Pigeons**: Flux et al. (2001) reported a three-fold increase in the parea/Chatham Island pigeon (*Hemiphaga chathamensis*) population on Chatham Island following the control of ship rats, possums and cats; and Innes et al. (2004) found that the nesting success of kererū/New Zealand pigeon increased following the control of ship rats and possums.
- **Whio/blue duck**: Aerial 1080 combined with trapping led to a significant improvement in whio productivity in the Wangapeka control area, with 90% nesting success and no female mortality while incubating or moulting (n = 10) (Steffens 2011).

Predator control has also had positive impacts on other native fauna, including frogs and land snails:

- **Frogs**: Baber et al. (2008) found that ship rat, stoat and possum control that was carried out to protect kōkako in the Hunua Ranges resulted in an increased abundance of Hochstetter's frog (*Leiopelma hochstetteri*); and Pledger (2011) found that Archey's frog (*L. archeyi*) benefited from ship rat control at Whareorino forest and on Coromandel Peninsula.
- **Land snails**: Predator exclusion fences, bait stations, traps and the aerial application of 1080 can all effectively protect land snail populations, although the rate of population increase, particularly at high-altitude sites, is often slow (K. Walker, DOC, unpubl. data).
- Bats: Stoat trapping and control of ship rats during mast years using anticoagulants in bait stations has increased the Eglinton, Walker Creek long-tailed bat population fourfold (C. O'Donnell, DOC, unpubl. data).

Work is underway to improve our knowledge of the long-term benefits of predator control using aerial 1080 to protect bird populations (see Box 2).

Box 2. Quantifying the ecological benefits of ship rat, stoat and possum control

Few studies have monitored long-term bird population or community responses to a sustained regime of aerial 1080 application (Veltman & Westbrooke 2011). Two exceptions are monitoring in the Landsborough Valley, where a range of forest birds have benefited from pest control (O'Donnell & Hoare 2012), and in the Catlins, where mohua have benefited (G. Elliott, DOC, unpubl. data).

To address this gap in 2009, DOC initiated a research programme to assess the effects of repeated 1080 use on forest birds. The programme is planned to run until 2016 and has two main aims:

1. To assess the impact of repeated 1080 use on forest birds
2. To refine the use of 1080 to maximise its benefit to forest birds

Research is being undertaken at three sites: in the Tararua Range near Wellington, at Tennyson Inlet in the Marlborough Sounds and near Lake Paringa in South Westland. At each site there is a treatment area, where 1080 is used to control predators according to DOC's current best practice, and a non-treatment area. Variations to standard 1080 use are also being assessed at additional treatment sites in the Tararua Range and South Westland—in the Tararuas, the current 6-year interval between applications of 1080 is being compared with a 3-year interval, and in South Westland the current 3–5-year interval is being compared with timing 1080 operations to coincide with times when forest birds are most vulnerable to predation.

Continued on next page

Box 2 continued

At each site, rats, stoats and possums are monitored using standard techniques, and forest birds are monitored using 5-minute bird counts or digital audio recordings, which can detect both long-term changes and short-term fluctuations in bird abundances. In addition, to investigate why any increases or decreases have occurred, the nesting success and survival of a few species are currently being monitored more closely—riflemen at all three sites, kākā and moreporks in South Westland; and robins and weka in the Marlborough Sounds.

To date, this project has demonstrated that all but the commonest native birds are more abundant in forest that has been treated with 1080 than in forest that has not in South Westland. Furthermore, zero mortality has been detected for moreporks, kākā and riflemen during recent 1080 operations (G. Elliott, DOC, unpubl. data).

5. What have we learnt?

Over the past 25 years, the effectiveness of pest control operations has increased as a result of not only improvements in the control techniques themselves, but also an increased understanding of factors that affect the efficacy of control methods and species responses following control. In this section, we begin by exploring some of the milestones that have been reached in improving control methods and efficacy, and discuss why pest control sometimes fails. We then present some case studies that highlight how rat, stoat and possum control can be integrated, depending on the target species for protection and the type of forest in which they live.

5.1 Milestones in improving control methods and efficacy

5.1.1 Improved control techniques

Existing methods

The discovery that aerial 1080 could be used to control not only possums, but also rats (Warburton 1989; Innes et al. 1995) and stoats (through secondary poisoning—Gillies & Pierce 1999; Murphy et al. 1999; Alterio 2000) opened the door to multi-species pest control at a landscape scale. Ongoing incremental improvements in aerial 1080 procedures to control possums and ship rats have also resulted in greater efficiency in its use (Brown & Urlich 2005; Morgan et al. 2006; Fisher et al. 2011; Nugent et al. 2011; J. Kemp, DOC, unpubl. data).

The development through the 1990s of intensive grids of bait stations and/or traps to control rats was a major breakthrough for managing rats on the mainland, resulting in the recovery of populations of native species (e.g. kokako). As mentioned previously, stoat control is currently one of the biggest challenges on the New Zealand mainland. The discovery that brodifacoum (as well as 1080) was very effective at controlling stoats through secondary poisoning (Alterio 1996; Alterio et al. 1997; Brown et al. 1998a; Alterio & Moller 2000) was a big milestone in stoat control; and recent evidence that trap-shy stoats can be controlled by using poison in addition to trapping to protect kiwi (H. Robertson, DOC, unpubl. data) is also very promising.

Development of new methods

In 1999, the New Zealand Government allocated $6.6 million to create an integrated stoat control research programme (Murphy & Fechney 2003). This programme has resulted in the development of new stoat management tools, including the new humane predator toxin PAPP and DOC 150–250 Series traps. DOC Series traps are now the traps of choice for mustelid control nationally and they have also been exported to enable pest eradication and control elsewhere (e.g. mongoose control in Hawaii).

Trained dogs are also now being successfully used to detect specific predators (Brown 2002; Brown & Sherley 2002; Gsell et al. 2010). Since 2002, DOC has run a dedicated 'Conservation Dogs Programme' (DOC 2013b). Pest detection dogs are specifically trained to detect predator species, usually (but not limited to) rodents, mustelids, feral cats and hedgehogs. They are used to confirm predator presence/absence after island eradication, confirm suspected invasion/reinvasion of an island, for quarantine purposes to make sure gear going to islands is pest free and to assist with trap placement.

5.1.2 Increased understanding of factors that affect control outcomes

Pest population responses to masting events

We now have a better understanding of the different community composition and dynamics of small mammals in masting (especially beech) and non-masting forests, which has a large influence on the control approaches taken in these two situations (Innes et al. 2001; Innes 2005; Efford et al. 2006; White & King 2006).

King (1983) was the first to recognise the significance of beech seed masting in her analysis of the abundance of house mice (*Mus musculus*) and stoats. Subsequently, long-term research in beech forest in the Eglinton Valley not only verified the relationship between masting and the risk of predation (O'Donnell & Phillipson 1996), but also identified that both ship rat and stoat irruptions have a devastating impact on forest birds (Dilks et al. 2003). It also demonstrated that local control could reverse declines in forest bird populations (O'Donnell et al. 1996), and gradually tested the effectiveness of larger-scale networks of stoat traps (Lawrence & O'Donnell 1999).

We now know that mast seeding of beech and podocarps are important drivers of changes in rodent and stoat abundance in many (but not all) New Zealand forests. Consequently, the distribution of mast seeding trees has a huge influence on rodent irruptions and the rate at which their populations recover following pest control.

Flow-on effects of predator control to other pest species

We can often successfully control one particular predator species, but without an understanding of how other predator species respond to this control, operations may not protect conservation values.

Since many mammalian pests kill other, smaller, mammalian pests, the removal of one species may lead to prey switching. Murphy et al. (1998) showed through diet analysis that following ship rat control operations, stoats switch from rodents to birds. Consequently, when ship rats are controlled (at relatively small sites), stoat control needs to be carried out over larger areas to reduce the predation of birds by reinvading stoats.

The removal of a particular pest species may also lead to a reduction in the level of predation or competition experienced by other pest species, causing their numbers to increase as a result of mesopredator or competitor release. I. Flux and C. Gillies, DOC (unpubl. data) found that ship rats are more abundant at some sites where stoats are controlled than at sites where they are not; and Ruscoe et al. (2011) and Sweetapple & Nugent (2007) found that the number of rats increased following the removal of possums, probably due to greater food availability.

5.2 Why does pest control sometimes fail?

At times, despite everyone's best efforts, pest control operations fail to reduce pests to target levels and/or to protect native animal populations. DOC has developed an Animal Pest Management Framework—a set of logical steps to prepare, plan, implement and report on pest control operations, with the aim of improving pest control outcomes and make processes more transparent (DOC 2014). Specific risk areas such as legal permissions and safety procedures for using pesticides are covered by Standard Operating Procedures (SOPs). The Framework also provides a current 'Best Practice System' and pesticides 'Status List', with up-to-date information about pesticides. This system underpins current DOC pest management .

However, few staff have completed the Animal Pest Management Framework training, and adoption of best practise is patchy. Furthermore, an analysis of DOC's pest management database (PestLink), which is intended to include information on all pest control operations carried out by DOC, revealed that not all DOC control operations were reported (K. Vincent, DOC, unpubl. data). This makes it difficult to identify causes of failure and thus improve future operations.

5.2.1 Failure to reduce pests to target levels

Based on our own observations, we have collated the following list of potential reasons why operations may fail to reduce pests to target levels:

- Failure to follow best practice, leading to result and outcome targets not being met
- Use of new products that have not been rigorously field tested
- Incomplete knowledge of the efficacy of some tools
- Scale of operations being too small, resulting in ongoing reinvasion
- Insufficient toxin used due to lack of understanding of pest abundance
- Budget insufficient to carry out intensive-enough control for the operation to be effective
- Use of less-effective tools because operators were reluctant to use a more appropriate 'controlled substance' due to the extra paperwork required
- Breakdown in communication between technical advisors and operational staff leading to poor design and inconclusive outcomes

5.2.2 Failure to protect native animal populations

In some instances, even large-scale, long-term intensive pest control fails to lead to an increase in bird abundance (Hoare et al. 2013). There are several possible reasons for this:

1. **Failure to control predators sufficiently**
   - –Hoare et al. (2013) suggested that an inability to control rats likely explains the lack of increase in some forest bird populations.
   - –Over 30 years of management in the Murchison Mountains has failed to increase and maintain takahē numbers, likely due to the impact of large stoat plagues on adult takahē survival having been underestimated (Hegg et al. 2013). Therefore, it is likely that more-intensive trapping and/or the landscape-scale use of toxins will be required to protect takahē in this area.
   - –Stoat trapping alone has not protected whio in steep-walled glacial valleys during stoat plague years (Whitehead et al. 2010) or in less-mountainous terrain during non-mast years (Steffens 2013). Therefore, it is again likely that toxins either alone or in association with trapping will be needed to protect whio.
2. **Competition with other native species**—more than a decade of intensive pest control has so far failed to return the orange-fronted parakeet populations in three North Canterbury valleys to their 1990s levels. This may be a result of competition with yellow-crowned parakeets, which have enjoyed a population increase (G. Elliott, DOC, unpubl. data).
3. **Surge in other pest species**—e.g. prey switching or mesopredator/competitor release (see section 6.1.2).
4. **Insufficient area being controlled**—as covered in section 3.4, the control area must meet or exceed the minimum area required for species persistence.

5.3 Integrating pest control at sites

The following case studies highlight the complexity of using integrated pest control to target multiple pests to protect native species and communities.

5.3.1 Protecting kōkako in mixed forest

Although rats, possums and stoats can all be suppressed at a site, they have different control requirements. The control of ship rats and possums to very low levels (<10% rat tracking, <20% stoat tracking and <10% possum residual trap catch over the kōkako breeding season) is regarded as essential for kōkako recovery. There is less certainty about the need for stoat control during the nesting season (Innes et al. 1999). Stoats have only rarely been filmed at kōkako nests, but are frequently suspected of preying on nests and are thought to have killed a third of the nesting females at Mapara in the years after rat and possum control ceased (Flux et al. 2006). Modelling has also suggested that stoat control (by trapping or through secondary poisoning) may assist kōkako (Ramsay & Veltman 2005).

Possums and ship rats can both be controlled to low levels with cholecalciferol or 1080 in bait stations (over smaller areas), or through the aerial application of 1080. When first generation anticoagulants are used (less acutely toxic and requiring repeat feeding), possum numbers are often first reduced with possum-specific control techniques (to prevent competition for bait with rats), such as by using encapsulated cyanide in biodegradable bags nailed to trees or in traps, before the rat bait station network is activated.

Effective stoat control over the entire 3–5-month kōkako breeding season requires treatment over large areas due to rapid reinvasion at smaller sites (e.g. <1000 ha). Both aerial 1080 and anticoagulant toxins in bait stations can, at least initially, significantly reduce stoat abundance through secondary poisoning. However, reinvading stoats will not be vulnerable to the toxin because the rats, which act as poison vectors, will be dead. Stoat trapping is required over larger areas than those required for rat or possum control because stoats have larger home ranges.

The size of kōkako management areas using ground-based control is currently limited by the cost of control of ship rats, rather than stoats or possums. This is partly because rats require more closely spaced bait stations (current best practice = stations <100 m apart on lines 100 m apart versus ≤150 m × 150 m for possums), which are labour-intensive, and therefore expensive, to maintain; and partly because rat populations have a high intrinsic rate of increase (Hone et al. 2010) and recover more rapidly than stoat or possum populations in some forest types.

Therefore, the large-scale aerial application of 1080 is the most cost-effective method for controlling ship rats, possums and stoats (see 3.3 above) over areas large enough to support a viable kōkako population (currently estimated at 2000 ha), even though this has yet to be tested through regular repeated use and meaningful cost comparisons with alternative ground-based methods are required.

5.3.2 Protecting mohua (and other species) in upland forests

Mohua suffer significant population declines in upland forests during stoat-only irruptions, and dramatic declines following simultaneous rat and stoat irruptions. To optimise the timing of rat and stoat control operations in these forests, beech flowering and seedfall and rodent abundance need to be monitored to provide an indication of the likelihood and potential magnitude of a subsequent rat or stoat irruption (O'Donnell & Phillipson 1996; O'Donnell & Hoare 2012). Rising rat numbers during the winter following a beech mast indicate that rat control will be necessary in spring, and rising rat and mouse numbers indicate that stoat control will also be required (G. Elliott & J. Kemp, DOC, unpubl. data).

In these forests, rats are only controlled when they are abundant, using either aerially applied 1080 baits or bait stations (Elliott & Suggate 2007). Aerial applicarion of 1080 is probably most beneficial if carried out in October, just before mohua start breeding (G. Elliott, DOC, unpubl. data); although, if long-tailed bats are also being protected and if rat numbers are especially high, earlier control may be desirable. Where bait stations are used, baiting is begun earlier, and bait stations are filled repeatedly to allow the rodent and stoat populations time to decline before nesting starts. A variety of poisons have been used in bait stations (e.g. brodifacoum, coumatetralyl, pindone, 1080), some of which have proven more effective than others (Gillies et al. 2003; O'Donnell et al. 2011).

For mohua protection alone, stoat control is only required in association with stoat irruptions following a beech mast. If there are other species, such as kiwi, whio or kākā present, then stoat trapping needs to be continuous. For example, in the Catlins, mohua are the only species of conservation concern and so stoats are only trapped in summers following a beech mast. By contrast, in the Dart Valley, where kākā are also a conservation focus, stoat trapping is undertaken for 18 months, commencing at the beginning of the kākā nesting season in November and finishing when the mohua stop breeding the following summer; and in the Eglinton Valley, stoat trapping is carried out continuously, primarily because the road that runs up the valley makes it easy and affordable to service the trap line.

Effective possum control can also often be achieved incidentally through possums taking poisons that were primarily intended for rats. If, however, rats do not need to be controlled for many years, possums may need to be controlled in the interim to protect native plant and animal values.

5.3.3 Protecting whio and kiwi

Stoats are the main predators of whio and kiwi. They are usually controlled by trapping, with traps being deployed using landscape features (e.g. along ridges, spurs and valley floors) at best practice spacing for kiwi or in lines along valley floors for whio. However, in some places, trapping alone has failed to reverse the decline of whio (Whitehead et al. 2010; Steffens 2011).

The application of aerial 1080 can help to protect populations of these species, bringing the greatest benefit in masting forests if it is applied during stoat and rat irruptions, and when it is applied at a frequency that is also sufficient to suppress possums. In some places, the aerial application of 1080 may be sufficient to protect kiwi and whio populations (Sutton et al. 2012; Steffens 2013), but a combination of trapping with the aerial application of 1080 will bring better survival and higher productivity to both (Beath 2010; Steffens 2011).

5.3.4 Protecting a range of native species in upland beech and lowland mixed forests

Sites that are home to a large number of native species requiring protection and that contain a range of different forest types require a rather complicated pest control regime. The Project Janszoon restoration project in Abel Tasman National Park provides a good example of this. In this project, integrated pest control is planned to protect a range of species, including land snails, kākā, mohua, kiwi and robins. Pest control will be carried out over approximately 19 000 ha of forest, ranging from mixed coastal forests at sea level to beech-podocarp forests at mid-altitude and silver beech (*Lophozonia menziesii*) forest at up to 1000 m above sea level.

Pest control includes a network of traps to control stoats (over 15 000 ha), periodic aerial applications of 1080 to control possums, rats and any trap-shy stoats (over 12 000 ha), and bait stations for the intensive control of rats in the Falls River catchment (over 1500 ha). Stoat traps will operate continuously, aerial 1080 operations will be timed to coincide with rat and stoat irruptions, and bait station use will be triggered by specific rat tracking rates.

It is anticipated that a combination of continuous stoat trapping and aerial applications of 1080 timed to suppress rat and stoat irruptions should almost completely neutralise the impacts of these predators on native species at very moderate cost in the high-altitude, silver beech-dominated parts of the project area, which cover >3000 ha. The Falls River catchment has the highest public use in the project area and so frequent aerial applications of 1080 may not be socially acceptable here; however, the intensive trapping and bait station network will allow the recovery of native birds and, although this will be relatively expensive, it is also well-suited to volunteer involvement. Stoat trapping and periodic aerial applications of 1080 over the mid-altitude forests may not be sufficient to allow the complete recovery of bird communities, but will be an improvement over the current situation and may allow some of the more resilient species to recolonise this habitat. Given that this regime is still experimental, outcomes will be monitored to gain knowledge for ongoing improvements.

6. Where to from here?

While there has been much improvement in the control of small mammalian pests in the last three decades, it is clear that there are more gains to be made. During the course of preparing this overview, a number of particular issues became apparent. The following text addresses 11 such pest research and management issues and provides recommendations for their resolution.

Issue 1: We do not yet fully understand the relationship between forest mast events and rodent population responses to these.

Mast seeding in beech and podocarp forests is an important driver of changes in the abundance of rodents and stoats in New Zealand. Although rodent control strategies are well developed for medium- and high-altitude beech forests, they are less well developed for low-altitude forests where rodents are always abundant, and for forests that are a mixture of high- and low-altitude forest types. Furthermore, our understanding of the pattern of beech masting over the landscape is poor. While there are years when almost no beech trees anywhere in New Zealand produce seed and there are years when nearly all beech trees produce seed; in most years, beech seeding is patchy in time and space. In addition, different beech species produce different quantities of seed.

> ***Recommendation 1***: *Develop optimum pest control strategies for all forest types through extending current research and modelling of forest dynamics and rodent population ecology.*

Issue 2: We don't know how big an area needs to be managed to achieve protection of many of our threatened species.

To date, little work has been carried out to determine minimum areas required for species persistence (MASPs). We need estimates of MASPs so we know the size of the area we must manage to ensure species persistence.

> ***Recommendation 2***: *Determine MASPs of New Zealand threatened species, with a particular focus on home range size, natal dispersal distances and minimum population size required for retaining rare alleles.*

Issue 3: We don't know the maximum residual pest abundance tolerated by different native species.

For pest control to be effective, pest populations must be maintained below levels that negatively impact the native animal populations we seek to protect. Few examples of such maximum pest abundance targets (e.g. < 10% rat tracking, < 20% stoat tracking and < 10% possum residual trap catch over the kōkako breeding season) are known.

> ***Recommendation 3:*** *Determine acceptable maximum pest abundance thresholds for New Zealand's most endangered native species.*

Issue 4: We need more-effective and safe ground-based control tools.

There will always be a need for ground-based control at smaller (< 1000 ha) sites (e.g. forest remnants, coastal, alpine and riverine strips). We already have many useful ground-based control tools (mainly traps and toxins) and are developing more that could significantly improve the efficiency and effectiveness of ground control programmes (e.g. long-life lures, A12 & A24 traps, Spitfire toxin dispensers and PAPP). However, preliminary research suggests that residues of anticoagulant poisons (not just brodifacoum) are widespread in New Zealand fauna, although the consequences of the residues are little understood. This may undermine social license to use such toxins in the future.

Recommendation 4: *Continue development of new long-life lures, traps and toxins that will continue to incrementally improve the effectiveness of ground-based pest control.*

Recommendation 5: *Continue research into the spread and consequences of both first and second generation anticoagulant toxins in New Zealand ecosystems.*

Issue 5: We require a prioritisation system that selects large sites for pest control.

Landscape-scale, multi-species pest control is required to maintain and restore multiple populations of native animals (i.e. functioning communities). Unless we routinely undertake pest control at a landscape scale in New Zealand, the bulk of public conservation land will receive no pest control and, in the future, will support only the most common and resilient species. Landscape-scale multi-species pest control is already carried out at some sites, including some Operation Ark sites and kiwi sanctuaries, and at more sites as part of the 'Battle for our Birds' project. However, at present the assessment of sites for landscape-scale pest control is ad hoc.

Recommendation 6: *Develop a system of prioritising areas for undertaking large-scale pest control that includes consideration of the existing smaller-scale Ecological Management Units and the necessity of controlling multiple pests.*

Issue 6: The effective aerial application of 1080 is legally, operationally and socially complex.

Different aspects of aerial 1080 use are managed by different parts of DOC, often to varying standards, which decreases efficiency, and increases risk. A more-integrated management approach using a dedicated team of legal, public awareness, operational and science staff could increase operational effectiveness, reduce cost and risk, and increase biodiversity outcomes and public support.

Recommendation 7: *Manage the use of aerial 1080 throughout the country as a single programme run by a national team.*

Issue 7: We have too few measures of the long-term benefits of 1080 use to different populations of native species.

Aerial 1080 is currently our most important pest management tool. We need to measure the benefits of aerially applied 1080 to native populations to ensure we are achieving the benefits anticipated and to support continual improvement. Better measures would allow refinement of management (e.g. optimisation of treatment return times) and provide a clearer understanding of its benefits, costs and risks to the New Zealand public. Better understanding would likely flow on to better support. Work that measures the responses of different native animal populations is currently underway.

Recommendation 8: *Continue to conduct research into the long-term benefits of aerially applied 1080 to native animal populations.*

Issue 8: Our current stoat control tools are either expensive, limited in rugged terrain or dependent on high rodent numbers.

Stoat trapping is expensive, labour intensive and not always effective (e.g. following beech mast events and when stoats avoid traps). A stoat-specific toxin for aerial application would complement other tools. PAPP could be applied aerially in commercially available meat baits at a fraction of the cost of other control methods (G. Elliott, DOC, unpubl. data) and, if used in alternative years to the aerial application of 1080 for rats, stoats and possums, could result in extremely effective pest control at a landscape scale. However, PAPP is not currently registered for aerial application.

Recommendation 9: *Test the efficacy of aerially applied PAPP and obtain registration.*

Issue 9: The effectiveness of pest control can be improved by adherence to best practise.

The quality of pest management operations has been variable, with operational objectives, best practice, standard operating procedures and legal requirements not always being met. However, just how variable operations have been is unknown, as not all control operations are written up, despite reporting being part of DOC's Animal Pest Management Framework best practice.

> ***Recommendation 10:*** *Manage to ensure that best practise as identified in the Animal Pest Management Framework is followed.*

Issue 10: Learning about the efficiency and effectiveness of large or new control operations is compromised by lack of robust monitoring and follow through.

If the uncertainty in management programmes (whether they achieve the intended goals) is not made explicit and then monitored, there is a risk that expensive mistakes will be repeated. Adaptive management offers a way to improve management techniques and outcomes by formalising informative feedback loops between intended and actual outcomes.

> ***Recommendation 11:*** *Learn from our landscape-scale pest control by establishing rigorous monitoring and apply findings in future operations.*

Issue 11: We lack accurate information on the costs of pest control nationally.

Greater accuracy in costing of pest control would not only allow us to make more informed choices about the most cost-effective method to use, and better comparisons of the costs and benefits of different methods, but would also reduce the risk of failure due to insufficient resources. DOC's current financial system is primarily activity based as opposed to project based.

> ***Recommendation 12:*** *Capture the costs of pest control projects systematically.*

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