Manaaki Whenua
Landcare Research

Conserving indigenous fauna within production forestry landscapes

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Summary

Project and Client

- This report includes a comprehensive literature review of current knowledge on indigenous fauna within plantation forests in New Zealand, and the impact of forest harvest. It also reviews international literature on practices used to conserve fauna within production forestry landscapes. The work was undertaken for Gisborne District Council through Envirolink Advice Grant 1854-GSDC150.

Objectives

- Review current knowledge on indigenous fauna within plantation forests in New Zealand, and the impact of forest harvest.
- Relate indigenous faunal conservation management methods in New Zealand with those that have been adopted overseas.

Methods

- Information on New Zealand and international faunal biodiversity within plantation/production forests was searched for using Google, Google Scholar, CAB abstracts, Current contents, and Web of Science search engines/databases.
- We collated and tabulated records and habitat requirements of biodiversity in New Zealand plantation forests, and harvesting impacts on them.
- We reviewed overseas approaches to biodiversity conservation in plantation forests and considered their application in New Zealand.

Results

- We summarised records of indigenous fauna (24 bird species, two bats, two frogs, 30 lizards, and 55 invertebrates) found within plantation forests in New Zealand that contained information on habitat requirement, home range/dispersal and/or impacts of harvesting, stand age preference and management options for conservation (Appendix 1).
- While few studies have been carried out on indigenous fauna in plantation forests in New Zealand, current knowledge generally links biodiversity of forest specialists with habitat age. Harvesting forests every ≤30 years does not allow representative, specialist, indigenous forest fauna to develop.
- The main overseas approach to fauna conservation in plantation forests is retaining some unlogged forest in logged stands (‘forest retention’)

Conclusions

- Given the diverse habitat requirements, dispersal abilities and threat status of native fauna in New Zealand, a multifaceted approach will be required within plantation forestry to help conserve biodiversity on a landscape scale.

- This should include retaining areas of forest which develop high structural complexity, maintenance of mixed age exotic stands, and individual threatened species programmes.
- Retention of set-aside forest is likely to be increasingly required by international certification schemes.

Recommendations

- A key area for regional and local authorities in future will be to determine if sufficient forest retention is occurring across landscapes (including within plantation forests) to help conserve indigenous forest fauna. This should include:
    - the prevention of further indigenous forest remnant removal (regardless of size) including legal protection in areas with gross inconsistencies between expected and actual vegetation cover as recommended by Price & Fitzgerald (2017)
    - a stocktake of existing habitat, and assessment of functional connectivity for species of interest (see Burge et al. (2017) for an example of how this may be done), to help with selection of new areas for habitat retention
    - providing support and lobbying central government for biodiversity grants (similar to those currently available for erosion control) to help forestry owners/managers move towards habitat retention goals set by Forest Stewardship Council and Programme for the Endorsement of Forest Certification schemes
    - national research on biodiversity, social, cultural, and economic outcomes of habitat retention initiatives.

1 Introduction

Nearly three quarters of indigenous forest has been cleared from New Zealand in the last 1,000 years (Ewers et al. 2006), including 85% of lowland forests and wetlands (Ministry for the Environment (MfE) 2007). In some of the main plantation forestry regions – Gisborne, Waikato, Bay of Plenty, Hawke's Bay and Canterbury – indigenous forest losses have been high (84%, 77%, 52%, 83% and 91% respectively; Ewers et al. 2006). Initially, much of this occurred in lowland areas for agriculture, followed by clearance of more marginal land for plantation forestry (Walker et al. 2006). This has now generally ceased (Maunder et al. 2005), but not entirely. Between 1996 and 2012 10,000–16,000 ha of indigenous forest was cleared nationwide (MfE 2015, 2018), and since 2008 approximately 2,500 ha of native vegetation was cleared, some of which was selectively logged, within the Gisborne district (Easton 2016; Gisborne District Council 2016; Salmond 2017). While 23% of the Gisborne region remains in native vegetation, only 15% of this is original vegetation and there are only 25 hectares of intact forest remaining in the lowland areas. Furthermore, nearly half of all forest in the Gisborne district is now exotic (Easton 2016; Ministry for Primary Industries (MPI) 2016; New Zealand Forest Owners Association 2017). Consequently, exotic plantation forests are becoming more important in some regions of New Zealand as habitats for helping to conserve indigenous fauna on a landscape scale.

New Zealand has been isolated for 85 million years and is recognised as a global biodiversity hotspot (Myers et al. 2000). It has very high endemicity – 63% of terrestrial vertebrates (Myers et al. 2000) and 90–97% of insects (Atkinson & Cameron 1993; MfE 2000; McGuinness 2007) – but habitat loss and fragmentation are major biodiversity threats (MfE 2015, 2018), with many indigenous species facing extinction, including 81% of resident bird species, 88% of reptiles and 100% of frogs (MfE 2015). The state of invertebrates has been particularly difficult to quantify as the total number of species is not known. In New Zealand about 21,000 invertebrate species (mainly insects) have been described, but about 50,000 may exist:

> With so many species unknown, and likely to remain so for a long time, many may disappear before they have even been identified as threatened. This has led some scientists to the view that single-species recovery programmes for invertebrates are too piecemeal and should be replaced by habitat protection programmes which scoop up many species at once. However, others have argued that simply protecting habitats is not sufficient on its own because representative habitat for many threatened species no longer exists, or is infested with predators. Towns and Williams (1993) propose a balanced approach, in which habitat protection and restoration is integrated with species recovery programmes. (MfE 1997)

Whether plantation forestry can help improve net biodiversity benefits or not is multifaceted (Carnus et al. 2006). If plantation forest replaces native forest then biodiversity usually reduces (Brockerhoff et al. 2008), whereas replacement of degraded (or agricultural) land is most likely to contribute to increased biodiversity (Bremer & Farley 2010). After plantation forestry is in place it can be argued that the potential for negative impacts on biodiversity in remaining primary native forest is reduced because the need to extract resources is offset (Pawson et al. 2013), and that plantation forests can provide good habitat for many native faunal species (Maunder et al. 2005; Brockerhoff et al. 2008; Pawson et al. 2010; Quine & Humphrey 2010; O'Hanlon 2011; Pawson et al. 2013), especially when native plant representation is high (Peralta et al. 2018). According to Maunder et al. (2005), the composition and abundance of native shrub and ground cover in older pine plantations can be diverse and well-developed and is comparable to that in indigenous forest (Allen et al. 1995; Ogden et al. 1997). In fact, Pawson et al. (2010) listed 118 threatened species of flora and fauna recorded or observed within plantation forests. However, intensively managed plantation forests do not provide the same quality of habitat that primary forests do (Paillet et al. 2010), and some even argue that exotic plantations have very low diversity of native flora and fauna, may be acting as a source of pests and pathogens to adjacent native forest, and that a transition to native plantations should be the long-term goal (Rosoman 1994).

Benefit to, and relevance of, native biodiversity within New Zealand's exotic plantation forests is not well defined or measured, but is most likely compromised by silviculture practices, particularly harvesting frequency (Brockerhoff et al. 2001; Pawson et al. 2005, 2010). This lack of knowledge may be partly due to poor interaction between policy makers, scientists and forest managers (Brockerhoff et al. 2001). However, as mentioned above, there is abundant evidence that plantation forests (overseas and in New Zealand) can provide valuable habitat, including buffer zones for indigenous remnants/riparian areas, connectivity between larger indigenous reserves and as stand-alone (often older-growth) forest containing threatened species (Ogden et al. 1997; Norton 1998; Brockerhoff et al. 2003, 2008; Maunder et al. 2005; Pawson & Brockerhoff 2005; Deconchat et al. 2009; Pawson et al. 2010, 2013). Furthermore, most forestry owners/managers in New Zealand are already committed to the conservation of threatened species that are known to occur within their forests and have signed a number of environmental agreements with conservation groups, including the New Zealand Forest Accord in 1991 and the New Zealand Principles for Commercial Plantation Forest Management (PCPM) in 1995 (Dyck 1997). Many forest owners/managers are also signatories to the International Forest Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification (PEFC) schemes (Dyck 1997; Weir 2016). Both New Zealand schemes acknowledge the distinction between indigenous and production forests, whereas both international schemes were developed overseas where production forests are predominately native species. Both FSC and PEFC are certification systems which offer an independently accessed formal approach for meeting global biodiversity goals and demonstrating accomplishments (Miller et al. 2009). Companies are assessed every 5 years and non-compliance can result in loss of certification (Hock & Hay 2003).

In the past, New Zealand forestry companies have been reluctant to see wider protection of indigenous biodiversity as a primary objective (New Zealand Forest Owners Association 1991; New Zealand Forest Owners Association Inc et al. 1995; Dyck 1997). Dyck (1997) emphasises the distinction between "the important heritage value of remaining natural forest and the value of commercial plantation forests as an essential source of renewable fibre" and that principles from the various New Zealand environmental agreements with conservation groups "clearly recognise that plantation forests are established primarily for wood production". This philosophy, along with a lack of knowledge of native species distribution and abundance and research to identify management tools to benefit biodiversity, has governed efforts to conserve indigenous biodiversity within New Zealand's plantation forests.

Pawson et al. (2010) published a list of threatened indigenous species known to occur within New Zealand's plantation forests and discussed general impacts of current forestry management practices. Impacts of harvesting are likely to be wide-ranging depending on species' habitat preference, home range and ability to disperse. We provide an up-to-date list of scientific literature, published articles and available unpublished reports, on native fauna found in New Zealand's plantation forests, particularly if impacts of harvesting on individuals and/or populations were available. Our search excluded freshwater and marine species which have been covered elsewhere (MPI 2017; New Zealand Government 2017). We discuss impacts of harvesting and how current plantation management practices may be modified to further enhance biodiversity. The intention of this report is to provide a starting point to better inform regional and local authorities and forestry companies on strategies for protecting our indigenous faunal biodiversity on a landscape scale.

2 Background

Environmental regulations for the New Zealand forestry sector have historically been inconsistent between regions and land users under the Resource Management Act (RMA), and this has led to inconsistent treatment of forestry operations across the country with variable environmental outcomes (Weir 2015; Fowler 2017). The new National Environmental Standards (NES) for Production Forestry (New Zealand Government 2017) have been developed to address these issues by providing a set of nationwide environmental regulations within which 'are a range of matters where territorial and regional authorities can be more stringent regarding certain 'local' issues' (Fowler 2017).

Protection for native fauna in the NES for production (plantation) forestry covers freshwater and marine fauna with regulations for river crossings, earthworks and post-harvest impacts near aquatic habitats or riparian zones, and includes supplementary material on fish distribution and spawning (MPI 2017; New Zealand Government 2017). In addition to the NES, Gisborne District Council (GDC) have developed a freshwater plan proposal which has been incorporated into the Tairāwhiti Resource Management Plan (Gisborne District Council 2015). The proposal is consistent with, and builds on, the National Objectives Framework specified by the National Policy Statement for Freshwater Management (MfE 2017). The plan reiterates NES regulations to reduce erosion and deposition of forestry slash into waterbodies and more generally promotes planting of riparian areas to enhance the habitats of freshwater flora and fauna. Forestry companies also have some good resources and awareness about erosion and freshwater biodiversity and have recently won environmental awards for innovative solutions for soil stabilisation and native fish passage through culverts (Ernslaw One Ltd 2016).

The only mention of terrestrial fauna in the NES is under the 'General provisions' section (subpart 10) on indigenous bird nesting. Forestry activity is permitted in the vicinity of Nationally Critical, Endangered or Vulnerable indigenous bird species' nest sites as long as trained forestry staff recognise and confirm these locations and collect information to help avoid or mitigate adverse effects (New Zealand Government 2017). No further information is provided regarding how adverse effects may be avoided or mitigated. Furthermore, there is no consideration given to other fauna recorded from New Zealand plantations including bats, frogs, reptiles and invertebrates, many of which are threatened. Previous reports on impacts of plantation forests in New Zealand have also focused on water and soil quality with limited attention to fauna (Hock et al. 2009). Gisborne District Council (GDC) is aware of this gap and have commissioned this report to review information on all known indigenous fauna in New Zealand plantations and how to best protect faunal biodiversity during harvesting.

The timing of this report coincides with the start of significant harvesting activity following large scale planting that occurred after Cyclone Bola in 1988. Forestry companies that are currently signed up with the FSC within the East Coast region identify where rare, threatened, and endangered species are located (i.e. falcon nests, Hochstetter frogs, and bats) as part of their resource consent application but this is based largely on informal sightings rather than formal surveys. For all other harvest areas, where species of interest have not been seen, there is no ecological assessment required unless the forest is located in an area known by the Department of Conservation (DOC) or GDC for significant natural values. Due to a lack of information it is likely that areas providing habitat for these, and other species, are not being identified (M. Cave, pers. comm.). The long-term objective is to move away from a passive consideration of biodiversity to an active awareness, on a landscape scale, that will result in better long-term biodiversity outcomes for the region.

3 Objectives

- Review current knowledge on indigenous fauna within plantation forests in New Zealand, and the impact of forest harvest.
- Relate indigenous faunal conservation management methods in New Zealand with those that have been adopted overseas.

4 Methods

The literature search was split into three stages:

- First, information on New Zealand faunal biodiversity within plantation/production forests was searched for using Google, Google Scholar, CAB abstracts, Current contents and Web of Science search engines/databases.
- Second, information on international faunal biodiversity within plantation/production forests was searched for using the above resources.
- Third, more specific searches focusing on New Zealand indigenous birds, bats, frogs, reptiles and invertebrates were completed.

Research comparing New Zealand and overseas attempts to conserve biodiversity within plantation forests was summarized and discussed. Individual species data were sorted into various categories based on habitat requirements, and tabulated. Habitat requirement categories include 'specialist/obligate' species that rely on intact forest throughout their life cycle, 'primary' species that spend most time in intact forest but occasionally leave to feed on seasonal foods elsewhere, 'generalist/facultative' species that occur in a range of habitats, and 'open' species that occur in open/disturbed habitats. These categories were chosen because they are reported as being relevant to forest harvesting impacts in the literature.

5 Results

Records of indigenous fauna found within plantation forests in New Zealand that contained information on habitat requirement, home range/dispersal, impacts of harvesting, stand age preference, and management options for conservation, are summarized in Appendix 1.

Birds and bats

Young plantation forest stands are structurally simple/homogeneous and mainly support facultative insectivorous birds (fantails, grey warblers, shining cuckoos) (see Appendix 1). As stands age and structural complexity develops, just before harvest, primary insectivorous hole-nesters/roosters (kiwi, long-tailed bats, rifleman, morepork) start to colonize. Finally, if left unharvested a range of facultative, primary, and obligate forest species, including nectivores (bellbird, kākā, tūī), frugivores (kererū, kōkako), and roosting omnivores (i.e. short-tailed bats), may eventually utilize old-growth pine forest habitat (30–100 years old?), where there is a well-developed native understory (Spurr & Coleman 2001; Peralta et al. 2018). Some species, such as the New Zealand falcon, utilize a range of habitats created within a forest plantation matrix relying on a mixture of stand attributes.

Management recommendations for protecting threatened birds during forestry operations vary depending on species, but under the new National Environmental Standard for Plantation Forestry involve confirmation of presence of indigenous bird species, confirmation of presence and identity of affected nest sites, and providing training for employees to help avoid or mitigate adverse effects on affected nest sites and indigenous bird species (New Zealand Government 2017). Other existing steps taken by forestry managers include the use of specially trained dogs in kiwi areas to detect birds before potentially destructive operations take place (Forest Owners Association 2006).

Frogs

There is limited information of native frogs in plantation forestry and the impact of harvesting. Most sightings have been in steep gullies that retain some native forest and are buffered from other land-use (such as agriculture) by pine forest. Pine-forest habitat is slightly less suitable than native forest but can provide habitat in the short term before harvesting. Hochstetter's frog (*Leiopelma hochstetteri*) prefers forest with old-undergrowth containing cobble (63–200 mm stones) and decaying logs >15 cm in diameter (Easton et al. 2016). Wind-throw events and disturbances during harvesting can impact on water quality (by introducing gravel, sand and silt) and expose habitats, leaving streams unsuitable for frogs.

Lizards (Geckos and skinks)

Very little is known about the use of plantation forests by lizards, and the impacts of harvesting. Species found in plantation forests and some information about habitat requirements are summarized in Appendix 1.

Invertebrates

Clear-fell areas and young plantation stands have higher invertebrate species richness (Pawson 2006; Berndt et al. 2008; Pawson et al. 2008) than adjacent mature plantation forest. Young stands are structurally simple/homogeneous and mainly support generalist invertebrates (see Appendix 1). As stands age and structural complexity develops, invertebrate feeding guilds such as the saproxylic wood feeders, fungal feeders and predators/parasites establish (Sky 2011). Finally, if left unharvested or if some pre-harvest structural complexity is retained, plantation forest may in time provide suitable habitat for obligate native forest invertebrate specialists if there are local source populations. In the case of the critically endangered ground beetle *Holcaspis brevicula*, management recommendations include giving some form of protection to any beetle hot spots that are found 'where attempts could be made to conduct forest management more sympathetic to the maintenance of biodiversity' (Brockerhoff et al. 2005). While specific actions are not recommended by Brockerhoff et al. (2005), Hartley (2002) suggests snag and reserve tree retention (e.g. leave strips), where mature trees and/or understorey vegetation are left unharvested or allowed to regenerate, and site-preparation favouring methods that reflect natural disturbances and conserve coarse woody debris.

Powelliphanta lignaria rotella (nationally endangered) is one example of a threatened giant land snail species that has re-colonized former habitat now in plantation forestry with a dense understorey of regenerating native vegetation. Management recommendations to conserve threatened land snails generally suggest not logging critical areas that are currently in plantation forest, not replanting with pines and blocking ditches formed by v-blading (to avoid drownings), and/or harvesting with great care. Harvesting with care includes avoiding ground hauling logs to maintain topsoil and litter, carefully protecting all gully remnants of native forest, and ensuring all machinery is thoroughly cleaned of weed seeds (Walker 2003).

While few studies have been carried out on indigenous fauna in plantation forests in New Zealand (Maunder et al. 2005), current knowledge generally links biodiversity of forest specialists with habitat age. Harvesting forest every ≤30 years does not allow representative, specialist indigenous forest faunal to develop.

6 Discussion

Biodiversity in plantation forestry is becoming more important as a component of native species conservation as land-use pressure intensifies. Plantation forestry makes up 18% of New Zealand's forests and 45% of those in the Gisborne district (Easton 2016; MPI 2016; New Zealand Forest Owners Association 2017) where most of the native biodiversity has been lost (Salmond 2017). Plantation forestry is now a large and potentially significant habitat for indigenous biodiversity in Gisborne but clear-fell harvesting is often incompatible with native forest fauna conservation.

Records of direct impacts of forest harvesting on forest fauna mostly come from studies on threatened species. These relate to immediate loss of habitat and the associated destruction or removal of roost sites, nests, burrows, foraging areas, decomposing wood, litter and soil. Individuals, especially juveniles, may also be killed or incapacitated by crushing, burning, exposure, predation and starvation. The Forest Owners Association has a website with guidelines for managing rare species in plantation forests, see http://rarespecies.nzfoa.org.New Zealand/fauna/ and actively promotes wildlife conservation on a species by species basis. In-direct impacts of forest harvesting on native fauna are not well known; however, some impacts can be inferred by looking at what species are left behind.

6.1 Retaining native biodiversity in plantation forests

Birds and bats

Data from plantation forests in New Zealand indicate that maximum avian richness will result from a mosaic of pine stand ages with high local heterogeneity. Within this mosaic, stand edges, clear-fell/areas with young plantation forest and pine stands over 20 years old are particularly important. However, if conservation of indigenous forest dwelling bird species is the management aim, then older stands must be well represented throughout. Plantation forestry, particularly older growth forest with high structural diversity, can support very high native bird densities (Clout & Gaze 1984; Fegley & McLean 1987; Seaton et al. 2010a). Kaingaroa pine forest has boasted the highest densities of birds recorded on the New Zealand mainland (Jackson 1971; Spurr & Coleman 2002; Pawson & Brockerhoff 2005; Forest Owners Association 2006). In fact, if left long enough (>100 years?), plantation forest set-asides would continue to improve as habitat for a range of native birds and other fauna (Ball et al. 2013) as an understorey of native flora developed (Spurr & Coleman 2001). Mature stands in the landscape (or better still native forest areas within plantations (Clout & Gaze 1984)) provide shelter/protection, breeding sites and feeding grounds for forest dwelling birds (Seaton et al. 2010a). For areas where retaining groups of mature trees is not possible, Clout and Gaze (1984) advocate for retention of dispersed old, or dead, trees from one rotation to the next to encourage hole nesting birds and planting of amenity areas with fruiting and nectar providing species for frugivorous/insectivorous birds. Bats also require old-growth forest to find trees suitable as roost sites. Short-tailed bats have been recorded roosting in long-dead native spars retained in young *P. radiata* stands (Borkin & Parsons 2010b) and may, in time, utilize pine forest if old enough trees are retained. There have also been some sightings of kōkako in plantation forests including one adult male which had a home range entirely consisting of old-growth pine forest with a well-developed native understorey (Innes et al. 1991). Kākā have also been recorded utilizing, and in some cases damaging, plantation trees deriving a considerable portion of their diet from their sap and seeds (Beaven 1996).

However, some forest dwelling species, like long-tailed bats, do benefit from edges and/or open corridors for movement and feeding (Borkin & Parsons 2009). The New Zealand falcon is another example of a species that has benefited from edge creation and now occurs in higher densities in and around plantation forests than in any other habitat in New Zealand. However, falcons are not strictly forest specialists, they can be found in a range of habitats relying on a mixture of open areas and young stands for nesting and hunting and mature trees as vantage points for hunting, territorial defence, and as shelter from heavy rain or strong winds (Horikoshi 2017; Horikoshi et al. 2017).

Frogs and lizards

Three of New Zealand's native frog species have become extinct, and of the four remaining species Hamilton's frog (*Leiopelma hamiltoni*) is one of the world's most endangered frogs (with less than 300 individuals remaining) and the Maud Island frog (*L. pakeka*) is only found on Maud Island in the Marlborough Sounds https://www.doc.govt.nz/nature/native-animals/reptiles-and-frogs/frogs-pepeketua/. Both Archey's frog (*L. archeyi*) and Hochstetter's frog (*L. hochstetteri*), have been recorded in plantation forests. Very little is known about Archey's frog in plantation forests and the impact of harvesting, but work on Hochstetter's frog demonstrates the importance of retaining native forest remnants in gullies that contain high quality streams. Any harvesting that compromises stream quality through the introduction on gravel, sand and silt will compromise frog habitat, including the removal of plantation trees that may buffer these areas from adjacent non-forest land-use such as agriculture (Green & Tessier 1990; Crossland et al. 2005; Easton 2015; Easton et al. 2016).

Because of their intrinsically slow population growth rates and vulnerability to introduced predators, lizards are not very good at reinvading after disturbance. The exceptions to a limited extent are some of the smaller more fecund skinks, such as *Oligosoma polychroma*. However, this is a terrestrial, sunlight-requiring species, so while it may spread to some extent into new forests while the trees are very young, the habitat will not be suitable once the canopy has closed. The reverse will be true for arboreal species, but these tend to have longer generations and lower fecundity, so will be slow to colonise even when suitable habitat is present. However, even quite small native remnants in plantation forests may well contain arboreal skinks and geckos (e.g., *Naultinus* and *Mokopirirakau*; also, possibly *Oligosoma striatum*) and in the North Island, litter-dwelling skinks such as *Oligosoma aeneum* and *O. ornatum* (R. Hitchmough, , DOC, Wellington, pers. comm. 2018).

Invertebrates including snails

As with birds, high invertebrate species richness in clear-fell areas and young plantation stands is due to the presence of more exotic and early successional/disturbance-adapted open habitat species (Pawson 2006; Berndt et al. 2008; Pawson et al. 2008), whereas native forest generalists become more common as stands age. Sky (2011) demonstrated how the development of feeding guilds, with a transition from primary wood feeders to predators/parasites and fungal feeders is related to increasing dead wood age. Native forest specialists that are probably more sensitive to habitat disturbance were either absent or in low numbers in studies by Pawson (2006), Berndt et al. (2008), and Pawson et al. (2008), and many, particularly threatened species, have specialist habitat requirements and host associations that are unlikely to be found in rotational plantation forests (Pawson et al. 2010). This has been demonstrated by Berndt et al. (2008), who found a forest specialist in very low numbers at Eyrewell Forest, where there has been historical clearing for agriculture before forestry and/or several plantation forest rotations, compared with large numbers in native southern beech stands in adjacent foothills of the Southern Alps. Pawson (2006) also commented that clear-fell sensitive species may have already been lost from his Central North Island study sites where two or three rotations had occurred. Furthermore, with approximately half of native invertebrates in New Zealand not even described (MfE 1997), it is hard to predict the magnitude of loss that has occurred in such heavily modified environments. Despite this, older exotic plantations (>30 years old) may still provide important alternative habitat for some native forest specialists in landscapes with a low proportion of native forest cover, but proximity to native habitat is likely to be an important predictor of beetle community composition (Pawson 2006; Pawson et al. 2008). It is difficult to predict dispersal abilities of forest specialists within a plantation scenario. Many are flightless and have already been 'filtered out', meaning experimentation is difficult if not possible. It is clear that some carabids can colonise entire 50-ha clear-fell areas within a rotation but more studies, such as that done by (Pawson et al. 2011), will be required to test the dispersal abilities of individual species across a native forest/plantation forest boundary.

Snails are another group where some information is available on impacts of forest harvesting (see Appendix 1). New Zealand's indigenous forests provide habitat for a number of native land snails including at least 16 species and 57 sub-species of the carnivorous *Powelliphanta* spp. representing some of the most distinctive invertebrates in New Zealand. Most *Powelliphanta* spp. are 'spot endemics', meaning each species and sub-species is confined to its own small area. Habitat loss including loss of native remnants is one of the major threats to the 40 taxa that are currently ranked as being of national concern https://www.doc.govt.nz/nature/native-animals/invertebrates/powelliphanta-snails/.

Lessons from overseas

Overseas studies have attempted to use lessons from natural forests to promote biodiversity within managed forests (Hansen et al. 1991; Irwin et al. 2000). These largely involve retaining structural legacy from pre-harvest stands, which ultimately enhance biodiversity and ecosystem function, including soil protection and nutrient retention (Franklin et al. 2002). Other approaches include mixed aged/species stands optimally juxtaposed across the landscape to help support biodiversity (Gjerde & Saetersdal 1997; Wigley & Roberts 1997) and patch clear-fell strategy work from New Zealand (Nghiem & Tran 2016). But success relies heavily on a good understanding of species' responses to harvest, time to population recovery, and distance from potential source populations. These approaches also assume survival of perpetually transient populations in relatively young, structurally simple, forests. In a New Zealand study, Pawson et al. (2009) recommends maintaining connectivity between stands with trees of at least 8 years old to maintain generalist native forest carabid fauna distinct from disturbance-adapted fauna in young stands. However, as noted by the authors, and mentioned earlier, it is likely that disturbance-sensitive forest-dwelling carabids had already been lost from these stands during an earlier agricultural phase or as a result of multiple forest rotations. A similar scenario was described by Berndt et al. (2008) in the Eyrewell plantation forest study.

Retention forestry

A recurring theme in almost all research on biodiversity within plantations is the importance of landscape heterogeneity and stand structure complexity (including snags, cavity trees, and coarse-woody debris) for conservation of forest-dwelling native fauna (Hansen et al. 1991; Freedman et al. 1996; Donald et al. 1998; Franklin et al. 2002; Lindenmayer & Hobbs 2004; Barbaro et al. 2005; Oxbrough et al. 2010; Gustafsson et al. 2012; Pawson et al. 2013; Fedrowitz et al. 2014; Mori & Kitagawa 2014). In fact, retention forestry, the practice of setting aside small areas within plantation forests, has emerged in recent decades as an effective, practical, approach to achieve biodiversity gains internationally and is now used in many countries including USA, UK, Canada, Australia, Germany, Sweden and Argentina (Hansen et al. 1991; Humphrey 2005; Aubry et al. 2009; Gustafsson et al. 2012; Lindenmayer et al. 2012; Pawson et al. 2013; Fedrowitz et al. 2014; Mori & Kitagawa 2014; Simonsson et al. 2015), and has also been suggested as an approach for New Zealand since the 1980s (Clout 1984). Despite the genesis of retention forestry being linked with native plantation forestry (80% of the world's plantation forests utilize native species; Payn et al. 2015), the principles can be adapted to old-growth exotic plantation species like *Pinus radiata*, which makes up 90% of New Zealand's plantation forests (New Zealand Forest Owners Association 2017).

Simonsson et al. (2015) have given a detailed account of the history of retention forestry in Sweden, including driving forces, debate and implementation. The Swedes (and the North Americans) were early adopters of retention forestry where it is now practised by all landowners, public and private (Gustafsson et al. 2012). During the early 1970s there was widespread criticism and protest of clear-cutting practices in Sweden. Foresters had difficulty understanding and assimilating the harsh and often general criticism, so the Ministry for Agriculture set up a working group in 1972. The group produced a report in 1974 that largely supported clear-cutting and suggested various kinds of retention forestry that mainly focused on aesthetic considerations. However, it was not until the threatened species-led approach, initiated by the publication of threatened species lists in 1975 (which later became part of the 'Red-listed species'), that retention forestry development in Sweden gained momentum. During the 1990s, various drivers, including increased public awareness of biodiversity, a 'timber depression', new Forestry Act regulations, and forest certification systems (FSC & PEFC), whose standards clearly state requirements for retention forestry, led to a breakthrough in retention forestry. An interactive map showing set-aside areas currently in place in Sweden can be found at: http://protectedforests.com/.

As a strict minimum, it is recommended that retention stands should retain 5–10% of trees well dispersed across the landscape; however, depending on local biodiversity requirements/challenges, larger or more closely spaced stands may be needed to provide better biodiversity outcomes (Woodley & Forbes 1997; Aubry et al. 2009; Sverdrup-Thygeson et al. 2014; Ruffell & Didham 2017). Aubry et al. (2009) found that retention of >15% of trees (the US federal standard in the Pacific Northwest) was needed to ameliorate microclimatic extremes and retain sensitive biodiversity. The pattern of retention, group versus single tree, did not have a significant effect on biodiversity, except that ≥1 ha group retention greatly reduced damage to, and mortality of, residual trees and provided short-term refugia for forest organisms sensitive to disturbance or environmental stress (deMaynadier & Hunter Jr 1995). Group retention does not always need to be large. Patches as small as 1 ha had value as habitat for forest birds, reptiles, frogs, mammals, and invertebrates (MfE 1997; Lindenmayer & Hobbs 2004). Even patches as small as 0.25 ha had high levels of invertebrate diversity in *P. radiata* plantations in New South Wales (Davies & Margules 1998; Davies et al. 2000), and have been suggested as suitable to provide temporary habitat and facilitate dispersal through the landscape in plantations in Britain (Humphrey 2005).

Despite recent meta-analyses by Fedrowitz et al. (2014) and Mori and Kitagawa (2014), there is still considerable uncertainty regarding the pros and cons of group versus single tree retention for biodiversity gains. However, it is likely that production losses would be higher with single tree retention in New Zealand, and in other countries, where the majority of plantation trees are shade-intolerant species (Bi et al. 2002). Whether there is a critical proportion of forest that needs to be retained is also unclear (likely to be different for each faunal species), but most data suggest that some retention is better than none (Gustafsson et al. 2012; Sverdrup-Thygeson et al. 2014), as is the retention of even very small native forest fragments (Ball et al. 2013). However, Matveinen-Huju et al. (2006) present data demonstrating that retaining 'a few tens of trees' is not enough to act as a 'lifeboat' for forest spiders. Also, retention areas should ultimately contain legacy features, such as old trees (groups and/or dispersed single trees), dead wood (including standing dead trees/snags), and patches of valuable habitats such as water-logged woodlands and buffer zones bordering watercourses, lakes and wetlands (Simonsson et al. 2015). This practice provides micro-reserves or lifeboats for species that require old growth through the regeneration phase of forest development and enhances connectivity over the larger landscape (Franklin et al. 1997; Simonsson et al. 2015).

Some highly sensitive or area-demanding species may have requirements that cannot be met by retention forestry and may need site-level conservation in combination with larger native reserves within the landscape (Gustafsson et al. 2012; Sverdrup-Thygeson et al. 2014). In the meta-analysis of retention forestry by Mori and Kitagawa (2014), arthropods, most vascular plants, and birds were favoured by group retention, while epiphytes were not and may only survive in larger conservation areas. Whether retention forestry is being practised in native or exotic plantations is also of relevance. In some situations, exotic plantations may be unsuitable as alternative habitat for the majority of native forest species (Braun et al. 2017), whereas others may be suitable for some but not all, with native plant representation in the understorey being key (Peralta et al. 2018). Despite these uncertainties, the coupling of protected areas with forest harvesting is an application of the precautionary principle. Because of the complexity of ecosystems, it is highly unlikely that even the most enlightened forest management practices could protect all elements of biodiversity (Freedman et al. 1996).

Forest certification schemes

Lessons from overseas demonstrate how a combination of specific rational environment concerns, regulatory pressure, and market demand can provide the backdrop for industry change. This is evident in the recent substantial growth of forest certification schemes, which are recognised as one of the most successful components of human responses to conservation of biodiversity (Butchart et al. 2010). According to FSC principles and criteria adapted for New Zealand, retention forestry is mandatory to protect biodiversity as part of the sustainable management of plantation forests (Pawson et al. 2013). The current makeup and distribution of these retained areas, agreed to in the National Standard for Certification of Plantation Forest Management in New Zealand, state 5% of the plantation forestry management unit must be retained or restored to the condition of natural forest and another 5% within the ecological district or region (Forest Stewardship Council 2012). The RMA, along with local, regional, and the new NES for planation forestry regulations, have also tightened erosion and water quality issues, requiring forestry companies to avoid, mitigate, or remedy damaged areas, which ensures the need for some action. In the past, terms such as 'practical' and 'where appropriate' were specifically used to recognise that it would not always be possible to avoid damage to streamside vegetation and reserves during harvesting (Dyck 1997). This concessionary approach now seems to be becoming less acceptable across a wider spectrum of environmental concerns.

6.2 Synthesis

In New Zealand, we still appear to be in a species-led conservation mind-set where threatened species are often located haphazardly across landscapes and managed individually to demonstrate biodiversity conservation. Forestry staff and contractors are encouraged to report any sightings of rare, endangered, and threatened species (Ernslaw One Ltd 2016), resulting in high profile rescue/conservation activities. Pawson & Brockerhoff (2005) states that 'New Zealand's unique bird fauna is without doubt a main focus of the country's conservation efforts'. Examples of 'high profile' faunal projects include kiwi programmes in the Whangapoua and Waimarino Forests (Ernslaw One Ltd 2016), New Zealand falcon research in Kaingaroa Forest (Horikoshi et al. 2017), Wildlands surveys of short and long-tailed bats http://www.wildlands.co.nz /services/fauna-surveys-monitoring/bats/, native frog studies in the Whangapoua Forest, *Powelliphanta* surveys in Shannon Forest (Walker 2003), and brown mudfish surveys in Santoft Forest http://www.ernslaw.co.nz /environmental-management/. These projects largely mirror the popularity of certain animals in the eyes of the public, and willingness to pay (Yao et al. 2014), and can often eclipse other aspects of conservation, such as the importance of quality habitat retention for maintaining rich faunal biodiversity. For example, soil fauna have been shown to benefit from retention (Matveinen-Huju et al. 2006; Siira-Pietikäinen & Haimi 2009). The only mention of soil fauna in New Zealand plantation forests is from one study on protura by Minor (2008). While species-focused activities are a valuable component of native faunal conservation, an appreciation for the broader concept of native species biodiversity has been limited (Pawson et al. 2005) and will require a more objective formal approach, including more general studies to determine the wider impacts of plantation forest age on biodiversity outcomes, such as that done by Pawson et al. (2011). A more formal approach should include a coordinated, objective, methodology to collect and collate biodiversity records from plantations to provide opportunities for both threatened and wider species conservation management. For example, a number of lower-profile hole-nesting bird species, including morepork, robins, tomtits and riflemen, require old, structurally complex, habitat. Retention forestry could help to achieve this in New Zealand, and other multi-species goals, by creating habitat heterogeneity on a landscape scale to support native forest fauna in a non-discriminatory way.

Although there is no expectation in New Zealand that existing plantation be retained, this is an option, particularly to buffer or extend indigenous reserves (Forest Stewardship Council 2012) or if insufficient representative indigenous forest exists on a landscape scale (Burge et al. 2017; Price & Fitzgerald 2017). The voluntary protection of plantation stands for biodiversity protection in New Zealand is currently rare, for example in Kaingaroa Forest (140 000 ha) only two small stands have been protected: one where long-tailed bats roost at Waiotapu, and one at Iwitahi where 36 species of native orchids grow (Maunder et al. 2005; Pawson & Brockerhoff 2005). An area of plantation forest has also been set aside in Rodney District, Northland, as a frog sanctuary (Pawson et al. 2010). Forestry companies need clear standards to aim for (Spellerberg & Sawyer 1996) that are financially viable. Retention forestry, like other strategies such as small-patch clear-cutting (Nghiem & Tran 2016), will reduce forestry profits, and it is important to acknowledge this. To help minimize costs, the selection of ecotones (transition areas between two biomes) that are logistically difficult to harvest (Baille 2010) but also have often have high biological value such as aquatic buffer zones (Carey & Johnson 1995) are likely to provide the best biodiversity gains for the lowest cost (Hartley 2002). Even areas in need of erosion control that are eligible for grants under the Erosion control funding programme (formally the East Coast Forestry Project) https://www.mpi.govt.nz/funding-and-programmes/forestry/erosion-control-funding-programme/[1] could help promote retention for biodiversity while helping to control erosion, although these areas may often provide poor quality habitat.

It is important to note that the irony of these costs to protect biodiversity within plantation forests, relative to other agroecosystem industries, is not lost on those managing forests (http://pureadvantage.org/news/2018/02/13/new-zealands-foresters-should-not-be-punished-for-managing-their-forests-sustainably/, (Dyck 1997). While the agricultural and horticultural sectors have environmental agreements, guidelines and codes of practice in place (MfE 2003; Barber & Wharfe 2010; Barber 2012, 2014), they are primarily aimed at reducing contaminant delivery to streams rather than for biodiversity goals. Central and local authority support should be considered to not only develop recommendations for managing biodiversity of native fauna in plantation forests, but to also provide grants for forestry owners/managers to help retain habitat that benefits biodiversity and exceeds what is required by New Zealand law. In Britain, private landowners have grants available to them that allow up to 20% of their land to be left unplanted for biodiversity values (Hodge et al. unpublished report, cited in Dyck (1997)). In addition to this, efforts are currently underway to increase the reach, availability, impact, and benefits of forestry certification, thus further rewarding signatories to international environmental standards (Griffiths 2014), but the rules, particularly around retention forestry, genetic modification and the use of chemicals, are also becoming tougher (Horner 2011).

Retention forestry has been the main sticking point in negotiations between the FSC and New Zealand forestry companies (Hock & Hay 2003). Forestry companies are aware that FSC certification may become more demanding and perhaps incompatible with New

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[1] Also see: http://www.fao.org/docrep/004/y2795e/y2795e06.htm for background information on this programme.

Zealand's unique plantation forestry system as the rules get tougher. For example, increasing requirements for set-aside areas, at a cost to the grower, along with restrictions on genetic modification and chemical use, may tempt growers to leave the scheme. This may be difficult though, as the FSC is growing in strength, and consumers such as the valuable Asian and North American markets are demanding reputable certification (Horner 2011).

Although biodiversity is not the primary objective of plantation forestry, it and all other businesses reliant on environmental services (including agriculture and horticulture) will likely benefit from proactive management that embraces biodiversity as an integral part of business planning, thus satisfying customer demands for environmentally friendly products. This trend is already evident in the rapid increase in forestry companies (from more than 100 countries now) signing up to certification systems such as FSC (Durand 2017).

The way towards more multifunctional plantation forests, which society will likely value in future (Lindenmayer & Hobbs 2004), and which allow for both commercial timber production and biodiversity conservation, will probably include a combination of large indigenous forest reserves, individual threatened species-led programmes, and modification of forestry practices (McIlroy 1978) to help retain legacy habitat on a landscape scale.

7 Conclusions

- Given the diverse habitat requirements, dispersal abilities, and threat status of native fauna in New Zealand, a multifaceted approach will be required within plantation forestry to help conserve biodiversity on a landscape scale.
- This should include retention of forest areas that develop high structural complexity, maintenance of mixed age exotic stands, and individual threatened species programmes.
- Retention of set-aside forest is likely to be increasingly required by international certification schemes.

8 Recommendations

- A key area for regional and local authorities in the future will be to determine if sufficient forest retention is occurring across landscapes (including within plantation forests) to help conserve indigenous forest fauna. This should include:
  - the prevention of further indigenous forest remnant removal (regardless of size), including legal protection in areas with gross inconsistencies between expected and actual vegetation cover as recommended by Price & Fitzgerald (2017)
  - a stocktake of existing habitat, and assessment of functional connectivity for species of interest (see Burge et al. (2017)) for an example of how this may be done), to help with selection of new areas for habitat retention,

- providing support and lobbying central government for biodiversity grants (similar to those currently available for erosion control) to help forestry owners/managers move towards habitat retention goals set by Forest Stewardship Council and Programme for the Endorsement of Forest Certification schemes
- national research on biodiversity, social, cultural and economic outcomes of habitat-retention initiatives.

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Appendix 1 – Records of indigenous fauna in plantation forests: habitat requirements and impacts of harvesting.

Common Name *Species*	Habitat requirements / Distribution / Home range / Dispersal	Impact of harvesting / Stand age preference / Management options	Reference and study area
*Threat classification – Robertson et al. 2016 (birds), O'Donnell et al. 2017 (bats), Hitchmough et al. 2005, 2015 (invertebrates, reptiles), Buckley et al. 2012 (*Peripatus* spp.)			
Specialist/Obligate – rely on intact forest throughout life cycle		Primary – spends most time in intact forest but occasionally leaves to feed on seasonal foods elsewhere	
Generalist/Facultative – occur in a range of habitats		Open – occurs in open habitats	
		Birds and bats	
		Insectivores	
Fernbird ***Bowdleria punctate*** ***declining**	Present in very old (unharvested) *P. radiata* plantation.		Ryder 1984 – Kaiangaroa Forest
	Radio tagged fernbirds caught in young growth plantations dominated by *Cupressus lusitanica*, *Pinus muricata* and *Acacia melanoxylon*.		Van Klink et al. 2013
Shinning cuckoo ***Chrysococcyx lucidus***	Common in all plantations.		Maunder et al. 2005, Norton 1998
	Exotic or native forest preferred for breeding or feeding. 5000 km adult dispersal.		Burge et al. 2017
Long-tailed cuckoo ***Eudynamys taitensis*** *** naturally uncommon**	Absent in Northland, uncommon in Coromandel and common in Volcanic Plateau plantations		Maunder et al. 2005, Norton 1998
	Native forest preferred for breeding and feeding. 8000 km+ adult dispersal.		Burge et al. 2017
Grey warbler ***Gerygone igata***	Common in all plantations.		Maunder et al. 2005, Norton 1998. Fegley & McLean 1987– Hanmer Forest Park.
	Exotic or native forest preferred for breeding or feeding. 900 m natal dispersal.		Burge et al. 2017
Whitehead ***Mohoua albicilla*** ***declining**	Common in plantation including Volcanic Plateau.		Maunder et al. 2005, Norton 1998
	Exotic or native forest preferred for breeding or feeding. 100 m adult dispersal, 350 m natal dispersal.		Burge et al. 2017

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Brown creeper ***Mohoua novaeseelandiae***	Sometimes present in plantation. Prefer structurally simple forest with dense canopies and bare leaf litter. Takes some fruit.	Preserve native stands no matter how small. Plant food sources in amenity areas around plantations. Retain old or dead plantation trees when stands are felled. Provide artificial nest-boxes. Have a diversity of species and aged stands.	Norton 1998, Clout 1984
South Island robin ***Petroica australis*** ***declining**	Found robins in *P. menziesii* forest but not *P. radiata* forest. No significant difference in the number of robins found in the *P. menziesii* compared with native forest. Robins favour structurally simple, monospecific, forest with dense and even canopies and extensive areas of ground covered by leaf litter (Clout & Gaze, Clout). Found robins in *P. menziesii* and *P. radiata* plantation but significantly more in *P. menziesii*. Those in *P. radiata* were more likely to be there if they were within 100m of *P. menziesii* plantation. *P. radiata* represents low quality habitat (Ducan et al.). Mean territory size of 2-3 ha (Flack 1976).	Retain a mosaic of stands of varying age and type within large-scale plantation forests to facilitate colonization by species such as the SI robin, that have a poor ability to disperse, so that stands of suitable ages are always available. This seems to be a reasonable strategy to adopt until the reasons for the uneven distribution of SI robin populations in areas such as Silverstream area are better understood (Clout & Gaze). Preserve native stands no matter how small. Plant food sources in amenity areas around plantations. Retain old or dead plantation trees when stands are felled. Provide artificial nest-boxes. Have a diversity of species and aged stands (Clout).	Borkin et al. 2007, Clout & Gaze 1984, Clout 1984. Flack 1976 cited in Duncan et al. 1999 – Silver Peaks (north of Dunedin)
North Island robin ***Petroica longipes*** *** declining**	Sometimes present in plantation (Norton). Common in Volcanic Plateau plantations (Maunder).		Maunder et al. 2005, Norton 1998
	Native forest preferred for breeding and feeding. 110 m adult dispersal, 15 km natal dispersal.		Burge et al. 2017
Fantail ***Rhipidura fuliginosa***	Common in all plantations.		Maunder et al. 2005, Norton 1998
	Exotic or native forest preferred for breeding or feeding. 150 m adult dispersal.		Burge et al. 2017

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Specialist/Obligate – rely on intact forest throughout life cycle		Primary – spends most time in intact forest but occasionally leaves to feed on seasonal foods elsewhere	
Generalist/Facultative – occur in a range of habitats		Open – occurs in open habitats	
		Insectivores (hole nesters/roosters)	
Great spotted kiwi ***Apteryx haastii*** ***nationally vulnerable**	Inhabit the full plantation forest matrix, mid-phase and mature stands, newly planted sites, slash, windrows, log piles and indigenous remnants. Present in *P. radiata* plantations and associated native remnants on the West Coast. Present in *P. radiata* and native remnants within plantations on the in West Coast. (pers. comm. NZFOA)	Harvesting remains a threat to kiwi especially during the breeding season. Management guidelines to increase awareness of threatened species and reduce impact of forest management activities include protecting indigenous vegetation (including corridors and riparian habitat), staging harvesting to provide escape routes, avoid burning (especially when kiwi are inactive during the day, find and re-locate with kiwi dogs, exclude non-kiwi dogs and control mustelids and cats.	Norton 1998, Pawson et al. 2010 http://rarespecies.nzfoa.org.nz/species/great-spotted-kiwi/
		Today, the rate of habitat loss has been greatly reduced and, in some cases, reversed due to habitat restoration and suitable habitat provided by exotic plantations. Therefore, introduced mammalian predators are now the key agents of decline.	Germano et al. 2017
Kingfisher ***Todiramphus sanctus***	Present in most plantations. Obligate tree-hole nester (but research shows they also nest in cliffs, banks and cuttings). Also prey on a wide range of invertebrates and vertebrates including crabs, tadpoles, freshwater crayfish, small fish, lizards, mice and small birds.		Maunder et al. 2005, Norton 1998
	Native forest preferred for breeding and feeding.		Burge et al. 2017
Long-tailed bat ***Chalinolobus tuberculatus*** ***nationally critical**	Roost in trees close to harvest age in plantation forests. Roosting home range; juveniles 2.9 ha, pregnant female 0.0001 ha, lactating female 0.3 ha and adult male 0.07 ha (smaller than found in non-plantation habitats).	Smaller roosting range size, fewer roosts were used and colony sizes were smaller post-harvest.	Borkin et al. 2011 – Kinleith Forest

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continued **Long-tailed bat** ***Chalinolobus tuberculatus*** ***nationally critical**	Bat activity was significantly higher along roads through stands compared with along stand edges unless streams present. No activity was recorded within the stand.	Higher density and species diversity of invertebrates at plantation edges compared to interiors suggests the forest patch area:edge ratio may be important for long-tailed bat success.	Borkin & Parsons 2009 – Kinleith Forest in one 26-year-old stand
	Found bats in all topographies and a range of habitats from harvested/unstocked land to young *P. radiata* forest and mature >17-year-old *P. radiata*, *Eucalyptus spp.*, *Pseudotsuga menziesii*, and *Sequoia sempervirens* forest, wetlands and native remnants. Bats prefer older pine forests and generally avoid unstocked land or younger forest. Bat activity and moth abundance significantly higher along roads in *P. radiata* stands compared to the same roads through native forest. Also more activity on roads compared with inside either *P. radiata* or native forest. Bats roost in older trees or trees with deformities/dead spars, or standing dead trees.	Felling may be negative; cause death, reduce available habitat and isolate bat groups, or positive; create foraging (edge) habitat and facilitate access. Pesticide use may also be a negative.	Moore 2001 – Kinleith Forest
	Detection rates higher in oldest stands, more roosts are available and well-established forests create warmer and more stable local climates allowing longer periods of profitable foraging. A variety of pers. comm. records of long-tailed bats in old-growth (60–78-year-old)/dead *P. radiata*, *Eucalyptus* spp. and in native remnants within plantations.	In America's Pacific Northwest, knowledge of bats' use of plantations has recommended the retention of 'legacy trees' (old trees which have been spared through harvest or survived stand-replacing natural disturbances) and snags (standing dead trees) in which some species roost. Bats have been seen flying off when roost trees were logged, and during thinning operations, or injured and later dying when roost trees were harvested. Likely that the impact of harvesting differs throughout the year and with gender and age – pregnant females are slower and less manoeuvrable, non-volant young are unable to escape. Conservative approach would be to assume bats are vulnerable from November to February.	Borkin & Parson 2010b – Horohoro, Maraeroa, Kinleith, Lake Taupo, Karioi and Waimarino plantation forests in the central North Island

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continued **Long-tailed bat** ***Chalinolobus tuberculatus*** ***nationally critical**	Female bats preferred 25–30-year-old stands to 10–20-year-old stands but males also selected open and unplanted sites, or younger stands (5–10 as well as 25–30-year-old stands). Home range between 75 and >1800 ha, depending on sex and reproductive stage.	Effects of harvesting are sex dependent. Males may cope better due to more flexible habitat requirements but long-term population impacts are almost certainly negative due to disruption of foraging sites and roosts. Harvest plans should ensure stands suitable for foraging and roosting are located within 4.4 ± 0.8 km (the mean home-range span) of the harvested stand.	Borkin & Parson 2011b – Kinleith
	Found both male and female bats roosting in *P. radiata* (median age 25–26 years old) and other exotic tree species (planted in the 1950s). Of the *P. radiata* roosts most were in peeling bark of dead trees (4 recently dead, 22 long dead). There is a high level of roost re-use in plantation forests compared with native forests. Roost selection is sex dependant with females roosted within 150 m of streams.	Management options could include; protection of roosts at harvest or when thinning by retaining trees with cavities or a broken crown (Guldin et al. 2007), extending streamside non-harvest areas so they are wider than the 5 m currently recommended (New Zealand Forest Owners Association Inc. 2005), waiting until after the breeding season to harvest stands within 150m of streams, and undertaking control of introduced bat predators (O'Donnell 2005).	Borkin & Parsons 2011a, Borkin & Parsons 2014– Kinleith
	Found about 15 bats in a roost in the cavity of a dead *P. radiata*. The roost was in a small decayed cavity 50 mm wide x 150 mm deep x 170 mm high in a 300-mm diameter trunk. Home range extremely variable from 4.6 to 559.2 ha.		Daniel 1981 – Waikato block owned by NZ Forest Products (in 1976) near Lake Arapuni, Tokoroa
	A study in central North Island Plantation forests (Fletcher Challenge Forests) found long-tailed bats to be widespread and roosting in old growth plantation trees that have sufficient roosting nooks (Moore 2002 – unpublished report for Fletcher Forests)		Maunder et al. 2005 – Kinleith Forest
Morpork ***Ninox novaeseelandiae***	Sometimes present in, to common in, all plantations. Obligate tree-hole nester. Also prey on small birds and mammals.		Maunder et al. 2005, Norton 1998

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North Island Brown Kiwi ***Apteryx australis mantelli*** ***declining**	84 banded study birds were located equally in *P. radiata* stands and very small native remnants within, suggesting there was no strong preference. Home range 5–80 ha. Territories that included native bush and swamps tended to be smaller (may be more resources on swamp margins and in gullies).	8 banded study birds were all accounted for during a logging operation. The birds were seen feeding in the open for up to 7 weeks (i.e. reluctant to leave their territory) before eventually moving to neighbouring swamp margins then dispersing into adjacent pine stands. During a post-harvest burn-off (2–6 months later) the kiwi had left so were unharmed. Authors suggest if burning is used (uncommon these days) in areas where kiwi are known to occur then it should happen at least 7 weeks after harvest.	Colbourne & Kleinpaste 1983 – Waitangi State Forest
	Home range of one of three pairs being radio tracked was half within a young *P. radiata* plantation, where they nested and fed, but still had a strong preference for native forest. The home range of another un-paired female also included a young *P. radiata* plantation. Mean range size was 30.3 ha.		McLennan et al. 1987 – Haliburtons (near the confluence of the Mohaka and Te Hoe Rivers in Inland Hawkes Bay)
	Common in Northland plantations and uncommon but present in Coromandel plantations. Omnivorous.		Maunder et al. 2005 – This study compared how common bird species were in plantation and indigenous forest in three regions; Northland, Coromandel and Volcanic Plateau
	Sometimes present in plantation forestry.		Norton 1998
	Native forest preferred for breeding and feeding. 330 m adult dispersal, 20 km natal dispersal.		Burge et al. 2017
	Kiwi are known to survive and thrive in managed plantation forests. They move in from nearby native bush and shrub land once a growing stand has developed sufficient ground cover and insect life. Some adult kiwi	Threats associated with forestry operations include; habitat loss and degradation, isolation of remnant kiwi populations, death from falling into steep-banked ponds and fire control dams, being hit by vehicles	Sporle 2016, 2017

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continued **North Island Brown Kiwi** ***Apteryx australis mantelli*** ***declining**	will successfully breed within an exotic forest, building a significant population over the plantation's lifespan. In some cases, kiwi will use both the exotic and native forest habitats as part of their territories. Kiwi often live in gullies containing native plants within the pine stands, but move around extensively looking for food and a mate. That means they cross logging roads and tracks and enter cut-over areas despite the lack of cover there. The size of habitat a kiwi requires depends on habitat fertility, invertebrate numbers, and proximity to other suitable habitat. Northland and Coromandel Brown kiwi are known to live in as small an area as 6 ha per bird, whereas Eastern and Western Brown kiwi occupy larger areas (20–90 ha). Translocation guidelines state that 500ha is a minimum area to be managed for predator control in Northland or Coromandel in order for a population of a minimum of 40 kiwi to be viable. There also needs to be other nearby suitable habitat they can disperse into. For Eastern and Western Brown kiwi, the minimum recommended area for protection is closer to 1000ha.	(especially logging trucks at night), being disturbed, injured or killed during land preparation or clearing, slash-burning and harvesting. During forest planning consider the following; where possible plan small forest compartment harvesting, retain riparian and wetland areas in native vegetation (leave an additional vegetated buffer around these areas where possible as in very wet winters kiwi may be 'flushed out' of swamps and need adjacent habitat), stagger woodlot ages and consider long rotation saw log regimes rather than short rotation pulp (small foresters can consider planting hardwood species in scrub light-wells, rather than clear felling all the scrub). During forest harvesting consider the following; where possible, leave escape routes for any kiwi that might be within the block to be logged (in particular, leave gullies and other enclaves of native bush undisturbed), don't leave 'forest islands' intending to return and harvest later, as kiwi may have retreated into these areas (move contiguously through the forest), if it is a small woodlot and all habitat is to be removed in a short time with no nearby habitat for the kiwi to retreat to, kiwi will need to be located and relocated (this needs to be planned for outside the breeding season, discuss with the Accredited Kiwi Handler, a translocation proposal will need to be developed well in advance). If a kiwi is found sitting on a nest try to work around the nest and return at a later date. If this is not possible, make immediate contact with an Accredited Kiwi Handler. The egg/s may need to be taken for incubation. If chicks are	Sporle 2016, 2017, con't

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		present, they may need to be rescued and translocated into a kiwi crèche. If adult kiwi flush leave them to find safe cover, if possible avoid harvesting in July and August when kiwi have just begun nesting. The 1st clutch nests have a better chance of survival as stoats may not have emerged from dens. Be aware that harvest initially attracts kiwi but as the harvested area dries out, the kiwi seek damper areas. Where possible avoid dragging logs through stands of native forest, or felling or dumping harvest waste into native gullies or enclaves of bush or scrub, as kiwi are most likely to have sought refuge there. Where there are options, avoid having log processing sites where kiwi may be roosting. Ridges will be less likely to be chosen by kiwi. During post-harvest operations consider the following; retain riparian and wetland areas with native vegetation (whether mature or regenerating), avoid disturbing known kiwi habitat or retreat areas (such as slash piles) during land preparation, where possible avoid burning slash 'birds-nests' in which displaced kiwi often roost.	
North Island tomtit ***Petroica macrocephala***	Common in all plantations. Found in exotic and native but preferred native forest.		Maunder et al. 2005, Norton 1998. Clout t al. 1984 – Rai-Whangamoa & Golden Downs State Forests.
	Native forest preferred for breeding and feeding. 3 km adult dispersal.		Burge et al. 2017

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Rifleman ***Acanthisitta chloris***	Absent from Northland and Coromandel, uncommon in Volcanic Plateau plantations. Obligate tree-hole nester. Rarely penetrates conifer stand but survives at Golden Downs in forest remnants > 100 ha. Reported within mature *P. radiata* forest, at least half a mile into the stand and 1.5 miles from the nearest podocarp forest in the western Ureweras. Only found in mature stands.	Preserve native stands no matter how small. Plant food sources in amenity areas around plantations. Retain old or dead plantation trees when stands are felled. Provide artificial nest-boxes. Have a diversity of species and aged stands.	Maunder et al. 2005, Norton 1998. Clout 1984 – Golden Downs, Tasman. Caughley & Challies 1960 – Matea Forest, Western Urewera. Seaton et al. 2010b – Kaingaroa Forest
	Native forest preferred for breeding and feeding. 300 m adult dispersal, 1.7 km natal dispersal.		Burge et al. 2017
	Nectivores		
Bellbird ***Anthornis melanura***	Absent in Northland, common in Coromandel and Volcanic Plateau plantations. Primarily nectar feeders but do eat fruits and insects. Found in *P. radiata* plantation but preferred old-growth.		Maunder et al. 2005, Norton 1998. Fegley & McLean 1987 – Hanmer Forest Park.
	Native forest preferred for breeding and feeding. 22 km adult dispersal, 100+ km natal dispersal.		Burge et al. 2017
Kaka ***Nestor meridionalis*** ***recovering**	Uncommon in Coromandel and Volcanic Plateau plantations, absent in Northland plantations. Primarily nectar feeders but do eat insects.		Maunder et al. 2005
	Present in plantations and in native remnants within plantations in Kaingaroa, Whirinaki and central North Island.		Pawson et al. 2010
	Recorded utilizing, and in some cases damaging, exotic plantation trees 1 km from native forest deriving a considerable portion of their diet by stripping bark to access sap. Bark stripping was not a common activity among kaka with only some individuals taking part.		Beaven 1996 – Whirinaki Forest
	Native forest preferred for breeding and feeding. 25 km adult dispersal, 25 km natal dispersal.		Burge et al. 2017

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Tui ***Prosthemadera novaeseelandiae***	Sometimes present in, to common in, all plantations. Also eats fruit and insects. Native forest preferred for breeding and feeding. 20 km adult dispersal, 5 km natal dispersal.		Maunder et al. 2005, Norton 1998 Burge et al. 2017
	Frugivores		
Kereru ***Hemiphaga novaeseelandiae***	Uncommon in Northland and Coromandel plantations, common in Volcanic Plateau plantations. Also nectivorous and take buds, leaves and flowers. Largely absent from plantations. Native forest preferred for breeding and feeding. 33 km adult dispersal.		Maunder et al. 2005, Norton 1998. Clout & Gaze 1984 –Rai/Whangamoa Valley & Golden Downs State Forest. Burge et al. 2017
North Island kokako ***Callaeas cenerea wilsoni*** ***recovering**	Absent in Northland, uncommon in Volcanic Plateau plantations. Birds have been found moving and feeding freely up to 300 m within exotic pine plantations which may provide corridors between adjacent native remnants. One male bird (Dale's bird) appears to have lived in a 50-year-old *Pinus elliottii* stand, with a well-developed (3–5 m deep) native understorey, for at least 4 ½ years. There are no records of kokako breeding in plantation forest. 8–12 ha territories in native forest. 1.4 km natal dispersal		Maunder et al. 2005 Innes et al. 1991 – Rotoehu and Kaharao Forests (Western Bay of Plenty), Pureora Forest (Central North Island) and Matahina Forest (Taranaki). http://www.nzbirdsonline.org.nz/species/north-island-kokako
	Frugivores (hole nesters)		
Yellow-crowned kakariki ***Cyanoramphus auriceps***	Absent in Coromandel plantations, uncommon in Volcanic Plateau plantations.		Maunder et al. 2005

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	Omnivores		
Lesser short-tailed bat ***Mystacina tuberculata rhyacobia*** ***declining** **NB: *M. tuberculata tuberculata*** ***recovering,** ***M. tuberculata aupourica*** ***nationally vulnerable**	All individuals studied (9 female, 9 males) used roosts within native forest. Bats in this study had smaller home-range areas and travelled shorter nightly distances than populations investigated previously from contiguous native forest. Furthermore, *M. tuberculata* occupied all 3 habitat types (open space, native forest, exotic pine forest), with native forest being preferred overall. However, individual variation in habitat selection was high, with some bats preferring exotic plantation and open space over native forest. Our findings indicate that *M. tuberculata* exhibit some degree of behavioural plasticity that allows them to adapt to different landscape mosaics and exploit alternative habitats.		Toth et al. 2015 – Pikiariki Ecological Area (within Pureora) bordered by *P. radiata* plantation forest and pasture
	Large populations have been found only in extensive (>1000 ha) areas of undamaged old-growth indigenous forest, which include many large trees suitable for colonial roosts (>1 m girth and >25 m high), numerous epiphytes and deep leaf-litter. The species composition of the forest is not important. Low numbers of bats have been recorded in a variety of habitats (logged forest, scrubland, pine plantations and farmland) in areas close to areas of undamaged old-growth forest.	Protection of roost trees at harvest time may lessen impacts of clear-fell harvesting. However, a better understanding of the frequency of their roosting within plantations and the types of roosts used will help.	Lloyd 2001
	Short-tailed bats have been found to utilise plantation forestry when it borders intact native forest where they roost, e.g. Horohoro, Maraeroa, Kinleith, Lake Taupo, Karioi and Waimarino plantation forests in the central North Island. Short-tailed bats have been radiotracked to roosts in long-dead native spars in young *P. radiata* stands within Maraeroa.		Borkin & Parsons 2010a – Horohoro, Maraeroa, Kinleith, Lake Taupo, Karioi, Waimarino and Maraeroa plantations.

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Silvereye ***Zosterops lateralis***	Common in all plantations. Present in all age stands but least common in mature stand next to native forest.		Maunder et al. 2005, Norton 1998. Fegley et al. 1987 – Hanmer Forest Park
	Exotic or native forest preferred for breeding or feeding. 100+ km adult dispersal, 160 m natal dispersal.		Burge et al. 2017
Weka ***Gallirallus australis***	Sometimes present in plantation. Are both scavengers and predators.		Norton 1998
		Predators	
NZ falcon ***Falco novaeseelandiae*** ***recovering**	Uncommon in Coromandel plantations and common in Volcanic Plateau plantations. Predator.		Maunder et al. 2005 – This study compared how common bird species were in plantation and indigenous forest in three regions; Northland, Coromandel and Volcanic Plateau
	Sometimes present in plantation forestry.		Norton 1998
	Nests all located in <4 year old pine stands, on the ground, several hundred metres from the nearest mature stand in Kaingaroa forest. Numerous confirmed reports of falcons nesting in exotic pine forest, particularly cutover, in Bay of Plenty, Hawkes Bay, Nelson, Marlborough, Canterbury, and Otago.		Stewart & Hyde 2004 – Kaingaroa with reports of falcons nesting in other locations
	Both sexes favour edges between pine stands <4 years old and >19 years old where prey densities are also at their highest. Females use interior of <4 year old pines more than males - probably because females do more of the incubating. Home ranges of non-breeding birds were 9.2 ± 4.2 km^2 for males and 6.2 ± 3.2 km^2 for females. Between egg laying and fledging period the home range was between 1.5 and 17.8 km^2.	Provide a mosaic of different aged stands, while ensuring that stands <4 years old bordering stands >19 years old are consistently available.	Seaton et al. 2013 – Kaingaroa Forest

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continued **NZ falcon** ***Falco novaeseelandiae*** ***recovering**	Selected for edge between young and mature stands despite low availability of habitat within their home range, i.e. distribution of edge-habitat determines home-range size. All nests followed (87) were in stands aged <4 years and on the ground. Stands up to 3 years since harvest contain features that falcon pairs require/favour for breeding; bare ground and debris for nesting and high prey availability (as clear-cut to 2 year old stands attract insectivores, early successional passerines and ground foraging seed eaters). These features disappear in 3 years as grass grows and woody debris decomposes. Trees >1m in height also inhibit ability for falcons to dive- bomb effectively to protect nests. Mature stands were used as vantage points for guarding nests from predators (62% of falcon nests were within 100m of the nearest mature stand and 84% were within 200m), roosting at night, territory defence, hunting and basking. If mature trees were removed from one nesting season to the next, most pairs shifted their nest locations towards the remaining mature trees within their breeding territories. Complete removal of mature trees could induce desertion of a site and/or mate. Home range of non-breeding birds was 19 ± 4.9 km^2. Smaller during breeding.	Protect edges between young and mature trees. Retain buffer zone of 100-200m around nests to avoid disturbance or damage during breeding. A greater proportion of edge-habitat created by having open patches (cumulative size created over multiple years resulting in pines <3 years old or bare ground) no larger than 4 km^2 that borders mature stands and distributed <3 km apart throughout the forest will maintain smaller falcon winter home ranges resulting in more potential nest sites and higher bird densities.	Horikoshi et al. 2017 – Kaingaroa Forest
	Evidence from a small number of birds that all stand ages within the forest were used in proportion to their availability (i.e. no preference) and juveniles remained within the forest after fledging.	Maintain a mosaic of different aged stands.	Thomas et al. 2010 – Kaingaroa
	Birds found in clear-cut areas and stands up to 3 years old. Densities similar to those found in Kaingaroa		Addison et al. 2006 – Hawkes Bay

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continued **NZ falcon** ***Falco novaeseelandiae*** ***recovering**	Nested in pines up to 5 years old (1 year old preferred) close to older pine trees and with cover over the scrape. Tended to nest in the same stand in following years or move to a larger stand. Nests as close as 970 m apart.	Benefit from clear-fell harvesting that creates a mosaic of stand ages suitable for both nesting sites and hunting. Forestry managers can support populations by; maximising the temporal and spatial availability of stands < 4years old bordering stands >20 years old, leaving pine slash after harvesting operations to provide nesting cover and foraging opportunities for falcons and their prey, and employing predator control. Authors note that increased use of exotic plantations by falcons since 1994 may be due to large-scale 1080 operations.	Seaton et al. 2010b – Kaingaroa Forest
	Exotic or native forest preferred for breeding or feeding. 20 km adult dispersal, 10 km natal dispersal.		Burge et al. 2017
		Frogs	
Archey's frog ***Leiopelma archeyi*** ***nationally vulnerable**	One sighting in Pureora area.		Biodiversity in plantation NatureWatch project
	One sighting in Whangapoua Forest, Coromandel.		Biodiversity in plantation
	Present in native remnants within plantation forest in *P. radiata* forest in Coromandel (BioWeb: Herpetofauna Database)		NatureWatch project Pawson et al. 2010
Hochstetter's frog ***Leiopelma hochstetteri*** ***declining**	Found in mature *P. radiata* (>30 years old) in Torere Forest. Cobble microhabitats were selected for in plantation and native forests as were partially decayed logs >15cm in diameter. As there was limited cobble cover in plantations frogs were more likely to select logs. Habitat suitability was slightly lower in plantations compared to native forests but mature plantations do provide suitable habitat at least in the short-term. High gravel cover and sand-silt were avoided.		Easton et al. 2016 – Torere Forest, Opotiki

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continued **Hochstetter's frog** ***Leiopelma hochstetteri*** ***declining**	Majority of frogs reside in steep gullies that retain some native forest and are buffered from the surrounding agricultural landscape by an encircling pine forest. Gullies provide an ideal habitat, with small waterfalls and cascades and abundant shelter under rocks. Frogs are reliant on good shelter and water quality. In most areas water quality is assured by the riparian margin of undisturbed native forest bordering the streams (pers comm? Lorna Douglas - cited in Pawson & Brockerhoff 2005).	Windthrow events and canopy disturbance from forest harvesting every 25–30 years can have an impact on water quality, resulting in periods of stream sedimentation. Monitoring by Lorna Douglas has shown that some frogs survive both windthrow and harvesting and have been found in regenerating stands after logging (cited in Pawson and Brockerhoff 2005).	Pawson & Brockerhoff 2005 – West coast.
	Surviving in indigenous remnants in plantation forest matrix in Northland, Coromandel and east Opotiki	Protect and carefully manage riparian areas adjacent to high quality small streams	Maunder et al. 2005 – Northland, Coromandel and east Opotiki
	Found on stream banks within mature *P. radiata* plantation and in a small mixed *P. radiata*/native vegetation riparian strip (~40 m wide) where surrounding forest had been harvested.		Crossland et al. 2005 – Mahurangi Forest
	Frogs absent from silted and disturbed streams, especially where there was no forest cover.	Avoid introducing sediment into streams.	Green & Tessier 1990
	Found in seepages, streams and riparian areas of embedded indigenous remnants and plantation stands in the Bay of Plenty and Auckland regions.	Forestry companies undertake periodic monitoring of *L. hochstetteri* populations to assess the impacts of harvesting within forest catchments (Douglas 2001, cited in Hall & Jack 2009). In a plantation forest in Rodney District (Northland), an area was set aside from harvesting and retained as a frog sanctuary.	Pawson et al. 2010

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continued **Hochstetter's frog** ***Leiopelma hochstetteri*** ***declining**	Approximately 10% of the current distribution of Hochstetter's frog consists of modified habitat (5% in exotic plantations and 5% in pasture) (Allen 2006 - cited in Easton 2015) A study by Crossland et al. (2005) in Mahurangi Forest detected fewer frogs in mature pine plantations compared to mature native forests, but even less in harvested areas. Hochstetter's frogs in Torere Forest mostly inhabit native vegetation in areas of high substrate stability (Black 2010 cited in Easton 2015) but they utilise a vast range of resources such as pine debris (Hutchings 2011 cited in Easton 2015).	Disturbances to local habitats are considered a major threat to the long-term survival of this species. Planned harvests of exotic plantations are thus likely to negatively impact resident frogs over many decades (Newman et al. 2013). As habitat loss and direct impacts to the frogs are inevitable in some cases, Hancock Forest Management follow strict guidelines to minimise negative impacts of tree removal (Black R, pers. comm.; Hutchings 2011). For instance, potential or confirmed frog habitat is identified and designated as protected areas during harvest planning so that they are preserved when harvesting commences (Black 2010).	Easton 2015
Lizards (geckos and skinks)			
Barking gecko ***Naultinus punctatus*** ***declining**	Southern and eastern parts of North Island. Can be associated with exotic forest.	Maintain wide and interconnected zones of potential lizard habitat, e.g. indigenous forest and shrubland, rocky gullies, cliffs and other distinctive habitat types. Create buffers around known habitat. Consider permanent protection of known habitat. Comply with best forest operational management practices to avoid damage to lizard habitat. Fell and haul timber away from lizard habitat. Exclude livestock from lizard habitat. Control possums, deer and goats that could enter lizard habitat. Raise awareness of staff and contractors of the presence of lizards and the need to protect them.	http://rarespecies.nzfoa.org.nz/fauna/lizards/

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Canterbury grass skink ***Oligosoma aff. polychroma Clade 4*** ***declining**	Central Canterbury and West Coast. This species has been found associated with exotic forestry around Hanmer Springs.	same as above	http://rarespecies.nzfoa.org.nz/fauna/lizards/
Canterbury spotted skink ***Oligosoma lineoocellatum*** ***nationally vulnerable**	Marlborough southwards to mid Canterbury. Found in open areas associated with exotic forestry, especially areas with rocky substrate and have been found associated with forestry at Spencerville, NE Christchurch	same as above	http://rarespecies.nzfoa.org.nz/fauna/lizards/
Chevron skink ***Oligosoma homalonotum*** ***nationally vulnerable**	Little Barrier Island and Great Barrier Island. Found associated with exotic forestry on Great Barrier Island.	same as above	http://rarespecies.nzfoa.org.nz/fauna/lizards/
Cryptic skink ***Oligosoma inconspicuum*** ***declining**	Southland and the damper parts of Otago. Likely to occur in areas of exotic forestry that are not planted, e.g. riparian margins and the edges of wetlands.	same as above	http://rarespecies.nzfoa.org.nz/fauna/lizards/
Elegant gecko ***Naultinus elegans*** ***declining**	Over the central and north of the North Island, south of Bay of Islands and north of Whanganui and East Cape. Elegant geckos have been located in exotic forestry in the Waikato, Northland Region and Bay of Plenty regions (DOC Bioweb herpetofauna database).	same as above	http://rarespecies.nzfoa.org.nz/fauna/lizards/
Forest gecko ***Mokopirirakau granulatus*** ***declining**	North Island populations occur in Northland and Auckland. South Island populations occur from the Marlborough Sounds to the West Coast. Forest geckos have been found associated with exotic forestry in Northland, Auckland, Spooner's Range, Nelson and on the West Coast.	same as above	http://rarespecies.nzfoa.org.nz/fauna/lizards/
Green skink ***Oligosoma chloronoton*** ***declining**	Otago and Southland. Individuals have been found associated with forestry around Dunedin, Hokonui Hills and West Dome (DOC bioweb herpetofauna database).	same as above	http://rarespecies.nzfoa.org.nz/fauna/lizards/

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Jewelled gecko ***Naultinus gemmeus*** ***declining**	A widespread species occurring over a large range of altitudes and habitats in Canterbury, Otago, and Southland. Jewelled geckos have been found associated with forestry in the Tasman River, Canterbury.	same as above	http://rarespecies.nzfoa.org.nz/fauna/lizards/
Korero gecko ***Woodworthia*** **"Otago/Southland large"** ***declining**	This is a widespread species in Otago and Southland, with three recognised colour morphs. Korero geckos have been found associated with exotic forestry on West Dome in northern Southland.	same as above	http://rarespecies.nzfoa.org.nz/fauna/lizards/
Marlborough green gecko ***Naultinus manukanus*** ***declining**	Marlborough. Known from over ten locations in and around exotic forestry.	same as above	http://rarespecies.nzfoa.org.nz/fauna/lizards/
Marlborough spotted skink ***Oligosoma aff. lineoocellatum*** **"South Marlborough"** ***nationally vulnerable**	Marlborough and may come into north Canterbury. Likely to be found in open areas associated with exotic forestry, especially areas with rocky substrate.	same as above	http://rarespecies.nzfoa.org.nz/fauna/lizards/
Matapia gecko ***Dactylocnemis*** **"Matapia Island"** ***declining**	Northland on Karikari Peninsula, Aupouri Peninsula and some offshore Islands, including Matapia Island. Found associated with exotic forestry on the Aupouri Peninsula, and other places over Northland.	same as above	http://rarespecies.nzfoa.org.nz/fauna/lizards/
Ngahere gecko ***Mokopirirakau*** **"southern North Island"** ***declining**	South-eastern parts of North Island including Kapiti Island and a newly established population on Mana Island. This species has been found associated with exotic forestry around Karori Reservoir, and at other locations within its range.	same as above	http://rarespecies.nzfoa.org.nz/fauna/lizards/
Northland green gecko ***Naultinus grayii*** ***declining**	Northland. Northland green geckos have been found on multiple occasions associated with exotic forestry.	same as above	http://rarespecies.nzfoa.org.nz/fauna/lizards/

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Ornate skink ***Oligosoma ornatum*** ***declining**	Widespread over North Island and associated offshore islands. Occur in and around forestry blocks of Northland, Waikato and Wellington. Do not enjoy dry habitats.	same as above	http://rarespecies.nzfoa.org.nz/fauna/lizards/
Pacific gecko ***Dactylocnemis pacificus*** ***relict**	Locally throughout North Island. Have been found associated with exotic forestry at Dome Forest, Auckland, and at Waitotara Valley Road.	same as above	http://rarespecies.nzfoa.org.nz/fauna/lizards/
Rough gecko ***Naultinus rudis*** ***nationally endangered**	Marlborough, Canterbury. Found associated with exotic forests around Hanmer Springs, North Canterbury. Can be found in scrub and on the ground and the species tolerates very arid conditions.	same as above	http://rarespecies.nzfoa.org.nz/fauna/lizards/
Scree skink ***Oligosoma waimatense*** ***nationally vulnerable**	Marlborough, Canterbury, Otago. This species has been found associated with exotic forests on Black Jack Island, Canterbury (although forestry is thought to cause their local extinction). They primarily inhabit rocky screes, boulder fields or river beds.	same as above	http://rarespecies.nzfoa.org.nz/fauna/lizards/
Small-scaled skink ***Oligosoma microlepis*** *** nationally vulnerable**	Central North Island, including around Lake Taupo. Likely to be found in open areas associated with exotic forestry.	same as above	http://rarespecies.nzfoa.org.nz/fauna/lizards/
South Marlborough grass skink ***Oligosoma aff. polychroma* Clade 3** ***declining**	North Canterbury and central parts of Marlborough. Has been found associated with exotic forestry in central Marlborough. Can occupy a range of open habitats.	same as above	http://rarespecies.nzfoa.org.nz/fauna/lizards/
Southern grass skink ***Oligosoma aff. Polychrome* Clade 5** ***declining**	Widespread over damper parts of Canterbury, Otago and Southland. Been found in association with exotic forestry in the Otago and Southland Regions. Can occupy a range of open habitats.	same as above	http://rarespecies.nzfoa.org.nz/fauna/lizards/

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Speckled skink ***Oligosoma infrapunctatum*** ***declining**	Central part of New Zealand, spanning both sides of Cook Strait. Have been found associated with exotic forestry in the Nelson Region.	same as above	http://rarespecies.nzfoa.org.nz/fauna/lizards/
Spotted skink ***Oligosoma kokowai*** ***relict**	Lower North Island, Marlborough Sounds and Nelson. Have been found associated with exotic forestry at multiple locations including Pureora Forest Park.	same as above	http://rarespecies.nzfoa.org.nz/fauna/lizards/
Starred gecko ***Naultinus stellatus*** ***nationally vulnerable**	Nelson to northern Westland where it abuts the range of the West Coast green gecko on the Stockton Plateau. Has been found associated with exotic forests in the Matai Valley, Nelson. An arboreal species that can also be found in the ground.	same as above	http://rarespecies.nzfoa.org.nz/fauna/lizards/
Striped skink ***Oligosoma striatum-done*** ***declining**	A widespread species with many populations yet to be discovered. Known from Auckland, Bay of Plenty, King Country, and Taranaki. Have been found associated with exotic forestry around Auckland and in the Waikato. They are thought to be strictly arboreal, but may linger in recently logged areas, on the ground. Probably does not thrive in dry environments.	same as above	http://rarespecies.nzfoa.org.nz/fauna/lizards/
Tautuku gecko ***Mokopirirakau* "southern forest"** ***nationally endangered**	Southern coast of South Island in Otago and Southland. Has been found associated with gum plantations in the Catlins and is also likely to occur in association with forestry blocks over the southern coast of both Otago and Southland. Primarily a rainforest species that can occur on the ground, in the canopy and in cut-over areas under rocks.	same as above	http://rarespecies.nzfoa.org.nz/fauna/lizards/
Waiharakeke grass skink ***Oligosoma aff. polychroma* Clade 2** ***declining**	North-eastern part of the South Island. Has been found associated with exotic forestry in the Wairau Valley. Can occupy a range of open habitats.	same as above	http://rarespecies.nzfoa.org.nz/fauna/lizards/

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Waitaha gecko ***Woodworthia cf. brunnea*** ***declining**	Canterbury from Kaitorete Spit to southern Marlborough. Known to occur within stands of pine on terrace riser habitat alongside the Rakaia River.	same as above	http://rarespecies.nzfoa.org.nz/fauna/lizards/
West Coast green gecko ***Naultinus tuberculatus*** ***nationally vulnerable**	Lewis Pass to northern Westland. Likely to be found associated with exotic forestry within their extensive range, especially in areas of scrub between blocks. Primarily arboreal. Can be found on the ground, basking in the sun, or in the canopy of forest trees.	same as above	http://rarespecies.nzfoa.org.nz/fauna/lizards/
	Invertebrates		
	Beetles		
	Carabidae (ground beetle)		
Aulacopodus calathoides	Indigenous forest? Flightless.	Found in all ages but most abundant in 1-year-old stands.	Pawson et al. 2009 – Central NI
Cicindela parryi	Generalist. Frequent flyer.	Found in all ages but trending toward 2–8-year-old stands.	Pawson et al. 2009 – Central NI
Cicindela dunedensis	Open. Occasional flyer.	Prefers young pine.	Berndt et al. 2008 – Canterbury (Eyrewell forest)
Cicindela tuberculata	Open – generalist predator. Frequent flyer.	Prefers clearfell.	Pawson et al. 2008 – Central NI
Cicindela tuberculata	Open – generalist predator. Frequent flyer.	Found in all ages but strong preference for 2-year-old stands.	Pawson et al. 2009 – Central NI
Cicindela tuberculata	Open – generalist predator. Frequent flyer.	Prefers 4-year-old stands.	Pawson et al. 2011 – Central NI
Ctenognathus adamsi	Generalist. Frequent flyer.	Found in all ages.	Pawson et al. 2009 – Central NI
Ctenognathus bidens	Indigenous forest?	Found in clearfell, pasture and mature *P. radiata* but trending toward nearby native forest.	Pawson et al. 2008 – Central NI

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Demetrida dieffenbachia	Generalist. Flightless.	Prefers old pine.	Berndt et al. 2008 – Canterbury (Eyrewell forest)
Demetrida natsuda	Generalist. Flightless.	Only found in 1-, 4-, and 8–year–old stands.	Pawson et al. 2009 - Central NI
Dichrochile maura	Indigenous forest?	Found in pasture & mature *P. radiata* but prefers nearby native forest.	Pawson et al. 2008 – Central NI
Holcaspis mordax	Indigenous forest? Flightless.	Found in clearfell, pasture & mature *P. radiata* but trending toward nearby native forest.	Pawson et al. 2008 – Central NI
Holcaspis mordax	Indigenous forest? Flightless.	Found in all ages but most abundant in 4-year-old stands.	Pawson et al. 2009 – Central NI
Holcaspis brevicula ***nationally critical**	Indigenous forest. Flightless.	Survived at least 3 rotations - only found in young pine.	Berndt et al. 2008 – Canterbury (Eyrewell forest)
Holcaspis brevicula ***nationally critical**	Indigenous forest/Kānuka shrubland. Flightless, moderate runner. Disperse at least 100 m.	Survived at least 2 rotations. Management recommendations include giving some form of protection to any beetle 'hot spots' that are found 'where attempts could be made to conduct forest management more sympathetic to the maintenance of biodiversity'. Snag and reserve tree retention (e.g. leave strips), where mature trees and/or understory vegetation are left unharvested or allowed to regenerate, and site-preparation favouring methods that reflect natural disturbances and conserve coarse woody debris.	Brockerhoff et al. 2005 – Canterbury (Eyrewell forest), Hartley 2002
Holcaspis elongella	Indigenous forest. Flightless.	Not found after 3 rotations – only in nearby Kānuka.	Berndt et al. 2008 – Canterbury (Eyrewell forest)
Holcaspis intermittens	Indigenous forest. Flightless.	Not found after 3 rotations – only in nearby Kānuka.	Berndt et al. 2008 – Canterbury (Eyrewell forest)

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Holcaspis mordax	Indigenous forest. Flightless.	Found in all ages but most abundant in 4-year-old stands.	Pawson et al. 2009 – Central NI
Hypharpax antarcticus	Open. Frequent flyer.	Prefers young pine.	Berndt et al. 2008 – Canterbury (Eyrewell forest)
Megadromus antarcticus	Generalist. Flightless.	Preference for young pine.	Berndt et al. 2008 – Canterbury (Eyrewell forest)
Metaglymma moniliferum	Generalist. Flightless.	Preference for nearby gorse.	Berndt et al. 2008 – Canterbury (Eyrewell forest)
Mecodema occiputale	Indigenous forest? Flightless.	Found in clearfell, pasture & mature *P. radiata* but trending toward nearby Native forest.	Pawson et al. 2008 – Central NI
Mecodema occiputale	Indigenous forest? Flightless.	Found in all ages but trending higher in 16–26-year-old stands.	Pawson et al. 2009 – Central NI
***Mecodema tenaki* *declining (Ball et al. 2013)**	Indigenous forest? Flightless.	Found in native forest but not nearby pine plantations (10–24 years old) or shrubland.	Ball et al. 2013 – Northland
Mecyclothorax rotundicollis	Generalist. Frequent flyer.	Found in pasture but prefers trending toward nearby clearfell.	Pawson et al. 2008 – Central NI
Mecyclothorax rotundicollis	Generalist. Frequent flyer.	Found in all ages except for 8-year-old stands but most abundant in 2-year-old stands.	Pawson et al. 2009 – Central NI
Mecyclothorax rotundicollis	Generalist. Frequent flyer.	Prefers nearby grassland.	Berndt et al. 2008 – Canterbury (Eyrewell forest)
Notagonum feredayi	Generalist. Flightless.	Only found in nearby grassland.	Berndt et al. 2008 – Canterbury (Eyrewell forest)
Oregus crypticus	Generalist. Flightless.	Trending toward young pine.	Berndt et al. 2008 – Canterbury -Eyrewell forest

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Pentagonica vittipennis	Indigenous forest? Occasional flyer.	Found only in 26+ year old stand (only 3 found).	Pawson et al. 2009 – Central NI
Platynus macropterus	Indigenous forest? Occasional flyer.	Not found after 3 rotations – prefers nearby gorse.	Berndt et al. 2008 – Canterbury (Eyrewell forest)
Platynus macropterus	Generalist. Occasional flyer.	Prefers clearfell.	Pawson et al. 2008 – Central NI
Platynus macropterus	Generalist. Occasional flyer.	Found in all ages except for 16-year-old stands, but most abundant in 1 year old stands.	Pawson et al. 2009 – Central NI
Scopodes fossulatus	Generalist	Trending toward nearby grassland.	Berndt et al. 2008 – Canterbury (Eyrewell forest)
Scopodes multipunctatus	Generalist	Only found in 16 & 24+ year old stands (very low numbers).	Pawson et al. 2009 – Central NI
Scopodes prasinus	Generalist	Prefers clearfell.	Pawson et al. 2008 – Central NI
Scopodes prasinus	Generalist	Only found in 4-year-old stands.	Pawson et al. 2009 – Central NI
Syllectus anomalus	Generalist. Occasional flyer.	Found in all ages.	Pawson et al. 2009 – Central NI
Latridiidae (minute brown scavenger beetles)			
***Melanophthalma* sp. 117**	Indigenous forest – Fungal feeder associated with deadwood and forest litter.	Prefers 16–26-year-old stands.	Pawson et al. 2011 – Central NI
Leiodidae (round fungus beetle)			
Paracatips phyllobius	Indigenous forest – Fungal feeder associated with deadwood and forest litter.	Prefers 26-year-old stands.	Pawson et al. 2011 – Central NI
Scarabaeidae (scarab beetle)			
Costelytra zealandica	Open – Root feeding larvae. Frequent flyer?	Prefers nearby pasture.	Pawson et al. 2008 – Central NI
***Odontria* sp.**	Open – Root feeding larvae, phytophagous adult.	Found in clearfell, native forest & pasture but trending toward mature *P. radiata.*	Pawson et al. 2008 – Central NI

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Odontria ?piciceps	Open – Root feeding larvae, phytophagous adult.	Found most frequently along plantation edge between 1–2 and 26-year-old stands.	Pawson et al. 2011 – Central NI
Saphobius squamulosus	Indigenous forest?	Found clearfell & mature *P. radiata* but prefers nearby native forest.	Pawson et al. 2008 – Central NI
		Scolytinae (bark beetle)	
Pachycotes peregrinus	Indigenous forest? – Borer.	Found in clearfell and native forest.	Pawson et al. 2008 – Central NI
		Zopheridae (false darkling beetle)	
Pycnomerus sophorae	Indigenous forest – Fungal feeder associated with deadwood and forest litter.	Prefers 16–26-year-old stands.	Pawson et al. 2011 – Central NI
		Lepidoptera	
		Crambidae (Crambid snout moth)	
Gaira petraula ***naturally uncommon (Hoare et al. 2015)**	Rocky places from steep rock faces to mountainous rocky ridges and pavement, all with a cover of lichens. Females flightless.		Patrick & Dugdale 2000 – Northeastern South Island south to Banks Peninsula http://rarespecies.nzfoa.org.nz/species/gadira-petraula/
		Protura	
Various species	Upper soil layers, leaf litter, decaying wood, moss. Flightless.	Only exotic species found in pine plantations ranging from 15 to 30 years old. Native species only found in native vegetation.	Minor 2008 – Manawatu–Wanganui region
		Snails	
		Rhytididae	
Paryphanta busbyi busbyi ***declining**	Found in northland and Auckland		http://rarespecies.nzfoa.org.nz/species/new-zealand-landsnails/

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Powelliphanta annectens ***serious decline**	Found in silver and red beech forest and in nikau forests	Logging of habitat followed by fires in remnant vegetation and replanting with exotics (along with predation) has resulted in serious decline. Allow native forest to regenerate after the first crop of exotic trees is harvested rather than replanting with exotic plantation species.	Walker 2003 – three separate sites near Oparara
Powelliphanta lignaria johnstoni ***nationally endangered**	Under litter and moss in silver beech and rimu forest, and in shorter forest and scrub of manuka, yellow-silver pine, mountain beech, *Dracohyllum* spp. and rimu.	Hot burns, drainage and root-raking kills snails. Re-invasion of old pine plantations has occurred where a dense understorey of native vegetation has regenerated. In areas ready for harvest, carefully protect remnants in gullies as sources of recolonization and select logging technique which protects the soil and litter layer. If the plantation area is to be regularly logged and replanted, snails will gradually be excluded. On land under Crown management, do not replant with pines, but instead allow regeneration of the native forest. In the areas that were root-raked, consider options for filling in the drainage ditches immediately after the pines are harvested. Predation is also an issue.	Walker 2003 – Mokihinui Forest, North Westland (total range <1500 ha)

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Powelliphanta lignaria rotella ***nationally endangered**	Under Gahnia (razor sedge) and moss in forest and scrub of yellow-silver pine and mountain beech.	Logging of over 75% of the forest habitat, and burning, draining and conversion to exotic pines of about 50% of the logged area (along with mining activity and predation) has resulting in this species being listed as nationally endangered. Snails have recolonised some areas of former habitat now in exotic trees with a dense understorey of regenerating native vegetation. However, when these forests are harvested, log hauling and burning or bulldozer clearing of the undergrowth before re-planting will likely reverse recovery. Harvest (if possible) with great care, avoiding ground hauling logs in order to maintain topsoil and litter layer. Carefully protect all gully remnants of native forest for recolonising snails. Ensure that all machinery is thoroughly cleaned of weed seeds. When the existing crop of exotic trees is harvested, do not replant with pines, but instead allow regeneration of the native forest. In the areas which were v-bladed, consider options for blocking up the ditches immediately after the pines are harvested.	Walker 2003 – Mokihinui Forest
Powelliphanta traversii tararuaensis ***nationally endangered**	Under litter and bush rice grass in rimu/miro forest with tawa, rewarewa and pigeonwood, and under low scrubby vegetation of the tree fern wheki where forest has been logged	Requires protection of adequate buffer zones beside pine plantations to prevent further losses during logging. Where practicable, purchase corridors of former snail habitat and encourage forest regeneration or start a revegetation programme to link the remaining fragmented snail populations. Predator control will be required.	Walker 2003 – two separate sites in the Tararua range

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	Peripatidae		
***Peripatus* spp. *naturally uncommon/data deficient**	The habitat requirements of peripatus may be flexible, as they can also be found in 'non-typical' and apparently marginal habitat, such as logs without tree cover, in tussock grassland, beneath rocks beside a glacier and in exotic plantations. Peripatus requires deep leaf litter and logs, which are vulnerable to disturbance or destruction by grazing stock and wild pigs and deer. Logs can require at least 45 years of decay to build large populations of peripatus.	For species of peripatus that cannot survive in plantation forest, population decline has been shown to be proportional to the percentage of habitat converted. However, some species can tolerate habitat disturbance such as selective felling, mining and some fires right up to the habitat edge.	Department of Conservation 2014, Hamer et al. 1997, Trewick 2000, Pawson et al. 2010, Barclay et al. 2000, Fox et al. 2004, Mesibov & Ruhberg 1991
	Found in plantation forest in Wanganui, Wellington, Mamaku, Coromandel (D. Gleeson, pers. comm.)		Pawson et al. 2010