



Honeybees (*Apis mellifera*) on public conservation lands

A RISK ANALYSIS

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Department of
Conservation
Te Papa Atawhai

Cover: Honeybee (*Apis mellifera*) approaching a white rata (*Metrosideros perforata*) flower. Photo: Jeremy Rolfe

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A risk analysis

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Abstract

The honeybee (*Apis mellifera*) has been intentionally introduced to many parts of the world to produce honey and improve the pollination of food crops. Although honeybees are seldom viewed as harmful in environments outside their natural range, a growing body of research confirms that their presence can have negative consequences for indigenous ecosystems across the globe. In recent years, there have been an increasing number of applications for beehives on public conservation lands in New Zealand, making it important that we fully understand the impacts that honeybees may have on indigenous ecosystems. Introduced honeybees are known to disadvantage indigenous fauna by competing for floral resources. However, in New Zealand ecosystems, these interactions are generally poorly understood, largely due to a lack of knowledge about species diversity, population numbers and the ecology of the majority of flower-visiting fauna. There is also a widely held belief that there is ample nectar/pollen within New Zealand ecosystems to support both introduced bees and indigenous flower visitors, although with recent changes in land use and environmental pressures, this may not be the case. Honeybees have also been shown to alter pollination processes in indigenous plants and facilitate the reproduction of weeds, and may act as vectors for pathogens and disease, although little information is available in the New Zealand context. Despite the lack of conclusive scientific evidence for the impact of honeybees in the natural environments of New Zealand, they do pose a very real threat to indigenous biodiversity. Therefore, it is recommended that the precautionary principle is used to inform the management of honeybees on public conservation lands in the interests of both conservation and economics.

Keywords: honeybee, *Apis mellifera*, apiculture, ecosystem, resource competition, weed pollination, pathogens and diseases, biodiversity, pollination processes

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1. Introduction

The honeybee (*Apis mellifera*) is indigenous to Europe, Africa and the Middle East, but has been intentionally introduced to most parts of the world, including New Zealand, to produce honey and improve the pollination of food crops (Dohzono & Yokoyama 2010). In light of such obvious economic benefits, it is perhaps unsurprising that honeybees are seldom considered detrimental in environments outside their natural range. However, a growing body of evidence from around the world is showing that they may have negative impacts on indigenous ecosystems. Introduced honeybees can compete with indigenous fauna for floral resources (Paton 1993, 1996; Goulson 2003; Dupont et al. 2004; Paine 2004), alter pollination processes in indigenous plants (Bond 1994; Celebrezze 2002; Celebrezze & Paton 2004; do Camo et al. 2004; Kato & Kawakita 2004) and facilitate the reproduction of weeds (Hanley & Goulson 2003; Gross et al. 2010), and may also act as vectors for pathogens and diseases (Furst et al. 2014; Li et al. 2014).

The Department of Conservation (DOC) currently regulates beekeeping activities on public conservation lands (PCL) in New Zealand within a concessions framework. Beekeeping applications are typically approved (with the exception of those concerning certain National Parks) providing that habitat disturbance is kept to a minimum when accessing or installing beehives and no public nuisance is caused by their presence.

A review of beekeeping relative to the conservation values of New Zealand's protected areas by Moller & Butz Huryn (1996) concluded that there were no demonstrated conservation impacts from beekeeping, both in New Zealand and internationally. Since then, however, the focus and scale of New Zealand's beekeeping industry has changed substantially, with renewed interest in (and increasing pressure on) indigenous floral resources, including those on PCL, as a result of an improving global market for New Zealand indigenous honeys and honey products.

Some concessions allow for year-round placement of hives, while others are only in place seasonally, either to allow colonies to recover after stints of commercial pollination work, to support hives over-winter, or to target specific flowering peaks. Beehives are often moved to follow peak flowering where the target plants have a short flowering season and are the dominant component of the vegetation (for example, mānuka). In such situations beehives may only be in place for four to eight weeks before they are moved off to a new site. Apiarists working such seasonal peaks require access to other vegetation types to sustain their honeybees outside the mānuka season and over winter. The increasing trend for apiary space in mānuka blocks on PCL is expected to be matched by a corresponding demand for space in non-mānuka areas.

In 1996 around 2036 individual hives were located within New Zealand's protected natural areas (Moller & Butz Huryn 1996). At time of writing (July 2015), approximately 14 850 beehives are located on PCL. Most of this growth has occurred recently, with beehive numbers on PCL increasing by 60% in the past twelve months alone. The number of applications currently pending has this total set to rise by a further 70% over the next few months. While the proportion of beehives on PCL relative to the total number of beehives managed by beekeepers across New Zealand has remained steady at around 3%, space for this activity on PCL is becoming more limited (particularly in highly desirable vegetation types such as mānuka/kānuka forest). With some concession applications being made at a scale that has not previously been seen (for example, a recent application to place 58 000 beehives on PCL across the central North Island) and others seeking very high stocking densities in certain reserves, DOC is looking to review its current stance about beehives on conservation lands¹.

¹ It is worth noting that while DOC can control the number of hives on PCL, it has little control over honeybee densities in PCL, as beekeepers often place beehives on neighbouring privately owned lands to access the floral resources within reserves. This practice is worthwhile for beekeepers as honeybees are able to forage more than 10 kilometres from their hives (Winston 1987; Beekman & Ratnieks 2000, Van der Steen 2015)—although in the majority of cases 95% of foraging occurs within 6 kilometres (Visscher & Seely 1982).

To assess the risk that honeybees pose to New Zealand ecosystems, we need to understand the nature of interactions between honeybees and indigenous flora and fauna, and the consequences of those interactions. Whether honeybees will have negative or harmful impacts will depend on whether resources are limiting, competition occurs (and, if so, between which species) or resources are simply shared with no disadvantage to either species (Paton 1996). The floral preferences of each species involved, the location of the plants relative to the foragers, the degree to which foragers on any given resource overlap in space and time, the local climate and topography, and the degree of habitat fragmentation or disturbance are also important considerations (Butz Huryn 1997; Steffan-Derwenter et al. 2002; Thomson 2004).

Although an understanding of the biology and ecology of honeybees can help us to understand the potential threats they may pose, these traits are extremely variable across the species' geographical range, as are the species and systems with which honeybees interact, meaning that the attributes observed in one location will not necessarily apply in another. This complexity presents a challenge for researchers seeking to understand whether honeybees present a significant threat to species survival/resilience and the integrity of indigenous flower-visitor networks. Consequently, despite there being an abundance of circumstantial evidence supporting assumptions that honeybees may be detrimental, it is difficult to verify (or disprove) these effects or assess them experimentally, and so there are very few data available on the topic either globally or in New Zealand (Goulson 2003).

Opinions as to whether honeybee presence in indigenous ecosystems is beneficial or detrimental remain divided. For over a century, many conservation reserves in New Zealand were populated by significant numbers of the wild (feral) progeny of managed hives (Goodwin et al. 2006). Popular opinion upholds the claim that these feral honeybees were purely a positive influence, causing no adverse ecological impacts in New Zealand's natural environments even when their numbers were plentiful. However, whether or not this is true remains a matter for debate—and since we almost completely lack baseline knowledge of plant-pollinator networks, the composition and abundance of flower-visiting fauna populations, and the nature of interactions between species from the period before honeybees arrived in New Zealand, we have little ability to assess this.

Since the arrival of the bee parasite *Varroa destructor* to New Zealand in 2000, feral honeybees have become extremely rare. Their absence has encouraged the popular view that managed honeybees are unlikely to be detrimental should they be reintroduced to natural areas because they would be far less abundant than feral honeybees once were, and therefore any effects would be negligible by comparison. When applied at the local scale, however, this reasoning is questionable. Environmental pressures arising from managed honeybee colonies can be greater at local scales because standard beekeeping practices (i.e. providing hives as nesting sites and feeding sugar when food resources are in short supply) allow greater densities to be sustained than would be possible under natural conditions (Geerts & Pauw 2011).

Given these changes and international evidence that now increasingly supports the likelihood that honeybees have detrimental environmental effects outside their natural range, it is timely to revisit the question of whether allowing managed honeybees in conservation reserves actually conflicts with the purposes of those areas, i.e. the preservation of indigenous flora and fauna. Therefore, the aim of this report is to summarise and assess current knowledge about the ecological risk posed by the presence of honeybees as a managed species within New Zealand indigenous environments.

The report begins with a brief history of the apiculture industry in New Zealand and then assesses the role of honeybees in:

- Competition with indigenous biota for floral resources (nectar/pollen)
- Pollination of exotic plants (including invasive exotic species)

- Alteration of pollination of indigenous plants (advantages and disadvantages)
- Transmission of pathogens to indigenous organisms

Potential management recommendations for honeybees on public conservation lands are then provided².

2. A brief history of honeybees and beekeeping in New Zealand

2.1 Establishment and growth of the apiculture industry

The first documented introduction of the honeybee into New Zealand was to the Hokianga area of Northland in 1839, when two hives arrived with Mary Brumby, the sister of an English missionary (Gillingham 2012). Further introductions were made to the South Island in 1842, and thereafter various imports of live bees occurred up until the 1980s, when the practice was halted to protect New Zealand's bee health status (MPI 2014).

New Zealand beekeeping (apiculture) grew steadily from these modest beginnings. Following the First and Second World Wars, the numbers of beekeepers and beehives increased considerably as lands were cleared and developed for agriculture, shaping what would eventually become a flourishing national industry. Today, apiculture contributes an estimated \$5.1 billion per year to New Zealand's economy, providing pollination services, exports of live bees, honey and honeydew, and other bee products including beeswax, propolis and venom. Current average annual honey yields amount to c. 13 400 tonnes, one-third to half of which is exported at a value of approximately \$187 million per year (MPI 2014).

Feral, unmanaged honeybee colonies had become plentiful in New Zealand's indigenous bush areas as early as the 1860s and considerable quantities of honey were being sold by Māori (Gillingham 2012). At their peak, feral honeybee colonies were estimated to number between 10 000 and 50 000 on each island (Goodwin et al. 2006; Howlett & Donovan 2010), and contributed a large proportion of the pollination services for pastures and horticultural crops. However, sometime around the year 2000, the bee parasite *Varroa destructor* arrived in the North Island, which not only changed the way honeybees would be kept and managed across the country, but also virtually eliminated all feral colonies in little more than a decade. By 2006, varroa had spread to the South Island and as at 2014 is considered to have established throughout the country, with the exception of the Chatham Islands and Stewart Island/Rakiura (MPI 2014). All domesticated beehives in New Zealand now rely on human interventions for survival (Goodwin et al. 2006).

Feral honeybee colonies, originating as swarms from managed hives, still occur, but these rarely survive for more than 2–3 years in the wild due to stresses imposed by varroa, disease and other colony disorders (Staveley et al. 2014). However, there is still a risk that feral colonies could be problematic for indigenous fauna and flora as they can have a relatively continuous presence in an area if source populations of commercial honeybees are always present at the time when swarming generally occurs (e.g. an apiary site on PCL which is used every year for many years). Feral colonies (unlike their commercial counterparts which may only be present in an area for

² In the interests of maintaining focus, specific details of pollination systems of New Zealand plants, indigenous pollinating fauna and pollinator networks are not included. Details, where available, can be found in comprehensive reviews by other authors (e.g. Lloyd 1985; Butz Huryn 1995; Goulson 2003; Newstrom & Robertson 2005; Howlett & Donovan 2010; Pattermore 2013).

several months of the year) continue to interact with a wide range of indigenous fauna and flora throughout the year; competing for floral resources. They also occupy tree hollows and cavities which might otherwise be used by indigenous fauna.

Although the New Zealand bee industry is not regulated, all New Zealand beekeepers are required by law to register the number and location of their hives in accordance with the American Foulbrood (AFB) National Pest Management Strategy, which is part of a plan to eliminate the destructive bacterial disease American foulbrood from managed bee colonies in New Zealand (National Beekeepers Association of New Zealand 2014). Therefore, a national Apiary database is maintained by the government-owned commercial company Asure Quality. This database shows that despite increasing challenges, the apiculture industry in New Zealand continues to thrive. As of July 2014, a total of 4814 beekeepers were registered with AsureQuality and the total number of beehives across New Zealand exceeded 500 000. The year 2014 also saw a record increase in the number of new beekeepers, with 857 added to the register (MPI 2014).

2.2 Pressure on indigenous floral resources

Indigenous forests are highly valued by beekeepers for the clean nectar and pollen sources that they provide (i.e. free from the chemical toxins that are often associated with food crops), which is an important requirement for maintaining and rebuilding the strength and health of managed bee colonies. Indigenous floral resources also underpin New Zealand's excellent international reputation and export market for a range of high-quality monofloral honeys (i.e. honeys that are predominantly sourced from a single indigenous plant species), such as rewarewa (*Knightia excelsa*), kāmahi/tōwai (*Weinmannia racemosa*, *W. silvicola*), rātā (*Metrosideros robusta*, *M. umbellata*), tāwari (*Ixerba brexioides*), kānuka (*Kunzea* spp.)³, and tea-tree/mānuka (*Leptospermum scoparium* agg.).

Arguably, no indigenous plant species in New Zealand is currently more sought after for its nectar than mānuka. Once maligned as a nuisance for its ability to rapidly recolonise lands converted to pasture, it is now keenly targeted by beekeepers following the development of a strong global market for its medicinal honey and other products derived from it. With extraordinarily high prices obtainable per kilogram of honey (for example, medicinal grade mānuka honey retails for the equivalent of \$300 per kilogram in the United Kingdom), the pressure on the mānuka resource is building rapidly.

Much of the floral resource required for maintaining healthy honeybee populations and for producing New Zealand indigenous honeys is located on PCL, as these areas retain the largest proportions of remnant indigenous vegetation and some of the largest continuous tracts of indigenous forest. Even areas that were once considered too remote or inaccessible for beekeeping are increasingly being sought after as the practice of placing and servicing hives by helicopter becomes more common and cost effective.

³ Ten species (all endemic to New Zealand) are currently recognised from kanuka (*Kunzea ericoides*). See de Lange, P.J. (2014)

3. Competition between honeybees and indigenous flower visitors

Although the ecological implications of managed honeybees in indigenous vegetation remain poorly known in New Zealand (particularly when there are high hive stocking rates or low seasonal levels of nectar and pollen production), recent research has shown that significant competition and displacement of some indigenous pollinator groups (mainly large flies) can occur when honeybees are present (Murphy & Robertson 2000; Bennick 2009).

Honeybees collect nectar and pollen from at least 224 indigenous plant species in New Zealand⁴, representing some 69 plant families (Moar 1985; Butz Huryn 1995; Donovan 2007). Consequently, honeybees will also interact with a wide variety of indigenous fauna (including insects, birds, reptiles and bats) that target many of the same plants for food supplies of nectar and pollen. This raises the question of whether or not interactions between species are competitive and, if so, what the implications are for weaker competitors and the ecosystems in which they occur.

The managed honeybee is a superior competitor to many indigenous species (particularly many invertebrate flower visitors), as its larger body size and the social structure of the hive allow it not only to maintain body temperatures that support longer foraging periods, but also to communicate the location of food resources, thereby improving foraging efficiency (Paton 1993; Goulson 2003; Dohzono & Yokoyama 2010). This competitive advantage is increased further by the fact that managed honeybee numbers can be maintained at unnaturally high levels by beekeepers, which shift hive locations to take best advantage of floral resources and also supplement hives with extra food (sugar) when natural supplies are low.

Internationally, there are numerous examples of honeybees interacting as the dominant competitor with indigenous fauna (e.g. Gross 2001; Hansen et al. 2002; Dupont et al. 2004; Kato & Kawakita 2004; Paini & Roberts 2005). Such competition generally either takes the form of interference (for example, where interactions with large numbers of honeybees force an inferior competitor to abandon a resource for an alternative) or exploitation (for example, where the quantity of nectar or pollen available to a competitor is reduced due to honeybee activity). This usually results in a loss of fitness⁵ and population vigour for the inferior competitor (Morin 1999).

Some research (e.g. Donovan 1980) proposes that there is ample floral food (nectar/pollen) within New Zealand ecosystems to support both introduced and indigenous bees, as well as numerous other flower visitors. However, although this may be true for some areas and plant species during times of peak nectar flow, evidence is lacking as to whether this applies across all habitat types or across all the seasons when honeybees are active. Additionally, such a view does not take into account changes in land use and environmental pressures.

Any detrimental impacts that do occur may be exacerbated where the presence of honeybees introduces additional competitive pressure at a time when a lack of floral resources (for example, during a poor flowering season) coincides with critical stages in the lifecycles of indigenous fauna (for example, when new indigenous bee adults are emerging from nests or when nectar-feeding birds are improving their condition for breeding).

In the following sections, I examine the potential impact of honeybees on various groups of flower visitors in New Zealand.

⁴ This is probably an underestimate, as more are likely but have yet to be reported.

⁵ Defined as the relative number of offspring contributed to the next generation by particular individuals or genotypes (Primack & Kang 1989).

3.1 Impact on insects

Most recent estimates suggest that the New Zealand insect fauna totals around 20 000 species, with some assessments going as high as 40 000 (Emberson 2000). Although this is not particularly diverse compared with other parts of the world, this fauna is unique, with a high proportion of endemic species (McGuinness 2001). Low diversity is particularly apparent within a few groups, including the indigenous bees, with only 32 species known (all of them solitary) (Donovan 2007), and butterflies, with fewer than 30 species occurring in New Zealand (Parkinson & Patrick 2000). By contrast, flies, beetles and moths are the most species-rich, possibly numbering in the thousands within each group (Dugdale & Hutcheson 1997). Beetles are the most diverse of all and, like the indigenous flies, have a wide range of diets and behaviours, and are present in almost every habitat type (Leschen et al. 2003).

It is not currently known how many of these species visit and feed from flowers, as we still lack basic information about many of them, including their distribution, abundance, preferred habitats, food requirements and interactions with other species. Such information is fundamental to gaining an understanding of whether these insects might be affected by honeybees where they occur together and, if so, in what way. However, there is relatively high potential for competitive interactions between honeybees and indigenous insects because (with some exceptions) New Zealand's indigenous flowers mainly conform to the 'small bee pollination syndrome'⁶, i.e. have a relatively generalised pollination system that suits not only honeybees, but also flies and a diverse range of other insects (Newstrom & Robertson 2005). Accordingly, each flower can be potentially important for a variety of species during its lifetime. Some floral visitors specifically target nectar as their preferred food supply (e.g. tabanid flies; Bennick 2009), others seek pollen (e.g. indigenous bees; Hart 2007), and some utilise both pollen and nectar (e.g. hoverflies; Hickman, 1995). Nocturnal species also target nectar and pollen supplies during the night (e.g. moths on tāwari; Thomson 2013).

Research both from within New Zealand and other countries has provided strong evidence that solitary and semi-social bees are often (but not always) poor competitors with the social honeybee (Butz Huryn 1997; Kato et al. 1999; Paine 2004; Moritz & Hartel 2005; Shavit et al. 2009). Competitive interactions can result in adverse consequences for foraging, e.g. native bees were disturbed from foraging at *Melastoma affine* flowers by honeybees in 91% of the interactions between them (Gross & MacKay 1988) and fitness e.g. *Exoneura asimillima* a semi-social Australian native bee (Sugden & Pyke 1991). The continued presence of indigenous bees in some of New Zealand's natural and modified landscapes suggests that they can compete adequately with other floral visitors (Donovan 1980). However, the fact that some indigenous bee species are now rare and some populations are showing significant declines (Donovan 2007; Hart 2007, 2014) indicates that they may be being outcompeted in some environments.

Other research has revealed that large flies (Diptera ≥ 5 mm) are displaced by honeybees from manuka and *Hebe* spp. (Murphy & Robertson 2000; Bennick 2009). However, in all cases, further investigation is required as to how (and to what degree) insect survival and fecundity are affected as a result of these interactions in order to better understand the consequences at the ecosystem scale.

3.2 Impact on birds

Birds feature strongly amongst the variety of species that visit the flowers of New Zealand indigenous plants (Kelly et al. 2010). They play a particularly important role in the pollination of plants with specialised flowers that conform to the bird-pollination syndrome (e.g. kōwhai ngutu kākā / kākābeak (*Clianthus puniceus*, *C. maximus*); Shaw 1993), but have also been reported visiting many other plant species with relatively unspecialised flowers (Castro & Roberston 1997;

⁶ A pollination syndrome is defined as a suite of floral characteristics (including rewards) associated with the attraction of specific types of pollinators (Fenster et al. 2004).

Kelly et al. 2010; Anderson et al. 2011; Howell & Jesson 2013; Pattemore & Anderson 2013). Most, if not all, of these plant species are also visited by honeybees (Moar 1985; Butz Huryn 1995).

Competition between nectar-feeding birds and honeybees has not been investigated in New Zealand. However, studies elsewhere (e.g. Australia, Mauritius, Canary Islands and South Africa) show that competitive interactions do occur between the two groups, with birds ceasing to visit flowers when honeybees become dominant in environments where floral resources are limiting (Vaughton 1996; Paton 2000; Hansen et al. 2002; Dupont et al. 2004; Geerts & Pauw 2011).

Of the seven indigenous and one self-introduced nectar-feeding bird species that are present in New Zealand, only the silvereye (*Zosterops lateralis*) is abundant. The others are no longer widespread and are often only locally abundant. Three of these species—the tūī (*Prosthemadera novaeseelandiae*), bellbird/korimako (*Anthornis melanura*) and stitchbird/hihi (*Notiomystis cincta*)—rely heavily on nectar as a major component of their diet and target many of the same plant species that are sought after by honeybees (Craig et al. 1981).

3.3 Impact on bats and reptiles

The endemic lesser short-tailed bat (*Mystacina tuberculata*) is the only indigenous mammalian pollinator in New Zealand (Cummings et al. 2014). This species is nationally threatened (O'Donnell et al. 2012), and supports equally rare endemic biota in its role as host and pollinator (Holloway 1976; Ecroyd 1996; Holzapfel 2005). Lesser short-tailed bats are primarily insectivorous, but also take nectar, pollen or fruit from around 20 different indigenous plants, including species that are also favoured by honeybees (Daniel 1976; Arkins et al. 1999; Lloyd 2001; Pattemore & Wilcove 2012)—most notably pōhutukawa (*Metrosideros excelsa*), rātā (*Metrosideros* spp.), mānuka, rewarewa (*Knightia excelsa*), perching lilies (*Collospermum* spp.) and a hebe (*Hebe macrocarpa* var. *latisepala*).

New Zealand is also home to a diverse terrestrial reptile fauna, which includes geckos, skinks and tuatara. While many of these species are fruit-eaters and are considered important for the dispersal of indigenous plants, some are also known to regularly visit flowers to feed on nectar and may aid in pollination (Whitaker 1987; Olesen & Valido 2003). Nectar-feeding species generally emerge at dusk and forage nocturnally (Eifler 1995), often congregating in great numbers on plants that are favoured by honeybees in the daytime, such as pōhutukawa, rātā, ngaio (*Myoporum laetum*), flax/harakeke (*Phormium tenax*) and koromiko/kōkōmuka (*Hebe* spp.).

Direct interference competition between honeybees and nocturnal foragers such as bats and reptiles is unlikely, given that honeybees forage only during daylight hours. However, competition through exploitation of resources could occur, as supplies of nectar and pollen may not be sufficiently replenished by the time nocturnal foragers become active, thereby forcing them to target alternative, possibly inferior, sources of food.

3.4 Conclusion

When assessing the risks around introduced honeybees it is important to consider the requirements for a continuous and high-quality food supply (nectar, pollen) for indigenous species in order to support population survival and fitness. Competition with honeybees is likely to have significant negative impacts on some populations of indigenous fauna if the continuity of a quality food supply cannot be guaranteed. In light of the examples discussed above, there is a strong argument that careful consideration needs to be given to the timing of beehive placement relative to flowering peaks and critical life-stages of indigenous fauna, and to the number of beehives (or beehive exclusion zones) that may be appropriate for any given area, particularly where competitive effects may be compounded by the presence of other introduced competitors such as wasps.

4. Changes to the pollination of indigenous plants

4.1 Honeybees as pollinators

There is a widely held belief that honeybees provide vital pollination services in areas of indigenous vegetation in New Zealand and that they improve the pollination of indigenous plants. However, there is little factual evidence available to support such an assumption. The value of honeybees as pollinators may be significant for some ecosystems, but they are not always the most effective or efficient pollinators of indigenous plants. Honeybees exhibit different behaviours in and around flowers from many indigenous flower visitors, and also have a different body size, shape and characteristics (e.g. tongue length), which means that they often provide very different pollination services to those offered by indigenous fauna (Dohzono & Yokoyama 2010).

The pollinating fauna of New Zealand includes birds (Clout & Hay 1989; Anderson 2003; Anderson et al. 2012), bats (Cummings et al. 2014), solitary bees (Hart 2014), flies (Bischoff et al. 2013), a variety of other insects (Heine 1935) and reptiles (Whitaker 1987; Olesen & Valido 2003). Although this fauna is considered depauperate in comparison to other parts of the world (Newstrom & Robertson 2005), it interacts with the indigenous flora via a wide range of biotic pollination systems.

Since all plant-pollinator relationships in New Zealand evolved in the absence of social bees, the presence of a species such as the honeybee could potentially alter ecological interactions that have developed over very long (evolutionary) periods of time and, by so doing, alter the course of evolutionary pathways of indigenous flora and fauna. For example, the introduction of honeybees into an existing web of indigenous species interactions alters the structure of interactions between species through competition and different demands on resources (i.e. pollen and nectar), different population dynamics (e.g. large social honeybee colonies vs. solitary indigenous insects) and different activity thresholds (e.g. earlier or later foraging activity by honeybees compared with indigenous insects, or no dormancy over winter) (Newstrom & Robertson 2005), which can lead to altered pollination outcomes for some plants (e.g. higher rates of self-pollination, or negative population growth and extinction) (Kalisz et al. 2004; Bobbly Roels & Kelly 2011).

The strength and type of interactions that take place between introduced honeybees, indigenous plants and indigenous pollinators will determine whether changes (beneficial or detrimental) occur in the pollination and seed-set of indigenous plants. Such changes can affect seed quality, plant fitness, inbreeding depression⁷ and other aspects of the genetic makeup of plant populations (Traveset & Richardson 2006; Kelly et al. 2010) via the following possible pathways (after Paton 1996):

- Displacing indigenous pollinators without providing equivalent pollination services, leading to a decline in seed production
- Adding to the pollination services provided by indigenous fauna resulting in increased seed production in indigenous plants
- Removing pollen from flowers reducing the likelihood and quantities of pollen being transferred to flowers by other pollinators, leading to a decline in seed production
- Altering the behaviour of indigenous pollinators in ways that alter patterns of pollen dispersal, leading to changes in seed production and possible changes in the genetic makeup of plant populations

⁷ Where breeding between close relatives results in a reduction in genetic diversity and the expression of negative traits in the population.

Consequences may be less significant for long-lived plants than for annual plants which complete their lifecycle within a single year or for short-lived plants (generation shorter than 10 years).

4.2 Evidence of pollination disruption and alteration of gene flow

While the mechanics and consequences of pollination disruption are relatively well understood for crop plants (Perley et al. 2001; Abrol 2012; Garibaldi et al. 2013; Rogers et al. 2014), they are poorly known for New Zealand's indigenous plant species. However, there is clear evidence in the international literature that honeybees outside their indigenous range alter patterns of pollination, seed-set and gene flow in plant populations as a result of their interactions with indigenous pollinators and plants (Gross & MacKay 1988; Gross 2001; Dupont et al. 2004).

The degree of dependency that exists between plants and pollinators (and therefore the impact of such a change) varies greatly. An association may be highly specific, where a flower can only be effectively pollinated by a single pollinating species, or it may be generalised, where multiple pollinators fulfil the reproductive needs of a plant species. In New Zealand, there is a variety of indigenous pollination systems but the flora has traditionally been considered relatively unspecialised, with few highly specific pollination relationships (Godley 1979). Recent reviews, however, suggest that there are moderate levels of specialisation (Newstrom & Robertson 2005; Pattemore 2013), which implies that there may be a higher risk of pollination disruption caused by introduced honeybees than once thought.

Insects, including the honeybee, are unable to fully replace pollination services that were provided by birds that are now rare or extinct, particularly for plants with bird-adapted flowers. Examples include the indigenous giant-flowered broom (*Carmichaelia williamsii*), which will not set seed unless visited by birds (Heenan & de Lange 1999), kōwhai (*Sophora* spp.), flax/harakeke, taurepo (*Rhabdothamnus solandri*) and toropapa/karapapa (*Alseuosmia* spp.) (Kelly et al. 2010; Anderson et al. 2011; Howell & Jesson 2013; Pattemore & Anderson 2013). Insects are inefficient pollinators of these species largely due to a mismatch in size (most insects will not contact the stigma when accessing nectar), specific behaviours such as nectar robbing at the base of the flower (bypassing both anthers and stigmas), or a preference for visiting male-phase or female-phase flowers with infrequent cross-over.

Inefficient insect pollination is not restricted to plants with bird-specialised flowers. Some New Zealand indigenous plant species with relatively non-specialised open-access flowers also require specialist invertebrate or vertebrate pollinators such as birds, bats or geckos to maintain adequate cross-pollination (Pattemore & Wilcove 2012).

Inadequate pollination of flowers results in reduced seed-set and compromises plant succession (Wilcock & Neiland 2002). This can have considerable consequences for plant populations that are seed-limited, i.e. it is the seed supply that limits the number of adult plants recruited to succeeding generations rather than the amount of suitable habitat available, such as New Zealand mistletoes (Kelly et al. 2007).

Honeybee-induced changes in pollination mechanisms and pollination success also influence how genetic variation is distributed amongst individuals in plant populations (England et al. 2001), which may have positive or negative (e.g. inbreeding depression) consequences. For example, honeybees could either improve or diminish long-distance gene transfer between fragmented populations depending on the native pollinators affected by them and whether the foraging range of the native pollinator is smaller or larger than the range of honeybees.

4.3 Conclusion

The mechanics and consequences of pollination disruption in New Zealand indigenous plants are currently under-studied. However, international research shows that where honeybees are present outside their range, there is a risk that patterns of pollination, seed-set and gene flow in plant populations will be altered as a result of honeybee interactions with indigenous pollinators and plants.

Disruption of plant-pollinator relationships and the pollination process is predicted to cause plant mating system evolution (Bodbyl Roels & Kelly 2011). There is also a risk that, for some plants, pollination disruption will result in negative population growth and, ultimately, extinction. In the New Zealand context, the latter is of most concern for plant species with declining or small remaining populations that are sought after but not pollinated by honeybees (e.g. specialised bird-pollinated plants such as kākābeak and giant-flowered broom).

5. Contribution of honeybees to the pollination of weeds

5.1 Honeybees and weed fecundity

As generalist (polylectic) foragers, honeybees gather nectar and pollen opportunistically from a wide variety of flowers. While their preferences shift according to the availability or proximity of the nectar or pollen resource (Pearson & Braiden 1990), in New Zealand they often favour introduced over indigenous species (Goulson 2005). This, in combination with a tendency towards floral constancy (restricting visits on any one foraging trip to the flowers of a single family or genus), means that the presence of honeybees may favour the reproductive success of introduced plants (Allen & Wilson 1992; MacFarlane et al. 1992; Butz Huryn 1997; Goulson 2004; Beavon & Kelly 2012).

It should be noted, however, that flower visitation alone is not a good measure for pollination and fertilisation success. Furthermore, even if a link between honeybees and increased seed-set in weeds could be confirmed, it does not automatically follow that this would lead to an increase in weed populations. Other factors such as the availability of suitable habitat and seedling survival also need to be taken into account (Goulson 2005; Butz Huryn 1997).

To date, only a few researchers have investigated the relationship between honeybee presence and the fecundity of weedy plants⁸ in New Zealand (e.g. Butz Huryn & Moller 1995; Murphy & Robertson 2000; Paynter et al. 2006), and so evidence of a link between the two exists only for a small number of species. In one such study, Butz Huryn & Moller (1995) examined the contribution of honeybees to weed spread in DOC protected natural areas (PNAs) in New Zealand, and concluded that honeybees were probably not an important factor in the abundance and spread of the majority of problem weeds in these areas; however, they were careful to point out that experimental evidence supporting this assumption was largely lacking.

Studies of some New Zealand species such as heather (*Calluna vulgaris*) have had conflicting results as to the importance of honeybees and weed fecundity (Mahy & Jacquemart 1998). However, a growing body of international evidence confirms that honeybees aid seed-set in plants that are regarded as serious weeds in New Zealand, including purple loosestrife (*Lythrum salicaria*) in North America (Goulson 2010), yellow star-thistle (*Centaurea solstitialis*) on Santa

⁸ Defined as introduced species that are naturalised to New Zealand which display vigorous growth habits and a tendency to out-compete their indigenous counterparts.

Cruz Island (Barthell et al. 2001) and lupin (*Lupinus arboreus*) in Tasmania (Stout et al. 2002). Honeybees are also important contributors to reproductive success in such noxious weeds as lantana (Goulson & Derwent 2004), Scotch broom (*Cytisus scoparius*) (Paynter et al. 2006; Simpson 2005) and banana passionfruit (*Passiflora tripartita* var. *mollissima*) (Beavon & Kelly 2012), and are abundant foragers on invasive willows (*Salix* spp.) (Cremer 2003).

The link between honeybees and weed fecundity is somewhat obscured by the fact that honeybees are not usually the only visitors to the flowers of introduced species in New Zealand, and therefore cannot be held solely responsible for pollination success and subsequent seed-set. Bumblebees (*Bombus* spp.), for example, visit a broad range of flowers and, like honeybees, appear to show preferences for many of the same exotics (Goulson 2005). This trait may be explained by the fact that introduced bees and many introduced plants in New Zealand originate from the same geographic regions, and the bees gain more rewards by visiting flowers with which they have co-evolved (Goulson 2003, 2011).

Indigenous pollinators (particularly invertebrates) also visit the flowers of introduced species in New Zealand. For example, based on rapid assessments of day-active floral visitors along transects in regenerating scrub habitats, Gross et al. (2008) found that indigenous bees were the dominant visitors to many exotic flowers. In addition, solitary indigenous bees (*Leioproctus* sp.) have been found foraging on non-indigenous weedy members of the Asteraceae family (Donovan 1980), indigenous bees and bellbirds were seen visiting the flowers of the invasive banana passionfruit in Nelson (Beavon & Kelly 2012), and a predominance of indigenous insects have been observed foraging on non-indigenous members of the Asteraceae (daisy) family in montane areas of the South Island (Primack 1983). Endemic New Zealand flower thrips are also known to inhabit a range of exotic flowers, including invasive species such as the yellow tree lupin (*Lupinus arboreus*), and may also play a role in pollination (Norton 1984; Teulon & Penman 1990; He et al. 2009). Therefore, further research is required to determine the relative contributions of these indigenous species to pollination and seed-set in these plants.

5.2 Invasive mutualisms

Honeybees have been shown to be important pollinators of Scotch broom, with both species forming an ‘invasive mutualism’ in New Zealand, i.e. an association whereby the flower-visitor benefits from the floral resource, and plant reproduction is improved by the relationship between a non-indigenous pollinator and a non-indigenous plant (the flowers of which are not (or only rarely) serviced by indigenous pollinators) (Parker 1997; Suzuki 2000; Simpson et al. 2005). These findings were also supported by Paynter et al. (2006, 2010), who demonstrated that honeybee pollination aided seed-set in broom and continued to drive broom invasion across New Zealand, despite limitations imposed by a seed-feeding bio-control agent *Bruchidius villosus* and reduced numbers of honeybees resulting from the effects of the varroa mite on feral hives.

Invasive mutualisms involving honeybees have also been confirmed for gorse (*Ulex europaeus*) populations on the Chatham Islands (MacFarlane et al. 1992) and for Darwin’s barberry (*Berberis darwinii*) (Allen & Wilson 1992). Honeybees and lantana (*Lantana camara* agg.) also form a mutualism in Queensland, Australia (Goulson & Derwent (2004), and so a similar relationship can be expected for New Zealand—although it is possible that endemic thrips and butterflies also contribute to pollination success of this species here (Mathur & Ram 1986; Day et al. 2003).

Several other honeybee-pollinated weeds that are present in New Zealand are currently in the early stages of invasion (‘sleeper weeds’). However, although these are not yet major problem species, they are known to have invasive tendencies in other countries and so can be expected to spread further aided by the presence of honeybees. Among these is the climbing spindleberry / oriental bittersweet (*Celastrus orbiculatus*), which naturalised in New Zealand in the 1970s and currently only occupies a small fraction of areas that are suitable for it; therefore, if unchecked, this species will continue to spread over wide areas (Williams & Timmins 1990).

5.3 Conclusion

There is unequivocal evidence that honeybees aid the reproduction of some weedy species in New Zealand, and that invasive mutualisms exist between honeybees and some problem weeds. The risks of detrimental consequences are particularly high where bee-pollinated weeds are present in areas of high conservation value and environmentally sensitive areas, and so weed invasion can pose a serious threat to indigenous ecosystem structure and function.

6. Transmission of pathogens to indigenous biota

Pathogens can be transmitted to pollinators through the shared use of flowers and can be a source of novel infections (Durrer & Schmid-Hempel 1994), and viral diseases or fungal spores can also be transferred via pollen loads (Singh et al. 2010). Arguably, therefore, any flower visitor that is capable of transporting pollen could act as a vector. Honeybees, however, pose a greater risk than some other species because they are extreme generalist foragers (increasing the probability that they will come in contact with a wide range of indigenous flora and fauna), collectively move large pollen loads and can be unnaturally abundant when farmed at high stocking rates.

The hairy bodies of honeybees are not only ideally suited to the transport of pollen grains from flower to flower, but are also very effective carriers of fungal and bacterial spores. Furthermore, the parasitic mite *Varroa destructor*, which is carried on bees' bodies, also acts as a fungal vector (Benoit et al. 2004). Honeybees have been implicated in the movement of myrtle rust spores, a devastating disease that affects a wide range of host plants in the family Myrtaceae around the world (most recently in Australia and New Caledonia) and which is considered a potential hazard to New Zealand (Clark 2011).

The ability of the honeybee to act as a pathogen vector is not limited by what can be carried on the body of the insect. Honeybees can also facilitate the reproduction (and therefore spread) of viruses within their bodies. For example, tobacco ringspot (a plant virus that is highly problematic in the horticultural industry) was recently confirmed as having jumped host and, instead of replicating in plant tissue, reproduced in honeybees and associated varroa mites (Li et al. 2014).

This ability to act as a vector also brings some benefits, however. For example, honeybees have been proven to be useful vectors for spreading biological control agents, including various bacteria, viruses and fungi for the control of pests and diseases in crops (Peng et al. 1992; Carreck et al. 2000; Thomson 2004).

6.1 Conclusion

It is not currently known whether honeybees (and their parasites) present more of a risk of transferring pathogens to indigenous species in New Zealand than any other alien or indigenous pollinating organism. Currently, there is little evidence to suggest that honeybees are vectors of pathogens or diseases that significantly threaten the health of indigenous flower visitors. However, as effective carriers of viruses and fungal and bacterial spores, and as generalist foragers, honeybees may present a significant risk to the health of indigenous flora where known pathogens are present.

7. Research gaps

Decisions around whether honeybee colonies should continue to be allowed on PCL requires careful consideration of whether the honeybees are competing for limited resources with native biota. International evidence has shown that competitive interactions can occur between honeybees and indigenous fauna. However, little is known about the interactions (both positive and negative) between honeybees and the New Zealand indigenous fauna, and so the ecological and evolutionary consequences of these interactions are currently poorly understood. This knowledge deficit will impede the development of appropriate management actions until such time as more research effort is directed towards understanding the structure and resilience of indigenous pollinator networks and plant populations in New Zealand, and the role of honeybees in these.

In the New Zealand context, research needs to focus on whether floral resources may be limiting and, if so, which ones, in order to better understand the nature and consequences of interactions between indigenous fauna and introduced honeybees. For the vast majority of flower-visiting fauna (i.e. insects) in New Zealand, there are also few or no records of species diversity prior to honeybees being introduced, and a paucity of information on population numbers, and the ecology, status and trends of species. Our understanding is further limited by uncertainty about which impacts can be attributed to honeybees as opposed to other social insects such as wasps, or to the effects of factors such as habitat loss/fragmentation, or local variation in climate or topography. Therefore, an improved understanding of New Zealand's indigenous flower-visitor networks, species and ecology is clearly warranted. The time and financial investment that will be required to address these issues will be amply repaid in more effective management of these important natural resources.

The role of the honeybee as a pollinator of indigenous New Zealand plants also warrants further investigation, specifically with regard to beneficial or detrimental changes in pollination and seed-set, consequences for seed quality, changes in plant fitness, risk of inbreeding depression and other aspects of the genetic makeup of plant populations. For many indigenous plant species, very little is known about their interactions with pollinators, their pollination mechanisms, or the long-term or evolutionary consequences of pollination disruption (the latter are particularly difficult to predict). Given that plant-pollinator mutualisms are crucial for maintaining the structure and diversity of many ecosystems (Bond 1994; Kearns et al. 1998), it is important from a conservation perspective to work towards a better understanding of the ecological and evolutionary impacts of factors that may alter these associations.

For some weed species in New Zealand, little is known about their pollinators or reproductive strategies. Therefore, in order to evaluate potential reproductive advantages afforded to weedy species by pollinators, particularly honeybees, it is important that targeted and species-specific research be conducted. A particular focus should be placed on understanding the contributions made by other pollinators (both indigenous and introduced) to weed reproduction, as a lack of knowledge in this area is a key stumbling block in the development of strategies for managing honeybees as pollinators of weedy species. It is also strongly recommended that the relative roles of honeybees and other indigenous and introduced pollinators in the seed-set of 'sleeper weeds' and those species that are already demonstrating a strong invasive mutualistic relationship with the honeybee be investigated.

Finally, an improved understanding of the role honeybees play in the transfer of plant pathogens is important for assessing the potential risks to indigenous flora—for example, their role in dispersing the globally widespread fungal disease myrtle rust, which is not yet in New Zealand but could have a large impact if it arrived.

8. Interim recommendations for the management of honeybee concessions on public conservation lands

Although there is a paucity of conclusive scientific evidence concerning the possible adverse impacts of honeybees in the natural environments of New Zealand, it is clear that they are a possible threat to our indigenous biodiversity, whether it be through competing for floral resources with indigenous flower visitors/pollinators, altering pollination processes in indigenous plants, changing patterns of genetic exchange, facilitating the reproduction of weedy plant species, or acting as vectors of pathogens and diseases. This does not negate the possibility that honeybees could, in some circumstances, also provide essential pollination services in areas where populations of indigenous pollinators have declined or been lost, however.

Applying the precautionary principle⁹, it is appropriate that conservation measures should be implemented in some areas. However, it is difficult to justify the exclusion of beehives from all PCL based on the ecological evidence alone, particularly since this would have significant economic and stakeholder relationship consequences. The challenge, therefore, is to define where such restrictions should be applied.

Taking guidance from the Australian situation, where the issue of managed honeybees in conservation areas has raised similar concerns (D. Paton, University of Adelaide pers. comm. 2014), I recommend:

- Excluding managed beehives from areas of high conservation value where there has been no history of commercial use (a policy to ensure the protection of indigenous flora and fauna, and the interactions between these)
- Securing some areas as honeybee free (even if there is a history of commercial bees in those areas), while permitting access to commercial apiaries in other areas
- Implementing research programmes to address knowledge gaps that exist around the ecological impacts of honeybees in New Zealand's indigenous ecosystems, including the research gaps formulated in section 7
- Monitoring the responses and performances of the interacting plants and animals is essential to make such a strategy work; this allows recommendations to be reviewed and management policy to be adjusted accordingly so the indigenous systems receive adequate protection.

Although this type of approach is not a new idea (e.g. see Paton 1996; Pyke 1999; Goulson 2004; Kato & Kawkita 2004) there has previously been little appetite to implement such a system in New Zealand given widespread hesitation to recognise honeybees as anything other than beneficial in ecosystems outside their natural range.

An alternative or complementary approach may be to apply a set of criteria to assess and identify significant ecological values on PCL. This will allow for robust and consistent assessments of ecological values to be made in the context of national, regional and local frameworks, and will provide useful guidance around whether activities such as beekeeping are appropriate within specific areas. Management strategies should also be targeted to the reservation of pollinator habitat and include recognition of the importance of continuity of food supply for the indigenous floral visitors. However, a full feasibility assessment of these options is beyond the scope of this report.

⁹ The precautionary principle states that 'where interactions are complex and where the available evidence suggests that there is a significant chance of damage to our biodiversity heritage occurring, conservation measures are appropriate, even in the absence of conclusive scientific evidence that the damage will occur' (Cameron 2006).

There is unequivocal evidence that invasive mutualisms exist between honeybees and some problem weeds. Therefore, it may also be appropriate to exclude beehives from areas where populations of such weeds occur. This approach would also make economic sense, as there is little to be gained by DOC spending resources on controlling exotic plant pests while also facilitating ongoing reproduction of the problem plants by allowing the main pollinator access.

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