Interactions between geckos, honeydew scale insects and host plants revealed on islands in northern New Zealand, following eradication of introduced rats and rabbits

D. R. Towns
Science and Research Unit, Department of Conservation, Private Bag 68 908 Newton, Auckland, New Zealand. E-mail: dtowns@doc.govt.nz

Abstract Invasive species that reach islands can have effects that ripple through communities. As a corollary, once invasive species are removed, the responses by resident species may also have ripple effects, sometimes with outcomes that are unpredicted. One such unpredicted response is reported on islands off north-eastern New Zealand following the removal of rabbits (Oryctolagus cuniculus) and Pacific rats or kiore (Rattus exulans). As composition of the vegetation changed and geckos became increasingly abundant, a source of energy for the geckos was revealed: honeydew produced by the scale insect Coelostomidia zealandica (Hemiptera: Margarodidae) infesting ngaio (Myoporum laetum) and karo (Pittosporum crassifolium). Honeydew may have significant effects on the carrying capacity of invertebrates and birds in mainland forests of New Zealand. However, its importance for geckos on islands was apparently masked by reduced gecko abundance in the presence of introduced predators, and suppression of host plants by introduced herbivores. Possible mechanisms of spread and new hosts of C. zealandica are described, and the vulnerability of the scale insect on islands with introduced mammals that suppress recruitment of selected host species is emphasised.

Keywords Scale insects, Coelostomidia zealandica; parasites; honeydew; geckos, Hoplodactylus maculatus, Hoplodactylus duvaucelii; hosts; ngaio, Myoporum laetum; karo, Pittosporum crassifolium; habitat modification; restoration.

INTRODUCTION

Island archipelagos show levels of recent extinction comparable to the most severe mass extinctions recorded in the Earth’s history (Paulay 1994). These losses are largely the result of direct or indirect human activity, including the accidental or deliberate introduction of a large number of alien organisms. For example, in New Zealand over 1600 species of plants, 1500 species of insects and 90 species of vertebrates are established alien species (Atkinson and Cameron 1993), and some of them are now serious weeds and pests. Among the vertebrates, most extinctions of island plants and animals are attributable to predation and browsing by about nine species of mammals, including humans (Atkinson 1989). Two of the most widespread mammals are rabbits (Oryctolagus cuniculus) and Pacific rats or kiore (Rattus exulans). The effects of these two species on island systems have not been well documented. In an extreme example, rabbits appeared responsible for the loss of three species of endemic birds and 22 species of plants from Laysan Island (Williams et al. 1995 and references therein), but around New Zealand they more commonly induce low-diversity browse-resistant vegetation (Ogle 1990; Towns et al. 1997). Over the last 15 years, rabbits and Pacific rats have been removed from at least 24 islands on the continental shelf of New Zealand (Veitch 1995 and unpublished data). The islands cleared of these organisms provide opportunities to determine the direct and indirect effects of the introduced species and to restore depleted island systems. For example, recent studies on islands from which Pacific rats were removed indicated pervasive direct effects while the rats were present. These included suppressed recruitment of selected woody plants (Campbell and Atkinson 1999), reduced diversity and abundance of large, ground-dwelling flightless invertebrates such as weta (Orthoptera), some spiders and darkling beetles (Atkinson & Towns 2001), reduced capture frequencies, abundance and diversity of lizards (Towns 1994, 1996), impaired recruitment of tuatara (Tyrrell et al. 2000) and reduced productivity of small burrowing seabirds (Pierce 1998).

In addition to direct effects, invasive species are likely to have other effects that ripple through communities as changes in the populations of one species affect others (Simberloff 1990). For example, goats (Capra hircus) that reduce vegetation cover leading to increased light levels may also make sites prone to the effects of additional invasive weeds (Towns et al. 1997). Ripple effects may also lead to further pressure on indigenous species. Atkinson (1989) described modification of forest by introduced herbivores, leading to increased exposure of New Zealand land snails to introduced predators.

Ripple effects need not operate in one direction as a spiral of degradation. In theory, the removal of a catastrophic disturbance event could lead to ripple or interactive effects in the course of recovery or succession. Because the pre-disturbance history of many sites is unknown, the responses by resident species may sometimes be either unpredictable or unpredicted.

In this account I describe a hitherto unknown plant-scale insect relationship that was revealed following the removal
of rabbits and Pacific rats from islands in north-eastern New Zealand. The relationship is between a scale insect that exudes honeydew, the margarodid *Coelostomidia zealandica*, its host plants, and vertebrates that feed on the honeydew. This example illustrates how human-induced disturbance, and the presence of introduced mammals, can suppress populations of scale insects, their host plants, and the links to vertebrate honeydew feeders.

**STUDY AREAS**

The study was based on Korapuki Island and neighbouring Green and Middle Islands in the Mercury Islands, New Zealand (36°40′S, 175°52′E), a group of seven islands and associated islets and stacks of volcanic origin. Korapuki Island (18 ha) was inhabited by rabbits and Pacific rats until the rats were eliminated using rodenticide in 1986, and the rabbits by shooting in 1987 (Towns 1988; McFadden and Towns 1991). Vegetation on Korapuki Island was, until 1987, dominated by flax (*Phormium tenax*), shrubs including mahoe (*Melycitus ramiflorus*) and a canopy of pohutukawa (*Metrosideros excelsa*) consistent with extensive forest clearance (probably by burning early in the 20th century) and subsequent browsing of regrowth by rabbits. Since removal of rabbits, there have been spectacular increases in the recruitment of soft-leaved understorey species as well as increased canopy development of species such as mahoe (Towns et al. 1997).

Green (3 ha) and Middle Islands (13 ha) have never had introduced mammals. The islands support coastal broadleaf forest with little evidence of previous human occupation (Towns et al. 1990).

**STUDY ORGANISMS**

*Myoporum laetum (ngaio)*

Ngaio is a light-demanding shrub or tree that is often low-growing in coastal areas, but can reach to 10 m with a trunk diameter of 30 cm (Allan 1961). The species was regarded as uncommon on Korapuki Island by Atkinson in 1962 (cited in Hicks et al. 1975), but in 1974 a stand of ngaio was present (Hicks et al. 1975). When rabbits were eradicated in 1987, there were two identifiable stands of ngaio and occasional scattered trees on cliffs. The total number of trees was estimated as less than 10 by Towns et al. (1997) and the largest tree had a basal circumference of 1.25 m (unpublished data).

*Pittosporum crassifolium (karō)*

Karo is a shrub or tree that can reach 9 m and, although found in forest margins and stream sides (Allan 1961), also inhabits coastal areas, including small rocky islets. The species is able to germinate in very low light conditions. On Green and Middle Islands, karō is a significant component of the understorey as well as an emergent tree near the coast (Atkinson 1964; Cameron 1990; pers. obs.). Karō was ranked as frequent, with plants seen singly or in patches on parts of Korapuki Island in 1962 (Hicks et al. 1975), but was rare in the understorey by the time rabbits were removed in 1987 (Towns et al. 1997).

*Coelostomidia zealandica*

Ten native species of plant-sucking scale insects in the family Margarodidae are associated with native trees and shrubs. Margarodids produce sugary secretions (honeydew) that are used as a food source by forest insects and birds. The secretions also provide a medium for sooty moulds that blacken the trunks of heavily infested host plants (Morales 1991). The life history of *C. zealandica* is unknown, but that of a related species, *C. wairoensis*, was summarised by Morales (1991). In brief, the female life cycle includes a mobile crawler, non-mobile intermediate feeding stages, and a fully legged, mobile, non-feeding, flightless adult. The male life cycle includes a mobile crawler, a non-mobile intermediate feeding stage, non-feeding pre-pupa, pupa and fully-winged adult male.

Female *C. wairoensis* may remain and deposit eggs in a hard ‘test’ formed on its host, but females of *C. zealandica* are free living and oviposit in the soil or under bark (Morales 1991). Crawlers settle in cracks on branches, insert their mouthparts, and produce a long anal tube to void sugary waste. The other visible sign of infestation of hosts are white cocoons spun by male prepupa on the trunks of trees. Hosts include a wide variety of coastal and forest shrubs, trees, and vines. Amongst these are ngaio and *Pittosporum tenuifolium* (Morales 1991).

**METHODS**

Observations of the distribution and abundance of vegetation infected by margarodids were made on Korapuki Island opportunistically between 1986 and 2000 and on Lady Alice Islands and adjacent islets between 1992 and 2000. Infected trees were identified by the presence of sooty moulds, anal tubes of margarodid nymphs and, on some trees, by the presence of cocoons and adult males and females. Species identification was confirmed by R.C. Henderson (Landcare Research, New Zealand Arthropod Collection).

On Korapuki Island, counts of geckos on trees were made by capturing the animals after sunset (between 2200 and 2300 hrs) and marking them with a dot of correcting fluid (TWINK). Estimates of relative density on beaches were obtained from sightings within a fixed period of ‘catch per-unit-effort’ (CPUE) at five stations along a set transect line parallel with the high tide line (Towns 1991). The CPUE transect line was adjacent to the smaller of the two stands of ngaio. Comparative data were obtained from mammal-free Middle Island.

Levels of scale infestation were estimated by searching for deformations of the bark of karō and visible anal threads with honeydew droplets on karō and ngaio. Thread density was estimated by counting the active threads (those
with droplets) within a defined 20 cm length of plant stem beginning 20 cm from ground level and continuing at 20 cm intervals (five per plant). The start of each counted cylinder was therefore 40 cm from the start of its predecessor. Thread density was calculated from stem circumference measured at the beginning of the counted sections and converted to threads per square metre.

RESULTS

Spread of ngaio and karo

Before removal of Pacific rats and rabbits from Korapuki Island, the remaining ngaio were infected by scale insects, and blackened by sooty mould. There was no visible recruitment of young ngaio to these populations. Likewise, karo was uncommon; there were no plants around the coastal beaches and apparently complete recruitment failure (Towns et al. 1997).

Following the removal of mammals, ngaio proliferated over most of Korapuki Island, but the seedlings and saplings failed to survive unless they occupied a canopy gap. The most rapid expansion was around the north-western coast of the island where ngaio formed almost continuous cover behind rocky beaches.

Likewise, after removal of mammals, karo proliferated throughout the island to become abundant on the coast and throughout forested areas (Towns et al. 1997). In coastal sites karo and ngaio formed mixed stands.

Spread of geckos

The two resident species of geckos, common gecko (Hoplodactylus maculatus) and Duvaucel’s gecko (H. duvaucellii), were regarded as rare during surveys conducted on Korapuki Island in the presence of rabbits and Pacific rats (Whitaker 1973; Hicks et al. 1975; Towns unpublished data). CPUE data obtained in 1985, 1990, and 2000 indicated a 28-fold increase in sightings of common geckos along a coastal transect when comparing data from a year before campaigns against introduced mammals began (1985) against data from 13 years after the campaigns’ completion (2000) (Fig. 1). Similarly, counts of geckos on flax flowers between 1986-1990 increased from 0% to 24% occupancy (Towns 1994). Both sets of data indicated an expanding population of geckos.

Margarodids on Korapuki Island and nearby islands

By 1994, eight years after the beginning of the campaigns against rats and rabbits on Korapuki Island, young ngaio trees on the coast adjacent to the original ngaio stands were infested with margarodid scale insects. In addition, the margarodids had infested karo trees growing beneath the original ngaio.

On karo, infestations were in the form of scattered raised wart-like growths on the bark with the margarodid anal tubes projecting from these growths. Occasionally, lower branches were buried in leaf litter, and on these were external encrustations of scale. Of 20 karo checked within a ngaio stand in December 2000, 19 (95%) were infected by scale. These included saplings only 50 cm tall.

Unlike the localised and scattered infestations of scale on karo, those on ngaio were present over the entire trunk. In December 2000, mean infestations on five young trees (range 17-69 cm basal circumference) ranged from 70-2200 threads/m². The most heavily-infected tree had a thread density of up to 3300/m².

Margarodid infestation of karo and ngaio plants checked on Green and Middle Islands indicated similar levels of infestation to those found on Korapuki Island. On Green Island, ngaio and karo were infected and large karo trees (basal circumference >50 cm) had deformed sections of bark up to 5 cm across as evidence of previous margarodid presence. On some trees the deformed areas had cracked open and were oozing sap. On Middle Island, evidence of scale was present on 24 of 25 (96%) karo trees checked along 400 m on or within 50 m of the coast (mean basal karo circumference ± SE: 45.06 ± 5.48 cm).

Few adult margarodids were seen on Korapuki Island when trees were inspected in late spring (November-December), but males and females were seen frequently during late summer (February-March). Adult females were orange-pink in colour and were visible during daylight slowly crawling about on the bark of ngaio and on the leaf litter beneath ngaio trees. Females were seen once on karo trees.

Fig. 1 Mean numbers (+ SE) of geckos sighted in November at five sites along a 100 m coastal transect on Middle Island (pale shading) and Korapuki Island (dark shading) one year before the start of campaigns against introduced mammals on Korapuki Island and in years subsequent to the completion of the campaigns.
**Invertebrates and geckos on honeydew sources**

Introduced *Vespula* wasps (probably *V. germanica*) were present on Korapuki Island until about 1990, but have not been seen since. Other introduced wasps include the Asian paper wasp *Polistes chinensis* and the Australian paper wasp *P. humilis*. Neither species has been seen accumulating around honeydew sources on ngaio. Two native insects were commonly active on ngaio at night: a cockroach (probably *Parellipsidon lattipennis*) and a byrrhid beetle (*Pedilophorus crysopepsis*). During the day, the native ant *Monomorium antarcticum* was seen on some trees and there were also occasional trails of the introduced ant *Technomyrmex albipes*.

Geckos were first seen aggregating on ngaio trees in March 1992. Both common and Duvaucel’s geckos were observed at night on ngaio. Up to 11 Duvaucel’s geckos and up to eight common geckos were observed simultaneously on individual ngaio trees. Both species were observed licking at the bark surface. An estimate of numbers of geckos using individual trees was obtained over six nights in December 1996. Of two trees checked, one had 10 common geckos and two Duvaucel’s geckos over a total stem length of 3 m, and the other had 32 common geckos and one Duvaucel’s gecko over a stem length of 7 m. Excluding recaptures, the number of common geckos observed on the two trees over six nights was 0.43 geckos/m/hour and 0.76 geckos/m/hour respectively.

**DISCUSSION**

**The ecological role of honeydew**

Congregations of geckos feeding on exudates from margarodids on ngaio trees have not previously been reported. There was little chance of observing the phenomenon before removal of introduced mammals from Korapuki Island because at that time geckos were rarely seen. Indeed, there is little published information on the use of honeydew by geckos anywhere in New Zealand, although the attraction of trees bearing honeydew to geckos has been exploited when surveying for geckos (A.H. Whitaker pers. comm.). Whitaker (1987) found at least 80 geckos (*Hoplodactylus pacificus*) feeding on honeydew on a 6 m tall karo on rodent-free Little Ohena Island. This is the only report now attributable to honeydew produced by *Coelostomidia zealandica*. Bishop (1992) included geckos in a diagrammatic representation of the users of honeydew in beech forest of the South Island, but gave no further details. Beggs (2001) included lizards among species that consume honeydew in beech forests of the South Island, but did not elaborate.

Honeydew can provide a major energy source in forest ecosystems (Beggs 2001). The most intensively studied honeydew-producing system in New Zealand is that of *Ultracoelostoma* spp. on black beech (*Nothofagus solandri var. solandri*), mountain beech (*N. solandri var. clifortioideae*) and red beech (*N. fusca*) in the northern South Island. The honeydew produced is rich in fructose, sucrose, glucose, and oligosaccharides, but low in protein (Grant and Beggs 1989) and is sufficient to provide the daily energy requirements of kaka (*Nestor meridionalis*), a large native parrot, after only three hours of feeding (Beggs and Wilson 1991). The sooty moulds that grow on the honeydew are also a food for arthropods (Morales et al. 1988), and there is evidence from northern hemisphere studies that honeydew washed into soil promotes the growth of microorganisms and these in turn affect processes such as carbon throughfall and nitrogen flux (Beggs 2001 and references therein).

Two species of Margarodidae were probably once widespread on the northern offshore islands: *Coelostomidia wairoensis*, most commonly on kanuka (*Kunzea spp.*), and *C. zealandica* on a variety of hosts including ngaio and

![Fig. 2 Conceptual models of interactions between honeydew, their host trees and honeydew feeders before (A) and after (B) the removal or disappearance of introduced mammals and wasps (circles) from Korapuki Island. Arrow width denotes likely interaction effects; unshaded arrows are for potential rather than observed effects.](image-url)
karo. Kanuka can form large stands in regenerating forest, such as those on Whatupuke and Lady Alice Islands in the Marotere Islands (Bellingham 1984). Duvaucel’s geckos were observed on Whatupuke Island by A.H. Whitaker and R. Parrish (pers. comm.) feeding on honeydew exudates on kanuka. The combined output of honeydew from scale insects on kanuka, ngaio, and karo may therefore once have been considerable on offshore islands.

The most frequently observed vertebrates attracted to honeydew produced by C. zealandica were geckos (Fig. 2), although the honeydew also appeared attractive to nectarivorous birds. For example, on Korapuki Island and in the Poor Knights Islands, bellbirds (Anthornis melanura) were seen foraging on ngaio and karo trees, presumably feeding on the exuding honeydew produced by C. zealandica (pers. obs.). Similarly, tui (Prosthemadera novaeseelandiae) were observed on Muriwhenua Island in the Marotere Islands foraging on ngaio infested with honeydew scale (Towns and Parrish unpublished data). Unlike flowering plants, which only provide seasonal nectar sources, honeydew has the advantage of being available continuously, although whether there is seasonal variation in the quantity and sugar concentration of honeydew produced by Coelostomidia zealandica is unknown. In beech forest, the composition and production of honeydew available varies during the year (Gaze and Clout 1983), but declines in honeydew production during late summer and autumn were probably due to consumption by introduced wasps (Moller and Tilley 1989). Activity by geckos is temperature dependent (Angilletta et al. 1999), so geckos may only feed on honeydew during the warmer months. There are no such constraints on birds such as bellbirds and tui.

Implications for restoration on islands

New Zealand margarodids are either quite host-specific or polyphagous. The most polyphagous species is C. zealandica (Morales 1991). However, only two of its previously reported host species commonly grow on the smaller northern offshore islands (less than 100 ha): the creeping vine Muehlenbeckia spp. and ngaio. The hitherto unreported capability of C. zealandica to infest karo provides a third host on these islands. Karo may also play a vital role in the scale insect’s transmission. Unlike ngaio and Muehlenbeckia, karo is able to survive in low light conditions under the forest canopy. On Korapuki Island, despite the small number of parent trees, regeneration by karo was rapid and widespread (Towns et al. 1997). Since adult female margarodids have limited powers of dispersal, progressive infestations of karo have apparently enabled the spread of margarodids through some of the gaps between new stands of ngaio (Fig. 2). As a corollary, the absence of karo (and perhaps other hosts) from low-light areas could break the infestation pathway. Without removal of rabbits from Korapuki Island, the margarodids on ngaio would have eventually lost their original host trees, as they became overtopped by an expanding canopy of mahoe.

Regeneration of karo is strongly inhibited by Pacific rats (Campbell and Atkinson 1999), so it is conceivable that the presence of these rats alone may be sufficient to initiate the disappearance of C. zealandica from some islands. For example, no evidence of margarodids was found on regenerating karo eight years after the removal of Pacific rats from Red Mercury Island (I. A. E. Atkinson pers. comm.). Similarly, following the eradication of Pacific rats from Lady Alice Island in October 1994 (K. Hawkins pers. comm.), surveys for margarodids on extensive ngaio on the western coast failed to reveal visible signs of infestation by margarodids (unpublished data). There were no visible anal tubes and the bark of all trees was clear of sooty moulds. Only three adult karo trees are known to have survived on the island before removal of Pacific rats and these trees also appeared free of margarodids. By comparison, on islets such as Muriwhenua Island adjacent to Lady Alice Island, ngaio were heavily infested by margarodids. Muriwhenua Island also supports dense populations of common and Duvaucel’s geckos (Whitaker 1978; Towns and Parrish unpublished data).

On the mainland, introduced organisms, especially wasps, can have devastating effects on the availability of honeydew for native species, reducing the standing crop of honeydew by 90% for five months of the year (Beggs 2001). On offshore islands, the threats to these resources appear to be more through the loss of infestation sources as a result of habitat destruction and modification of forest composition by introduced mammals (Fig. 2). Because the female margarodids are flightless, once the source of infestation is lost, there is no way for scale insects to re-establish, even when abundant host plants are present. This situation appears to prevail for C. zealandica on Red Mercury and Lady Alice Islands. Because of the implications that the presence of margarodids has for carrying capacity of invertebrates, geckos, and nectar-feeding birds, artificial spread of scale insects as part of island restoration projects now needs to be seriously considered.

ACKNOWLEDGMENTS

My thanks to Northland and Waikato Conservancies of the Department of Conservation for permission to visit the Marotere and Mercury Islands (respectively), Richard Parrish and Chris Green who assisted with transport between the islands, and to Ian Atkinson, Lynette Clelland, Rod Hay, Keri Neilson, Tony Whitaker, and two reviewers, Peter Gaze and Rosa Henderson, for useful comments on the manuscript. The study was part of Science and Research Unit Investigation 3236.
REFERENCES


