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Systematic measurement of effectiveness for conservation of biodiversity on New Zealand islands

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Abstract

The offshore islands of New Zealand have a history of use by people, including conversion to farming, the introduction of livestock, pests and weeds, and comprehensive destruction of indigenous ecosystems. The removal of pests since the mid 1980s has become increasingly effective, with at least 70 islands in public or private ownership now free of all introduced mammals. Goals for management on these islands vary with land tenure and legal classification. On some islands management aims to maximise ecological integrity through ecological restoration whereas on others iconic species are managed through community participation. We identify a range of performance measures for different management regimes. We then use case studies to demonstrate the use and applicability of selected measures for the differently managed islands. We found that outcome-specific measures of effectiveness can be applied to a wide range of conservation activities on islands.

Key words: island management, performance criteria models, Middle Island, Aorangi Island, Korapuki Island, Motuora Island, Tiritiri Matangi Island, Motuihe Island, New Zealand

Introduction

The indigenous biotas of islands have suffered disproportionately high levels of extinction (King 1984, Paulay 1994) largely due to harvesting and introduced invasive species (Atkinson 1989). In New Zealand, the effects of predators and human modification were described by Diamond (1990) as one of the worst tragedies to befall any island archipelago. An endemic family of birds (Dinornithidae) is now extinct, and others, such as Acanthisittidae, have been severely depleted (Worthy and Holdaway 2002). Fortunately, many other species survived on islands beyond the dispersal range of most introduced species or of such difficult topography that invasive predators were not landed by boat (Atkinson 1986, Daugherty et al. 1990). Nonetheless, the number of island sanctuaries has declined as invasive predators continued to spread. For example, in the early 1980s Norway rats (*Rattus norvegicus*) invaded Whenuakura Island (2 ha), following which the entire population of >130 tuatara (*Sphenodon punctatus*) disappeared (Newman 1986). In response, new methods for systematically eradicating species such as rats (Towns and Broome 2003) have contributed to a growing number of islands from which all mammalian pest species have been removed (Parkes and Murphy 2003, King 2005). Conservation of threatened species on these islands has often been far more effective than similar attempts on the mainland. For example, among the reptiles, both species of tuatara and at least 12 species of lizards have increasing populations on islands while on the mainland many species continue to decline.

One could therefore argue that much conservation effort in New Zealand should focus on islands. At least 220 of the 770 islands > 1 ha (Parkes and Murphy 2003) are managed by the Department of Conservation, but there are additional islands managed as public-private partnerships, as traditional Maori land and as freehold private land. Therefore, although the resource can be identified, there are over-arching issues of land tenure, responsible agencies and appropriate land management. This greatly complicates the decision-making process because there may be a multitude of goals, which unless clearly stated and owned by all parties, can lead to conflict (Salafsky et al. 2002). Furthermore, without clear goals it is not possible to define measurable criteria for success (Christensen 2003).

Pest removal from islands around New Zealand has long been heralded as a global example (Diamond 1990). With this perception in mind, we ask two questions: how many pest eradications on islands succeeded and where eradications were successful, how did biodiversity benefit? Answers to the latter question require definitions of management goals and measures of success against these goals.

For analyses of the benefits of management to biodiversity we used indicators developed by Lee et al. (2005) as measures of ecological integrity. We then tested these measures on a series of island case studies. We show that there are numerous measures of change in island systems. If systematically collated, these measures would provide a wealth of information about long term change on highly protected islands and about short term change on those that are intensively managed.

Methods

We assessed overall management effectiveness by counting the number of islands from which all pest mammals have been removed, and identifying the responses of native species of plants and animals. Based on generic measures of ecological integrity (Lee et al. 2005), we then developed a list of explicit measures of the biodiversity outcomes of management on islands. Ecological integrity as applied here aims to realize the full potential of indigenous features and natural processes functioning in sustainable communities, habitats and landscapes. The definition has nine objectives (Lee et al. 2005), five of which we used in developing performance measures: maintaining ecosystem processes; reducing the spread and impact of exotic/native species; preventing declines and extinctions; improving ecosystem composition and community participation in conservation. We tested the measures of ecological integrity on islands with different management goals then circulated the measures for verification by five island managers within and outside of the Department of Conservation.

A selection of the resultant measures was tested for six case studies (Fig. 1) to indicate efficacy of the measures.

Results

A total of 162 islands (mostly < 100 ha) has so far never been reached by mammalian pests. In addition, about 70 islands have been permanently cleared of all alien mammals to the extent that there has been no reinvasion. This has increased the area free of pest mammals from 2162 ha before eradications began to over 29 000 ha (see also Parkes and Murphy 2003). The benefits vary from range recovery of at least 200 species of vascular plants (including 13 endemics) on Great Island after removal of goats (P. deLange pers. comm.), to reappearances and increases in the abundance or management of 14 species of invertebrates and 70 species of vertebrates. For some of these, the species to benefit represent a major portion of the native fauna (Table 1).

The following case studies cover four of the five test objectives. The fifth, preventing declines and extinctions, crosses all case studies (Table 2). The case studies include one island that has never had introduced mammals and five from which introduced mammals have been removed. The islands were chosen because they illustrated key objectives of ecological integrity and have sufficient data for comparisons. We identified 35 measures of biodiversity outcomes for management on these islands. The relevance of these measures varied according to management goals of which we identified four groups (Table 3).

Case studies

1. Maintaining ecosystem processes

Middle Island (Mercury Group)

This island represents a largely unmodified seabird-reptile-invertebrate-plant system (Atkinson 1964) lost elsewhere due to the effects of invasive species. There are at least 9 species of threatened plants and animals, including the only natural population of tusked weta (Table 2). Middle Island has been colonised by 20 species of invasive plants, none of which are regarded as of sufficient threat to require control (R. Chappell pers. comm.). The island is also visited by up to 7 species of naturalized birds, but of these only hedge sparrows (*Prunella modularis*), blackbirds (*Turdus merula*), chaffinch (*Fringilla coelobs*) and starlings (*Sturnus vulgaris*) appear to be resident, with starlings the most abundant. There are no records of introduced mammals and there are no known problem exotic insects.

Extensive soil and vegetation surveys were conducted by Atkinson (1964); there have been subsequent vegetation analyses (Cameron 1990, Towns et al. 1997), periodic surveys for reptiles beginning in the 1970s (e.g. Whitaker 1978, Southey 1985, Towns 1991), and more recent repeats of geochemical analysis and studies of the effects of seabirds on plant growth rates and litter invertebrate composition (Fukami et al. 2006, Towns et al. 2009).

These analyses indicate that the island system is driven predominantly by diving petrels (*Pelecanoides urinatrix*) with average burrow densities of 6864/ha. Soil analyses in 1964 and about 40 years later both demonstrate this influence with soil pH of 3.8-4.9 and C:N ratios of 9.0-12.5. The forest has remained dominated by milk tree with an understorey of coastal broadleaved species such as wharangi (*Melicope ternata*) and mahoe (*Melicytus ramiflorus*). Litter cover is low as a result of seabird effects. Recent studies have also indicated that forest structure (Fukami et al. 2006) and the distribution of naturalized plants are modified by seabirds (N. Grant-Hoffman pers. comm.). Reptile surveys have demonstrated long term consistency of the relative abundance of lizards (Whitaker 1978, Towns 1991, Towns 2002a). There are regular biosecurity checks, including visits with rodent-detecting dogs (R. Chappell pers. comm.), which have revealed no incursion by invasive mammals.

2. Reducing the spread and impact of invasive species

Aorangi Island (Poor Knights Group)

This island was inhabited by Maori until 1823. Extensive rock walls and historic accounts show that much of the forest vegetation was removed for cultivation (Hayward 1993) and resident Buller's shearwaters were harvested for food and trade (Harper 1983). Towards the end of the 18^{th} Century pigs (*Sus scrofa*) were introduced to the island (Hayward 1993). When the island was abandoned in 1823, pigs became feral, proliferated, stripped the island bare of palatable vegetation and attacked petrels and prions, which were rooted from their burrows. The pigs were cleared from the island in 1936, following which low mixed forest regenerated and seabirds recolonised. At least five species of burrowing seabirds survived on the island or recolonised soon after the pigs were removed. Since 1938 the population of Buller's shearwaters increased from the low hundreds to an estimated 200 000 pairs, and by 1983, had displaced three other species of seabirds that had initially recolonised. A fourth species, fairy prion (*Pachyptila turtur*) is confined to nesting in crevices (Harper 1983).

Surveys for reptiles indicated that a full complement of 8 species survived the pigs and were as abundant as on neighboring uninvaded islands (Whitaker 1978). Vegetation on the island still has areas of early successional forest (deLange and Cameron 1999), but no species of plants appear to have been lost as a result of previous disturbance (Atkinson 1988). There are at least 44 species of threatened plants and animals (Table 2). The flora comprises 282 species, of which 55 (20%) are naturalized exotics. Of these, Mexican devil (*Ageratina adenophora*), mist flower (*A. riparia*), mothplant (*Araujia sericea*) and pampas grass (*Cortaderia selloana*) are wind-dispersed environmental weeds that are intensively controlled (deLange and Cameron 1999). There has been no detected incursion by invasive mammals, but suspected observations of mice (probably geckos) escaping from bait stations have invoked full rodent contingency responses (A. Booth, pers. comm.).

3. Improving ecosystem composition

Korapuki Island (Mercury Group)

This island was extensively burned about 100 years ago, then rabbits (*Oryctolagus cuniculus*) were released. Kiore or Pacific rats (*Rattus exulans*) were almost certainly already present and may have been there for centuries. Seven species of burrowing seabirds survived on the island. These were dominated by little blue penguins (*Eudyptula minor*), grey-faced petrels (*Pterodroma macroptera*) and fluttering shearwaters (*Puffinus gavia*). There was also a small breeding population of the rare Pycroft's petrel (Hicks et al. 1975). The absence of storm petrels (*Pelagodroma marina*) may reflect the historic effects of rats, in which case only 89% of the potential fauna is present. There are five resident species of threatened plants and animals (Table 2). The rats were eradicated in 1986 (McFadden and Towns 1991) and rabbits in 1987 (Towns 1988).

Vegetation in 1987 was predominantly of fire-induced and rabbit-resistant native species. The canopy was predominantly pohutukawa (*Metrosideros excelsa*), over a largely open forest floor, but with some subcanopy and open stands of mahoe and extensive coastal areas of flax (*Phormium tenax*) (Hicks et al. 1975, Atkinson 2004). Since removal of the rats and rabbits, canopy species such as milk tree have spread, an extensive and expanding subcanopy has formed and much of the coastal flax has been overtopped by shrubs and small trees (Towns et al. 1997, I. Atkinson pers. comm.). Reported weeds include boxthorn (*Lycium ferocissimum*), which is periodically controlled with herbicide and pampas (*Cortaderia* sp.), which died out when overtopped by the forest canopy.

Concurrent with successional shifts in vegetation structure and composition, many species of large invertebrate reappeared (Green in Towns et al. 1997), honeydew scale (*Coelostomidia zealandica*) spread and resident populations of skinks (Towns 1996) and geckos (Towns 2002b) increased in abundance and expanded into new habitats. The few patchily distributed diving petrels (Hicks et al. 1975) also became widespread around the coast.

Restoration of the island aims to reinstate a seabird-reptile-invertebrate-plant system typical of the archipelago (Towns and Atkinson 2004), with reintroductions of species that are incapable of natural dispersal over water. Successful releases include Auckland tree weta, robust skink, Whitaker's skink and Suter's skink. Released species for which self-sustaining populations cannot yet be claimed include the large darkling beetle, tusked weta and marbled skink. A female ship rat (*Rattus rattus*) was detected in index traps set to test the success of the kiore eradication in 1988 (Towns and Broome 2003). No subsequent incursions have been detected.

4. Community participation in conservation

The following three examples are volunteer projects run as partnerships with the Department of Conservation. The projects range from ecosystem restoration to a mix of natural and historic resource management.

Motuora Island (Hauraki Gulf)

This island has no history of introduced predatory mammals. The island is distinctive for the sandy beaches and extensive shore platform found in the Inner Gulf Islands Ecological District, but rare on islands elsewhere. During a long period of farming, almost all native forest cover was removed and replaced by exotic pasture and trees. Livestock (cattle) were removed permanently in 2006 (Heiss-Dunlop and Fillery 2006).

At inception of restoration, only about 20 ha of perimeter coastal forest remained and there was one resident threatened species (Table 2). Much of the remainder of the island had a cover of weeds such as gorse (*Ulex europaeus*) and boneseed (*Chrysanthemoides monilifera*), or was under pasture formed by an aggressive weed, kikuyu grass (*Pennisetum clandestinum*). Aside from the loss of vegetation, farming activities appear to have directly or indirectly led to severe depletion of invertebrate and reptile faunas. For example, only two resident species of small skinks have been reported from a potential fauna of up to 13 species. Similarly, aside from about 300 scattered grey-faced petrels, all seabirds have been lost, reducing the fauna by at least 80% (Gardiner-Gere et al. 2007).

Restoration of the island aims to reconstitute an ecosystem comprised of plants and animals that would have been present before human contact (Hawley and Buckton 1997), but with initial emphasis on encouraging ecosystem drivers such as honeydew scale insects and seabirds (Gardner-Gere et al. 2007, H. Lindsay pers. comm.).

Between 1990 and 2006, almost 206 000 plants comprising 21 early successional species and some of tall forest were planted in 35 ha of retired pasture (Gardener-Gere et al. 2007). The flora comprises 288 taxa of which 123 (43%) were native and 165 (57%) were exotics including garden relicts (Heiss-Dunlop and Fillery 2006). Aggressive weed control has reduced boneseed and boxthorn to restricted areas, most pines (*Pinus* spp.) have been removed, and Madeira vine (*Anredera cordifolia*), climbing asparagus (*Asparagus scandens*) and pampas have been heavily suppressed. New invasions by holly fern (*Cyrtomium falcatum*) and Chinese privet (*Ligustrum sinense*) are also under control (Lindsay 2006, Heiss-Dunlop and Fillery 2006).

Since 1999, Motuora Island has been a crèche for headstarting juvenile North Island brown kiwi incubated at Auckland Zoo. Once they reach sufficient weight to avoid predation by stoats, the kiwi are returned to the mainland. Some birds appear to have eluded capture and may be breeding on the island.

Shore plover (*Thinornis novaseelandiae*) were released on Motuora in 1994, but despite intensive efforts to maintain and supplement the population, birds either departed or were attacked by moreporks (*Ninox novaseelandiae*). By 2000, only one pair remained and the attempt was abandoned (Miskelly 2001). In 2007, Duvaucel's geckos fitted with radio transmitters were released to test their susceptibility to predation from native ground-feeding birds such as pukeko (*Pophyrio porphyrio*). A male Norway rat was detected on the island in February 2008 and was trapped 16 days later (R. Renwick pers. comm.).

Tiritiri Matangi Island (Hauraki Gulf)

The island has had a working lighthouse since 1865, with much of it farmed since the early 20th century. Farming outside the lighthouse reserve ceased in 1971, leaving 24 ha (11%) of forest remnants, 115 ha (52%) in rank pasture and the remainder in early successional ferns and scrub (Esler 1978). However, 13 ha around the lighthouse remained in pasture and with stock until 2005. The only introduced mammalian predator on the island was kiore, which were eradicated in 1993.

Restoration of the island was, at least initially, designed to support the relict bird populations, which included bellbirds (*Anthornis melanura*) and little blue penguins, and to provide a location where threatened and endangered birds could be viewed by the public (Craig 1990, Hawley 1997, Rimmer 2004). Regeneration was assisted by volunteers who planted 280 000 trees into the rank pasture, mainly during 1984-1994 (Rimmer 2004).

In 1975, the flora of the island comprised 339 taxa, of which 186 (55%) were native (Esler 1978). By 2007, and despite intensive planting, the number of taxa was 443, of which 231 (52%) were native (E. Cameron pers. comm.). The main weed species under control are Japanese honeysuckle (*Lonicera japonica*), mothplant and boxthorn, although there are localized treated areas of boneseed, periwinkle (*Vinca major*) and mile-a-minute vine (*Dipogon lignosus*) (H. Lindsay pers. comm.).

One species of threatened plant, three species of reptiles and 11 species of birds have been released on the island (Table 2). A release of tomtits (*Petroica macrocephala toitoi*) apparently failed when the entire population disappeared; some returning to capture sites on the mainland (Rimmer 2004). After initial high reproductive output (Craig 1990), most brown teal (*Anas aucklandica*) appear to have succumbed to avian predators (R. Renwick pers. comm.). Three other species, takahe, kokako and hihi, are held on the island as part of threatened species programmes. The hihi population is intensively managed with supplementary feeding, and is the only surviving translocated population on an island.

In 2000, Argentine ants (*Linepithema humile)* were discovered in about 10 ha around the only wharf. An intensive baiting campaign conducted over five years appears to have eliminated the entire population (C. Green pers. comm.). Mice (*Mus musculus*) (number unspecified) in stores were detected and killed in 1986 and in 2007 a Norway rat was detected and eliminated on the ferry that services the island (Russell et al. 2008).

Motuihe Island (Hauraki Gulf)

The island was purchased from Maori as a farm in 1839, and it is most likely during farming operations that mice and Norway rats reached the island. Rabbits were also introduced and cats (*Felis catus*) became feral on the island from about 1984 (ISSG database). A long history of varied human use has left at least 60 Maori archaeological sites, military gun emplacements, and groves and avenues of exotic trees. Farming over 150 years led to reduction of coastal forest to two remnants of pohutukawa/kohekohe (*Dysoxylum spectabile*) and taraire (*Beilschmeidia tarairi*) covering about 19 ha. These areas were also degraded by stock and invaded by aggressive weeds such as mothplant and woolly nightshade (*Solanum mauritianum*). A local population of bellbirds disappeared in the 1950s probably due to introduced pests and habitat degradation by stock (Lovegrove in Morton 1993). Today, 130 ha of the island is rank pasture after removal of cattle in 2005.

Like Motuora, Motuihe Island has significant sandy beach habitats and extensive rocky tidal platforms. On Motuihe, these are used by shore birds including New Zealand dotterels, which with two species of plants, are the only resident threatened species (Table 2). Mice and rats were eradicated from the island in 1997 (Veitch 2002), cats in 2002 and rabbits in 2004 (Clout and Russell 2006).

Management of the island is based around four themes: management of physical and cultural resources, rehabilitation of natural biodiversity, providing for recreational use and advocacy for conservation through participation (Hawley 2004). In order to cater for these diverse goals, the island has effectively been separated into a historic area in the 13.5 ha northwestern portion and archaeological sites scattered throughout. Most of the remainder is to be managed coastal habitats, forest and wetlands inhabited by native species and accessible from trails and viewing points.

As of 2004, Motuihe had a flora of 453 taxa of which 132 (29%) were native and 321 (71%) were exotics including 109 taxa identified as plantings. These include common garden and ornamental plants associated with previously settled areas. However, planted historic species such as olives (*Olea europaea*), *Pinus* spp., Moreton Bay fig (*Ficus macrophyllus*) and holm oak (*Quercus ilex*) have naturalized and without control could become invasive. The most serious of 15 weeds include evergreen buckthorn (*Rhamnus alaternus*), moth plant, and woolly nightshade, each of which is present on the mainland or nearby islands and capable of continued dispersal to Motuihe (Hawley 2004, H. Lindsay and P. Brown pers. comm.).

In 2005, saddlebacks (*Philesturnus carunculatus*) were released on the island as the first of an array of proposed introductions (Taylor and Taylor 2007). In 2006, there was a serious biosecurity threat when a local shipping company twice careened barges on a sandy foreshore. In April 2008, a female Norway rat detected on the island was tracked down by a rodent-detecting dog and destroyed within 48 hours of first discovery.

Between and within island comparisons

The value of measuring success is illustrated from the above case studies by comparisons between islands. For example, when the exotic and indigenous components of the flora are compared (Fig. 2), high indigenous dominance at the three reserves with high ecological integrity as the goal (≥80%) contrasts with the other three islands (as low as 29%). Within island comparisons can also be revealing. On Korapuki Island, over an approximately 40-year time span the native flora increased from 54 species in the presence of rats and rabbits to 103 species after their removal, while the exotic component declined from 26% to 19%.

Reptiles form the largest resident vertebrate group on many northern islands, with Aorangi (8 species) and Middle (11 species) still supporting the full compliment within each archipelago (Fig. 3). On the other four islands, restoration of reptile assemblages is a stated goal, but is closest to completion on Korapuki, with 82% of the expected fauna now present. These figures are based on the assumption that all releases succeed (Towns and Ferreira 2001), but the history of bird releases on Tiritiri Matangi illustrates that criteria for success are also required for species introductions.

Discussion

Our analysis of the effectiveness of island conservation involved three levels of measurement. The first was a coarse measure of management effectiveness across all islands from which pests have been removed. The second was to identify and test selected performance measures within island categories. The third aimed to demonstrate the value of comparisons between islands and within islands over time.

Across all islands, the removal of all introduced mammals from at least 70 islands around New Zealand is an extraordinary achievement. Since the eradications were designed to protect and enhance indigenous species and ecosystems, one test of effectiveness is to ask whether any eradicated species have reinvaded. In our sample, there were no reinvasions, with some islands clear of pests for many decades. However incursions by mice and rats, and the new invasion of Tiritiri Matangi by Argentine ants, provide a warning of the effects of lapsed biosecurity.

Those aside, the more important measure of effectiveness of the eradications is to identify the number of native species to benefit. These statistics are also remarkable, amounting to improved prospects for 70 species of vertebrates, including 33% of all lizard species and 40% of all birds. Furthermore, just within the six case study sites, effective protection against mammal invaders, removal of pests and species translocations have been of benefit to at least 60 threatened taxa (Table 3).

At the second level of measurement, we expanded on the proposed performance measures (Lee et al. 2005) to account for the range of management goals represented in our sample. This exercise gave useful insights. First, the range of measures in Lee et al. (2005) is best viewed as generic and can usefully be modified according to management goals. Second, because management goals vary, not all measures are required at all sites. For example, on Middle Island species introductions should not be contemplated since the goal is maintenance of existing high ecological integrity. Therefore, many measures of the effectiveness of threatened species management or of translocations are not relevant. They are, however, important measures at other locations (Table 3). Third, the frequency of measurements varies according to objective. For example, measures of ecosystem representation, such as representativeness and irreplaceability, may only be needed once. However, they are needed for all sites.

In developing our case studies, we found useable data to support all measures applied on the three islands aiming for high ecological integrity (measure n=13-20 depending on management goals) and for 78-85% of the measures applied on the three islands managed in partnerships with communities (n=13-23). On these latter islands, consultation with project leaders indicated that most missing data should be obtainable. One surprising information gap was for Tiritiri Matangi Island. Despite the focus on management of birds, there are no published bird lists that enabled calculation of changes in indigenous dominance (the relative contributions in bird communities of indigenous and exotic species).

The third level of measurement is through comparison between islands and within islands over time. Such comparisons can be instructive. For example, the flora of three islands with a history of farming had a high exotic component. As revegetation progresses, there is potential for this component to decline (for example, as indicated on Korapuki Island). The least modified islands also set benchmarks for species occupancy, which is the degree to which organisms that potentially could occupy ecosystems are in fact represented. For example, compared with Aorangi and Middle Island, reptile assemblages elsewhere provided a measure of local extinctions due to historical activities. In our sample, Middle Island also has measurable densities of seabirds and high (74%) indigenous dominance of its flora. As a restoration island, Korapuki has an expanding flora which maintained very high indigenous dominance (> about 80%), an increasing fauna of large invertebrates and reptiles through reintroductions, and an increasing influence from seabirds. By comparison, the three islands where community participation is the goal have low levels of indigenous dominance. This may eventually increase through active planting of native species, but even after 30 years of effort, the proportion of indigenous species has not increased on Tiritiri Matangi Island. It makes sense that the short-term focus of projects on such islands is to reduce exotic spread and dominance, which is being undertaken through weed control.

The least modified sites may also have potential to provide data for an additional objective of ecological integrity: measuring climate change and variability. As the relative stability of the seabird driven system on Middle Island indicates, the frequency of such measures may provide useful data even if at decadal timescales.

The key message from these systematic measures of achievement is that information must be accessible and repeatable. To this end, a national island management strategy in development should help with defining management goals relative to island use and legal status (Anon. 2007). Measures of achievement against these goals should not be seen by conservation managers or community groups as an imposition but more importantly as a means of plotting progress, even if very simple measures are used. They will also provide for adaptive management where lessons learned can be transferred between sites and community groups. At a more technical level, there should also be potential to develop restoration models and track progress against them (e.g. Towns and Atkinson 2004), where restoration models become testable hypotheses.

This account explicitly aims at measuring the effects of management on biodiversity. We have not undertaken a similar analysis for community participation in conservation, although generic measures are provided by Lee et al. (2005). People participate in the management of all islands in different ways depending on reserve type. The three examples used here are for islands where there is a particularly high level of involvement through hands-on management by communities with a leadership role. At present, the social goals of such activities appear poorly defined. This is surprising given that the involvement of local communities is a key part of the New Zealand biodiversity strategy (Anon. 2000). Indeed, it is unclear whether the development of community-led restoration projects on islands was primarily to meet social (conservation awareness) or biodiversity goals. Internationally, the results from community-based conservation have been mixed (Berkes 2003), perhaps because social and biological goals can produce internal conflict.

Consequently, although we can identify a range of informative biological measures of success for island management projects, we still lack clear measures of their social effects.

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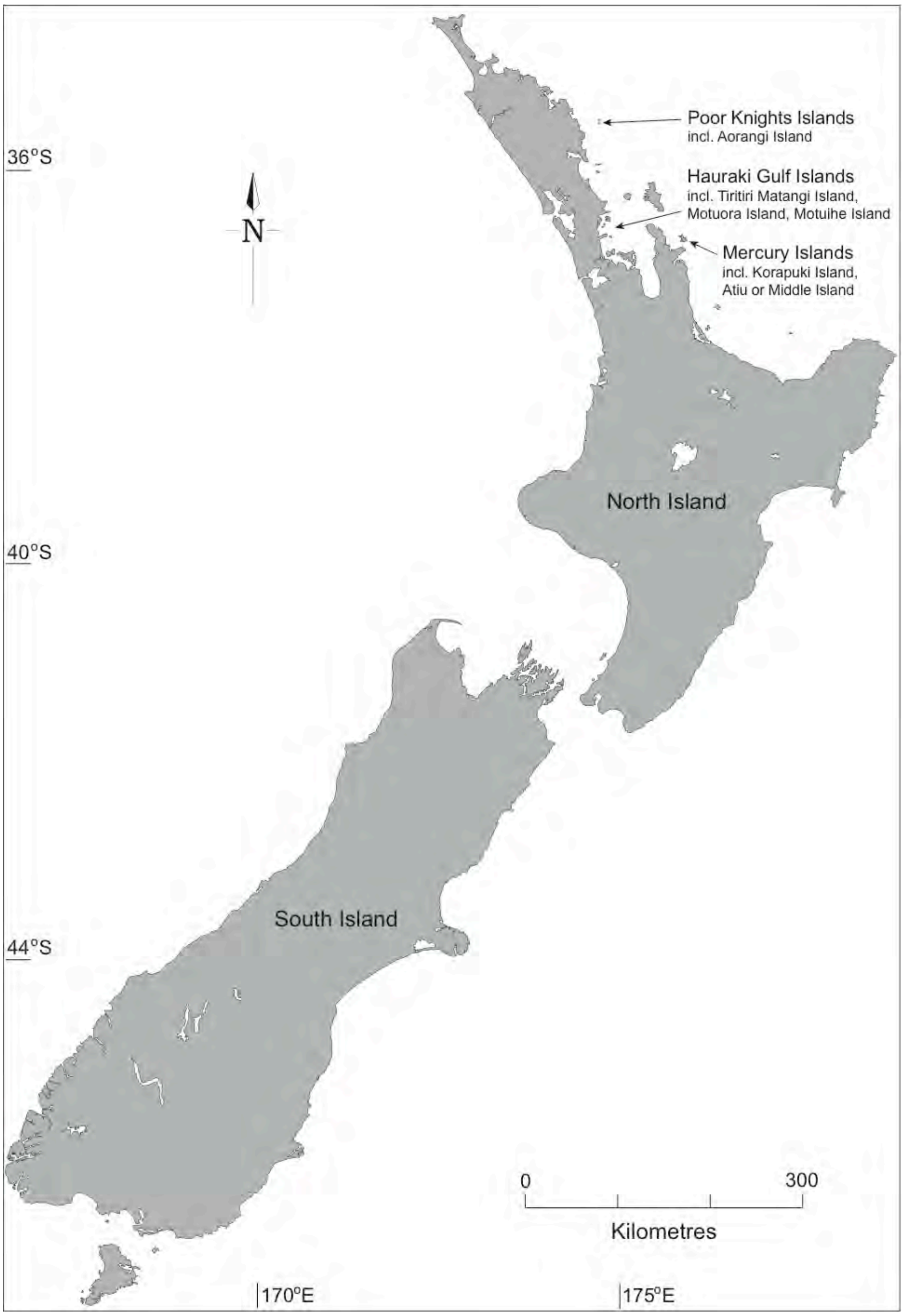


Figure 1. Locality map showing case study sites.

Table 1. Numbers of selected species that show measurable benefits from pest eradications from New Zealand islands up to 2007.

Taxonomic group	**Recolonisation or recovery *in situ***	**Trans-location**	**Total**	**Percentage of total biota**	**Comments**
Plants	>200	Excludes plantings	>200	>90%	Applies only to vascular plants of Great King Island (Three Kings) after removal of goats; but also 32 native species recolonised Korapuki Island after removal of rats and rabbits.
Invertebrates	3	11	14	N/A	Relates mostly to large flightless species; few data on *in situ* responses
Amphibians (frogs)		2	2	50	Native frog species with few island populations and restricted island secondary endemics
Tuatara	1 (subspecies)	3	3	100	Entire fauna island secondary endemics; includes natural recovery at some sites and translocations at others
Geckos	3	6	7	18	Includes species with natural recovery at some sites and translocations at others
Skinks	8	11	16	40	Includes species with natural recovery at some sites and translocations at others
Terrestrial birds	4	25	29	40	Includes 6 species managed on islands where individual populations are not self-sustaining
Seabirds	12	4	12	14	Includes species with natural recovery at some sites and translocations at others
Mammals (bats)		1	1	50	Outcome of translocations still unclear

Table 2. Island case studies with indicative management goals and outcomes and species to benefit, with threat status according to Hitchmough (2002) to indicate "preventing declines and extinctions". Species are listed as 'managed' if only sustainable on island with assistance, 'translocated' if probably outside historic range and 'reintroduced' if likely within historic range (unsuccessful translocations have not been included).

Island & area (ha)	**Reserve type (legal)**	**Management goal**	**Management outcome**	**Key species to benefit**
Middle (13)	Wildlife Sanctuary	Protection of ecosystems with high ecological integrity	Maintenance of ecological integrity	Resident species: (Plants) Cook's scurvy grass (*Lepidium oleraceum*) (En); mawhai (*Sicyos* aff *australis*) (Sd); milktree (*Streblus banksii*) (Sp);(Insects) tusked weta (*Motuweta isolata*) (Cr); (Reptiles) tuatara (Sp); Duvaucel's gecko (*Hoplodactylus duvaucelii*) (Sp); marbled skink (*Cyclodina oliveri*) (Rr); robust skink (*C. alani*) (Rr); Whitaker's skink (*C. whitakeri*) (Vu); Suter's skink (*Oligosoma suteri*) (Rr)
Aorangi (110)	Nature	Protection of ecosystems with high ecological integrity undergoing natural recovery from disturbance	Restoration of ecological integrity	Resident species: (Plants) *Tortella mooreae* (Rr); *Asplenium pauperequitum* (En); *Chionochloa bromoides* (Rr); Cook's scurvy grass; *Cordyline obtecta* (Sp); *Hoheria equitum* (Rr); large-flowered broom (*Carmichaelia williamsii*) (En); *Linum monogynum* var *chathamicum* (Nc); *Macropiper excelsum* subsp *peltatum* f *peltatum* (Rr); mawhai; milktree; *Myrsine aquilonia* (Rr); Parapara *Pisonia brunoniana* (Sp); *Picris burbidgeae* (En); Poor Knights lily (*Xeronema callistemon*) (Rr); *Rorippa divaricata* (En); *Senecio marotiri* (Sp); *Solanum aviculare* var *latifolium*; (Snails) *Allodiscus cooperi* (Rr); *Amborhytida pycrofti* (Rr); Charopidae sp. (Rr); *Laoma minuta* (Rr); *Liarea egea* (Rr); (Insects) *Crisius* sp. (Rr); *Exomesites* sp. (Rr); *Gastrosaurus* sp. (Rr); *Hadracalles fuliginosus* (Rr); karo weevil (*Hadramphus pittospori*) (Rr); *Mimopeus* sp. (Rr); *Navomorpha neglecta* (Rr); *Neotamus* sp. (Rr); *Omedes nitidus* (Rr); *Paralissotes manganuiensis* (Sp); *Phrynixus* sp. (Rr); *Praolepra* sp. (Rr); Poor Knights giant weta (*Deinacrida fallai*) (Rr); (Reptiles) tuatara; Duvaucel's gecko; Poor Knights gecko (*Hoplodactylus* sp.) (Rr); Poor Knights marbled skink (Rr); Poor Knights skink (*Cyclodina hardyi*) (Rr); Suter's skink; (Birds) Buller's shearwater (*Puffinus bulleri*) (Rr); Poor Knights bellbird (*Anthornis melanura oneho*) (Rr)

Threat categories from most to least threatened are: Nationally critical (Cr), Nationally endangered (En), Nationally vulnerable (Vu), Serious decline (Sd), Sparse (Sp), Range restricted (Rr).

Table 2. (continued).

Island & area (ha)	Reserve type (legal)	Management goal	Management outcome	Key species to benefit
Korapuki (18)	Wildlife Sanctuary	Restoration of disturbed site to highest possible level of ecological integrity	Restoration of ecological integrity	Resident species: (Plants) *Blechnum norfolkianum* (Sp); mawahi; milktree; (Reptiles) Duvaucel's gecko; (Birds) Pycroft's petrel (*Pterodroma pycrofti*) (Rr). Reintroductions of: (Insects) Auckland tree weta (*Hemidiena thoracica*); tusked weta; large darkling beetle (*Mimopeus opaculus*); (Reptiles) marbled skink; robust skink; Whitaker's skink; Suter's skink
Motuora (80)	Recreation	Research, restoration, public participation and education	Management of ecological integrity in the context of public awareness and enjoyment	Resident species: (Plants) *Calystegia marginata* (Sp). Translocations of (Birds) North Island brown kiwi (*Apteryx australis*) (Sd). Reintroduction of (Reptile) Duvaucel's gecko
Tiritiri Matangi (221)	Scientific	Research, restoration, public participation and education	Management of ecological integrity in the context of public awareness and enjoyment	Reintroductions of: (Birds) North Island fernbird (*Bowdleria punctata vealeae*) (Sp); North Island robin (*Petroica australis longipes*); North Island saddleback (*Philesturnus carunculatus rufusater*) (Rr); red-crowned kakariki (*Cyanoramphus n. novaezelandiae*); whitehead (*Mohoua albicilla*); tuatara; Duvaucel's gecko; shore skink (*Oligosoma smithi*). Translocation of little spotted kiwi (*Apteryx owenii*) (Rr). Managed: (Plant) kakabeak (*Clianthus puniceus*) (Cr); (Birds) North Island kokako (*Callaeas cinerea wilsoni*) (En); hihi (*Notiomystis cincta*) (En); takahe (*Porphyrio hochstetteri*) (Cr)
Motuihe (179)	Recreation	Protection and restoration of cultural, historic and natural resources	Management of ecological cultural and historic resources in the context of public awareness and enjoyment	Extinct: (Plant) Shore splurge (*Euphorbia glauca*) Resident species: *Blechnum norfolkianum*; fireweed (*Senecio scaberulus*) (En); (Birds) Northern New Zealand dotterel (*Charadrius obscurus aquilonius*) (Vu). Reintroduction of North Island saddleback

Threat categories from most to least threatened are: Nationally critical (Cr), Nationally endangered (En), Nationally vulnerable (Vu), Serious decline (Sd), Sparse (Sp), Range restricted (Rr).

Table 3. Measures of biological importance, change and success of biodiversity management on islands within objectives for ecological integrity of Lee et al. (2005) in bold face and primary measures in italics. Examples of measures relevant to define management goals are marked X.

	Management goal			
Measures	**Maintenance of ecological integrity**	**Restoration of ecological integrity**	**Restoration management with high levels of public involvement**	**Management of ecological, cultural and historic resources**
Maintaining ecosystem processes				
Soil status and productivity				
Ecosystem drivers (role and identity)	X	X		
Soil geochemistry	X	X		
Vegetation density at ground & shrub level	X	X		
Depth of plant litter	X	X		
Native species occupancy				
Composition of vegetation	X	X	X	
Composition of invertebrates	X	X	X	
Composition of vertebrates	X	X	X	
External influences on integrity	X	X		
Convergence with restoration models*	X	X		
Reducing exotic spread and dominance				
Naturalisation of weeds and pests				
Number of exotic plant species	X	X	X	
Increased area in indigenous vegetation		X	X	
Species of weeds present	X	X	X	X
Species of weeds controlled	X	X	X	X
Species of weeds eradicated	X	X	X	X
Number / control of problem invertebrate species	X	X	X	
Number and control of problem bird species	X	X	X	
Number and control of problem mammals			X	X
Effectiveness of biosecurity	X	X	X	
Preventing extinctions and declines				
Status of threatened taxa				
Threatened taxa present	X	X	X	X
Indigenous species exported	X	X	X	
Threatened species managed		X	X	
Threatened species self sustaining	X	X	X	
Translocations that have failed		X	X	
Improving ecosystem composition				
Composition of communities				
Species of indigenous plants	X	X	X	X
Species of indigenous invertebrates	X	X	X	X
Species of indigenous reptiles	X	X	X	X
Species of indigenous birds	X	X	X	X
Species of indigenous mammals	X	X	X	X
Species recolonised		X	X	
Species imported – plants		X	X	X
Species imported – invertebrates		X	X	X
Species imported – reptiles		X	X	X
Species imported – birds		X	X	X
Species imported – mammals		X	X	X
Improving ecosystem representation				
Environmental representation and status				
Representativeness	X	X	X	X
Irreplaceability				
Unique/distinctive habitats	X	X	X	X
Endemic species	X	X	X	X
Unique populations	X	X	X	X

* Milestones for ecosystem recovery derived from other measures in Table 3.

Figure 2. Plant species lists as measures of indigenous dominance on six islands in northern New Zealand, including Korapuki with and without rabbits; native species in shaded columns and exotic species in open columns.

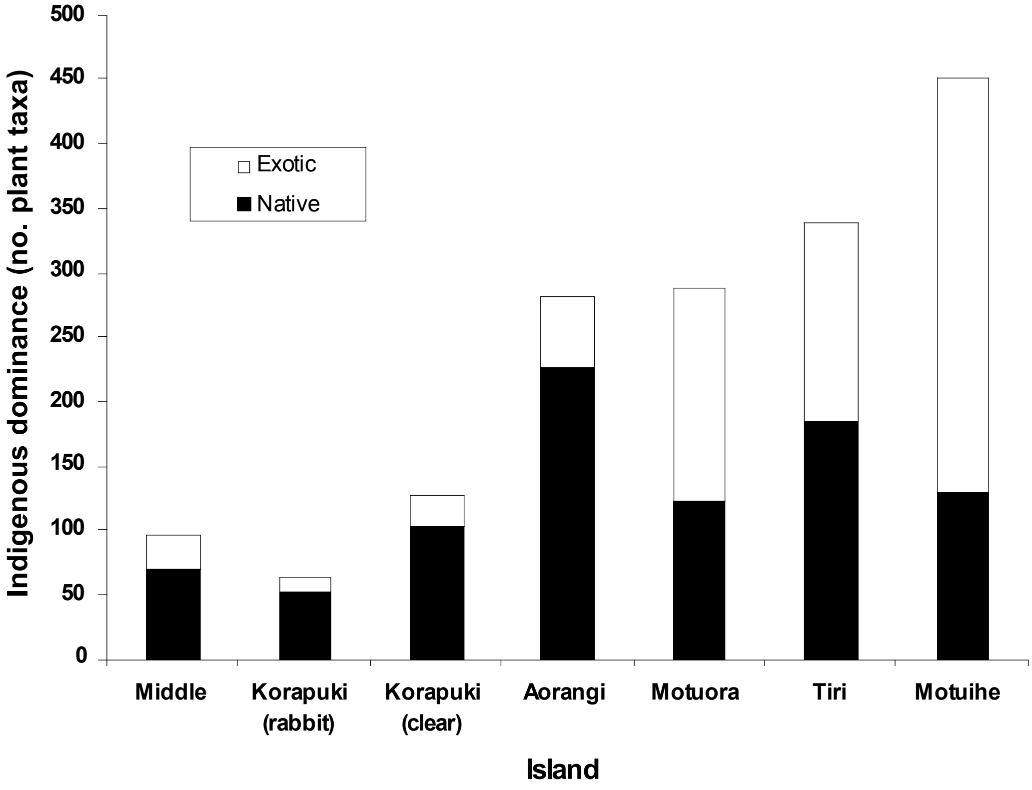
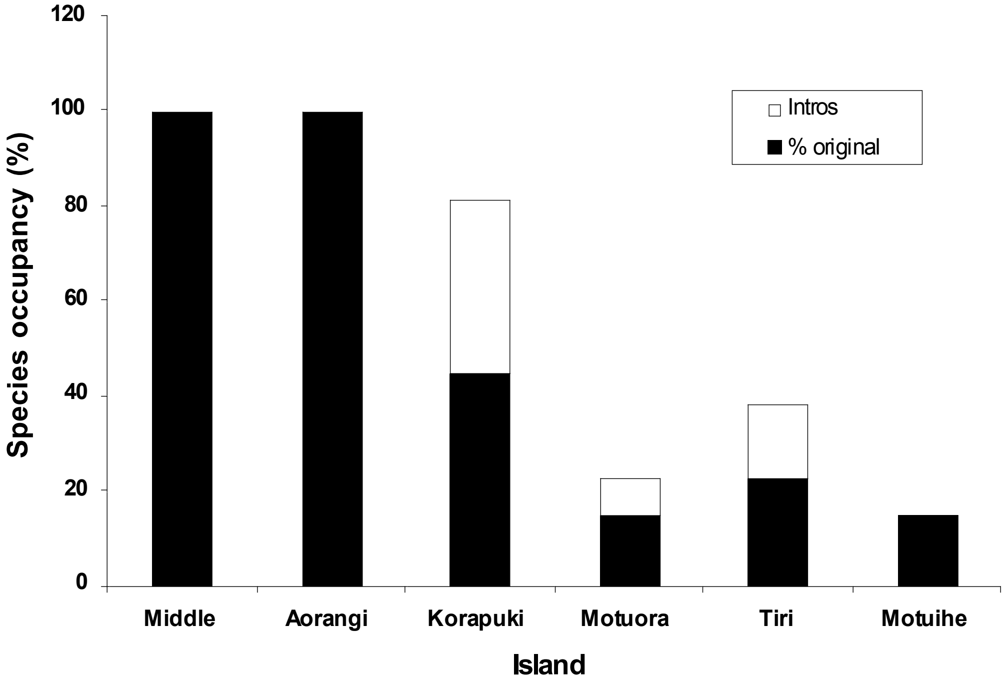


Figure 3. Reptile species lists used as measures of species occupancy on six islands in northern New Zealand with potential fauna estimated from extant or subfossil faunas on neighboring islands or the adjacent mainland; original fauna in shaded columns and those introduced for restoration in open columns.



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