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A research strategy for biodiversity conservation on New Zealand's offshore islands

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Abstract: New Zealand's (NZ) offshore islands are refuges for many threatened species, a high proportion of vertebrate diversity, and the world's most diverse fauna of seabirds. We present key issues and questions that can be used to guide research on the conservation of biodiversity on these islands. Four global reviews formed a basis from which we identified research questions of potential relevance to the management of NZ islands. The research questions were assigned in the context of nine objectives proposed as a means of achieving ecological integrity. For each of the nine objectives, we then asked what has been achieved in terms of island research and management, and what needs to be achieved in order to meet long term goals. We used local examples to identify issues and questions specific to islands in the NZ region. Our analyses revealed two research areas in which current understanding is poor. One is the need to understand ecosystem processes and their resilience to long-term environmental change. The second is the need to define and better understand the consequences of direct involvement by the public in the management of islands, including partnerships between government agencies, *tangata whenua* (original people of the land - Māori) and non-government organisations such as community groups.

Keywords: ecological integrity; needs assessment; ecosystem processes; invasive species; pollutants; extinctions and declines; ecosystem composition; environmental representation; climate change; sustainable use; community involvement

Introduction

Island ecosystems worldwide are particularly vulnerable to extinctions (Carlquist 1965; Quammen 1996; Wilson 2002). In New Zealand (NZ), 41% of all bird species have become extinct since settlement by people began about 730 years ago (Tennyson & Martinson 2006). The NZ Government's Biodiversity Strategy (NZBS) co-ordinated by the Department of Conservation (DOC) and the Ministry for the Environment (MfE) was a response to continuing population declines of many remaining species of flora and fauna, concerns about habitat deterioration, and the effects of biological invasions (DOC & MfE 2000). One goal of the NZBS is to "maintain and restore a full range of natural habitats and ecosystems to a healthy functioning state; enhance critically rare habitats….and maintain and restore viable populations of indigenous species and subspecies across their natural range and maintain their genetic diversity." The NZBS also advises agencies to develop research strategies that identify gaps in the knowledge and understanding of key threats to biodiversity.

Like islands globally (Caujapé-Castells et al 2010), offshore islands are a crucial component of NZ's natural habitats. The origins, distribution and history of conservation on these islands are described in detail by Towns & Ballantine (1993), Towns et al. (1997) and Bellingham et al. (2010a). In brief, NZ's offshore islands span a latitudinal range nearly twice that of the main North and South Islands, maintain populations of species endemic to specific archipelagos, and contain relict populations extinct elsewhere. Notably, the islands support a disproportionally large amount of the national biodiversity of vertebrates (Daugherty et al. 1990), including

85 species of seabirds, 42% of which are regionally or nationally endemic (Taylor 2000). At least 95 (17%) of the 577 invaded islands > 1 ha have now been cleared of all introduced mammalian predators and herbivores (Parkes & Murphy 2003; Towns in press), with benefits for the conservation of numerous species of plants and animals (Towns et al. 2009b; Bellingham et al. 2010a). These island restoration efforts include initiatives that involve *tangata whenua* (original people of the land or iwi Māori) and community groups (e.g. Mansfield & Towns 1997; Hunt and Williams 2000), as part of an increasing interest and involvement of iwi and the public in hands-on conservation management (Hardie-Boys 2010).

About 250 (34%) of the 735 islands >1 ha are managed by DOC (Parkes & Murphy 2003), including all subtropical and sub-Antarctic islands under NZ administration. How DOC will contribute to objectives of the NZBS is defined in an annual Statement of Intent to Parliament. Since the NZBS does not provide methods for measuring progress towards its goals, changes in the condition of NZ biodiversity are measured by DOC through changes in ecological integrity (e.g., DOC 2009). A similar approach is used to support measurements of the status of natural resources by agencies such as Parks Canada (reviewed by Lee et al. 2005). In NZ, ecological integrity is defined as *the full potential of indigenous biotic and abiotic features, and natural processes, functioning in sustainable communities, habitats and landscapes* (Lee et al. 2005). Achieving improved ecological integrity relies on the support and participation of communities of people, a point regularly emphasised in DOC's Statements of Intent (e.g. DOC 2009, 2010a), and accommodated in two of the indicators (objectives) listed by Lee et al. (2005). Combined views of biodiversity and social goals through multi-scaled systems analysis is increasingly advocated as the most effective long term approach to measuring and resolving problems related to environmental change (e.g. White et al. 2008; Anderson et al. 2009; Lindemayer & Hunter 2010; Sterling et al. 2010).

Biodiversity management and community participation on NZ offshore islands are likely to advance most rapidly if long-term goals are defined for all islands (Atkinson 1990; DOC & MfE 2000; DOC in press). This possibility was recognised by DOC and Landcare Research, who requested that we identify information needs and promote them to funding agencies as national priorities. Here we demonstrate how national priorities for NZ offshore islands could be informed by listing key issues and questions relating to the management of biodiversity. To achieve this, we identified global research questions that may be applicable to NZ and locally relevant biodiversity issues. We then sorted these according to indicators of change in ecological integrity. Finally, we defined specific research questions that, if investigated, should be of particular assistance to the conservation of biodiversity on islands.

For the purposes of this review, we have used the definition of biodiversity in the NZBS, which in brief is the "variety of all biological life – plants, animals, fungi and microorganisms – the genes they contain and the ecosystems…where they live" (DOC & MfE 2000). An offshore island is any landmass permanently surrounded by water off the three main islands (mainland) of NZ.

The national context for our investigation was provided by a review of the state of island conservation in NZ (Bellingham et al. 2010a), guidelines for the management of islands administered by DOC (DOC 2010b), an outline of potential measures of the ecological integrity of island ecosystems (Towns et al. 2009b), and a forum on cross-cultural views of environmental research and management (Stephenson & Moller 2009). These sources identified the following four key issues and challenges of relevance to NZ islands.

First, invasive species removals from islands since the beginning of the 20th Century have increased the habitat available to those indigenous species sensitive to introduced mammals from around 2,000 ha to at least 35,000 ha. These eradications have potential benefits to more than 70 species of native vertebrates and numerous species of invertebrates and plants (Bellingham et al. 2010a). Most eradications have been on islands that are uninhabited. The challenge will be to record the way these systems recover and protect them from reinvasion or invasions by new species.

Second, the long-term security of threatened species that require larger areas of habitat, and the protection of some sub-Antarctic ecosystems, can only be achieved on a small number of very large islands. By area, some of these may individually exceed the total area so far recovered by all previous invasive animal eradications. In these cases, the challenges include large scale, high financial cost, and, on some islands, the presence of resident communities.

Third, the NZBS advocates community understanding and involvement with conservation of biodiversity (DOC & MfE 2000), and there are now numerous examples of community-led island restoration projects (e.g. Towns et al. 2011). For this goal to be met, relationships will need to be strengthened through improved mutual understanding and defined social goals for the relationships. Participation in conservation activities as well as measuring their outcomes (e.g. Jackson 2001) should also help with the wider goal of involving residents in the eradication of problem organisms from the larger, inhabited islands.

Finally, the NZ government has a relationship with Māori through the Treaty of Waitangi that is enshrined in legislation (e.g. Section 4 of the Conservation Act, 1987). This relationship carries with it opportunities and obligations that are reflected in other goals of the NZBS (DOC & MfE 2000): protecting the interests iwi have in indigenous biodiversity, building and strengthening their partnerships with Crown agencies, and conserving and sustainably using indigenous biodiversity. The challenge will be to understand cross-cultural views of environmental management (Taiepa et al. 1997).

Methods

We obtained references to published research strategies elsewhere from three sources: (i) Google Scholar using the keywords island, biodiversity, research, strategy; (ii) BIOSIS advanced search TS=(island AND (research OR strategy) AND (biodiversity)); and (iii) the contents pages since 2006 (the last five years) for the highly cited conservation journals *Conservation Biology*, *Biological Conservation*, and *Biodiversity and Conservation* (e.g. Liu et al. 2011). These sources revealed two reviews of particular relevance: an account of 100 questions of importance to the conservation of global biodiversity (Sutherland et al. 2009) and key research questions identified to manage non-indigenous species (Byers et al. 2002). Hitherto unpublished information was gleaned from 140 presentations at an international conference on island invasive species (Veitch et al. in press); and a global review of the ecology, effects of invasions and restoration of seabird islands (Mulder et al. 2011). Only a fifth of the global questions posed by Sutherland et al. (2009) were directly relevant to islands, so we have included this subset in our review.

To ensure comprehensive coverage of issues and questions specific to NZ islands, we sorted all questions from the global reviews according to the nine objectives of ecological integrity listed by Lee et al. (2005). Using this framework, we then used case studies based on our collective experiences with NZ island ecosystems to illustrate specific issues raised by the objectives of ecological integrity. For each objective we asked: what has been achieved in terms of NZ island management, and what needs to be achieved in order to meet long term goals? Such exercises are commonly referred to in business as a needs assessment or gap analysis. Finally, we used the needs assessment to identify key research questions that will require resolution so that management goals can be met. Specialists or specialist groups from DOC (as a government agency) and the Auckland Council (as a local authority responsible for inhabited and uninhabited islands) and ecological specialists on two Conservation Boards were then asked to test how the needs assessment related to their island management activities and to identify more specific questions that could be developed into research topics. The results of these exercises were then organised into the final research questions.

Global questions and local issues

The research questions derived from global reviews (Table 1), and the local issues identified through case studies, are outlined below within the following objectives for ecological integrity.

Objective 1: Maintaining ecosystem processes

Ecosystem processes refer to the transfer of energy and matter as a result of interactions between organisms and their environment. If critical processes are disrupted, ecosystems can be transformed, degraded or lost (Lee et al. 2005). In NZ, islands that escaped invasion by introduced mammals represent ecosystems with highest ecological integrity. However, many of these island ecosystems were modified after long periods of occupation by Māori; nearly all close to the mainland were burned and have been invaded by non-native plants, invertebrates and birds. Despite these effects, the less modified islands provide models of how ecosystems functioned elsewhere in NZ before mammalian introductions, and can also guide the ecological restoration of islands more extensively modified by invasive mammals. Because islands with the highest ecological integrity span >23 degrees of latitude, a range of benchmark sites could also be established for regular measurement of ecosystem attributes and processes. Long term environmental monitoring (LTEM) sites are proposed for Australia (Likens & Lindenmayer 2011) and 15 years data from an environmental change network has demonstrated long term trends in the UK (Morecroft et al. 2009). In NZ, a systematic approach to LTEM on land administered by DOC will be implemented from 2011 and builds upon a regular sampling approach (E.F. Wright, DOC, pers. comm.), but because sample points are on a 8-km × 8-km grid, very few of these points are located on offshore islands (Allen et al. 2003). Thus developing LTEMs for NZ's offshore islands necessitates a stratification to obtain sufficient sampling to document temporal changes in their biota and to inform plans for the management of small populations confined to islands. Longer-term perspectives could also be gained from palaeoecological studies at such sites, especially if they indicate the likely influence of climate change on island ecosystems (Wilmshurst et al. 2004).

At present, there are few comprehensive comparisons of biotic communities on islands unaffected by introduced mammals. Nonetheless, sampling over 40 years on Middle Island in northern New Zealand (Box 1), indicates little change in the composition of plant or vertebrate communities. However, these data were not obtained systematically and we lack studies of most invertebrates so subtle changes could have been overlooked. This problem could be overcome using standardised methods which, however, need to be comparable with those used to collect data from the New Zealand mainland (Allen et al. 2003) and internationally. Physical and biotic attributes have already been used in global comparisons across archipelagos (Mulder et al. 2011), and these could be applied in NZ. Mātauranga (Māori traditional ecological knowledge) of islands also has an important role in identifying changes in physical and biotic attributes and formulating future research questions (Lyver 2002; Newman & Moller 2005).

Marine-to-land transfer of nutrients by seabirds is a crucial ecosystem process on many islands (Fukami et al. 2006; Hawke & Clark 2010). Changes to the marine environment, such as shifting sea-surface temperatures, loss of seabirds as bycatch from fishing, and historic harvesting of marine mammals, could alter these nutrient subsidies. For example, populations of New Zealand fur seals (*Arctocephalus* *forsteri*), including some with >100,000 individuals, were nearly extirpated for pelts from southern islands in the 19th century (e.g. Taylor 1992). The seals likely modified coastal nutrient transport and disturbance regimes, but the extent of these effects is unknown. Conversely, the potential benefits of marine reserves adjacent to relatively unmodified island ecosystem are also unknown, as is the potential for feedback effects of nesting seabirds on islands into the adjacent marine environments.

Objective 2: Reducing exotic spread

Corrected for land area, NZ has more introduced species than any other archipelago (Vitousek et al. 1997). Many of these have become invasive, leading to extinctions and modified vegetation composition through predatory and herbivorous mammals, disturbance regimes and ecosystem processes modified by invasive plants, and competition for food plus predation through the effects of social insects (Lee et al. 2005). Aside from Sutherland et al (2009), this problem has been emphasised by many global reviews, with numerous questions about the effects and management of invasive species in islands (e.g. Caujapé-Castells et al. 2010; Table 1).

In NZ, reducing the spread of invasive species into island ecosystems has long been the focus of work on Nature Reserves, where it is required under legislation (Reserves Act, 1977). On some larger islands this has involved the control or eradication of non-native species over many decades. For example, on subtropical Raoul Island 1000 km north-east of NZ, the removal of some invasive plants and animals and the control of others has taken over 40 years (Box 2a). The successes on Raoul Island demonstrate how the spread of introduced mammals can be reversed. However, there are numerous species of invasive plants that once established proved exceedingly difficult to remove and there have been few attempts to eradicate invasive insects or birds. Invasive plants can have interactive effects with introduced herbivores, facilitate invasions by other species ("invasional meltdown" *sensu* Simberloff & Von Holle 1999), proliferate when herbivores are removed, and persist for decades in the seed bank. Non-native birds have colonized nearly all offshore and outlying islands (>50 km offshore) from the main islands of NZ including Raoul Island. Some non-native birds, such as starlings (*Sturnus vulgaris*), create additional problems because they roost preferentially on islands that are free of predatory mammals, preferentially dispersing non-native plants within island groups and from the mainland (Ferguson & Drake 1999; Chimera & Drake 2010). However, non-native birds can also disperse the seeds of native plants (Kawakami et al. 2009; Bellingham et al. 2010b). Other species, such as the common (Indian) myna (*Acridotheres tristis*), also compete with or prey on native birds (Tindall et al. 2007).

The effects of mammalian herbivores and predators on NZ islands are relatively well studied (but see Towns in press). By comparison, the effects of introduced birds have not been studied systematically and those of invertebrates remain poorly understood. There has been little effort to identify those non-native components that are tolerable in our least modified systems. It is also unclear whether control of one invasive plant species may release another, and whether there are detrimental effects of removing invasive animals. For example, the effects of multiple invasive animals can be exacerbated when one species is removed altering the dynamics of other previously suppressed non-native species through trophic interactions (Courchamp et al. 1999; Rayner et al. 2007). Furthermore, even if problem animals and plants are removed, disrupted communities may follow novel successional trajectories (Mulder et al. 2009;

Bellingham et al. 2010b). However, whether these produce disturbance legacies that are irreversible remains unclear (Jones 2010).

Investment in the eradication or control of problem species can be wasted if there are no effective biosecurity procedures to prevent or deal with reinvasions or new arrivals. Islands close to the mainland are particularly prone to incursions of non-native species, so detection methods for them need constant refinement. A recent incursion (arrival but non-establishment) of two ship rats (*Rattus rattus*) in the Marotere Islands in northern NZ (Box 2b) adds to numerous examples of rats transported by boats to islands around NZ (Russell et al. 2008) and cost $115, 900 in biosecurity responses on the islands. Protection of the investment in eradications requires comprehensive risk analyses (including likelihood of reinvasion), quarantine checks before departing the mainland on the food and equipment being transported to sensitive islands, and methods for detecting invasions on the islands. There has been considerable investment in methods for detecting rats (e.g. Russell et al. 2008), but mice (*Mus musculus*) can be particularly difficult to detect at low density and there has been a relatively high failure rate for eradication attempts (Howald et al. 2007). Some effects of the eradications themselves have been poorly studied. For example, despite numerous successful eradications of invasive animals, including at least 60 involving the aerial spread of baits (Bellingham et al. 2010a), some direct and indirect effects of the eradication campaigns are poorly understood. A question often asked by the public and agencies that regulate the use of chemicals is how toxins affect island food webs after eradications (DRT pers. obs.), but it is a question that remains largely unanswered.

Objective 3: Mitigating effects of environmental pollutants

Uninhabited islands can be threatened by material released at sea or from waste produced on land elsewhere that has entered the marine environment. On inhabited islands, pollution sources are largely the same as those on the mainland, including surface runoff from agriculture and urban sources such as roads and human waste. In NZ, such issues are confined to a few large islands. On the more numerous smaller islands, the least studied threats are likely those identified in the global literature for seabird islands (Table 1). One of these is the potential effects of oil spills, which were illustrated after a relatively small release of oil during fine weather off the Poor Knights Islands in north-eastern NZ (Box 3). Although it is a poor test of the effects of a serious spill, this example does emphasise the vulnerability of seabird islands to marine pollution if large vessels are damaged or founder near islands in poor weather. Risks from spilled petrochemicals are increasing for two reasons. First, as predators are removed from islands, the area inhabitable by dense populations of seabirds has increased >10-fold and now includes islands off north-eastern and central NZ that are close to major ports. Second, exploration for petrochemicals in deep water off NZ is now being undertaken near islands such as the Snares, where an estimated 1,100,000 (± 66,000) pairs of tītī or sooty shearwaters (*Puffinus griseus*) breed (Newman et al. 2009). The risks to seabirds from petrochemical spills are particularly high in NZ, with its extraordinary seabird diversity (Taylor 2000) and enormous densities of birds nesting in burrows. For example, it is unclear whether the current methods for dispersing spilled oil are appropriate given their potential effects on pelagic seabirds (e.g. Butler et al. 1988). Little is known of the effects on terrestrial ecosystems when they are saturated by petrochemicals during storm conditions, whether marine pollutants bioaccumulate in island food webs, whether there would be large-scale defoliation of vegetation as a result of wind-dispersed petrochemical products, whether soils are affected by oil imported into burrows by birds, or what long-term effects on island ecosystems would result from the combined effects of an oil spill and high seabird mortality. Furthermore, given the wide foraging and migratory ranges of many species of seabirds, those nesting in NZ may be affected by pollution such as plastics ingested far offshore. These effects are also unknown.

Objective 4: Preventing extinctions and declines

Prevention of extinctions and the loss of populations are fundamental to the maintenance of native biodiversity (Lee et al. 2005). Losses and declines of native biodiversity are particularly widespread on islands (Quammen 1996; Wilson 2002), but only two research questions relating to them were raised from the four sources of global literature (Table 1).

Islands around NZ have long been havens for species threatened with extinction on the mainland, either because of natural relict distributions after extinctions elsewhere, or as a result of translocations. Since 1985, at least 55 taxa have been translocated to or between islands, including 9 taxa of invertebrates, 2 species of frogs, tuatara, 18 species of lizards, 19 species of land birds and 4 species of seabirds (Bellingham et al. 2010a). Species such as saddlebacks (*Philesturnus* spp.) have been translocated numerous times from a single source island population. North Island saddlebacks (*P. rufusater*) are now established on at least 13 islands, and collectively number around 6 000 birds (Parker 2008). Following the removal of introduced predators, other species of invertebrates and vertebrates have recolonised or are now recovering on islands after long periods of predation (Bellingham et al. 2010a).

Tuatara exemplify the complexity of recovery activities, including captive breeding, predator release and translocations (Box 4). By 2008, historic declines of tuatara appeared to have been reversed following the removal of rats such as kiore (*Rattus exulans*) from seven of the nine islands inhabited by tuatara. Tuatara have also been released onto six islands within their historic range (Sherley et al. 2010). However, although an apparently successful recovery programme, there is continuing uncertainty for two reasons: the long term genetic effects on populations that have been substantially reduced by predation are unknown (Miller et al. 2009), and the species is so cryptic and reproductive output so low, whether translocations have been successful remains unclear (Nelson et al. 2008).

The genetic effects of population suppression and fragmentation have been quite well studied for NZ vertebrates (Jamieson et al. 2008). For example, although non-selected microsatellite markers in tuatara indicate relatively high levels of genetic variation in most island populations, there is very low microsatellite genetic variation in the North Brother (Cook Strait) population (MacAvoy et al. 2007). Low genetic variation has implications for fitness. One measure of fitness is through major histocompatibility complex (MHC) genes, which are linked to disease resistance. On North Brother Island, tuatara have only 20% of the MHC sequences and 14% of the genotypes found in tuatara on nearby Stephens Island, which may compromise the ability of the Brothers tuatara to respond to novel diseases (Miller et al. 2008). Similarly low variation in MHC genes is found in black robins (*Petroica traversi*) (Miller & Lambert 2004), which recovered from a population of just five birds (Ballance 2007). Despite this solid background of genetic evidence, there have only been a few systematic attempts to overcome potential loss of fitness by raising the heterozygosity of founder populations (Miller et al. 2009). However, it is a problem that has become the focus for management of birds such as kakapo (*Strigops habroptilus*; Robertson 2006).

Aside from the genetic issues of small populations, recovery may be impeded through the effects of interference competition and predation from native species. The effects of interactions between translocated species and resident species on islands may be difficult to predict from mainland locations where such species combinations no longer exist. For example, although the native rail, weka (*Gallirallus australis*), is an endangered or vulnerable species on the three main islands, the species' introduction to offshore islands has been so damaging to resident populations of seabirds (Harper 2007), reptiles and invertebrates, they have since been eradicated from at least three islands (Bellingham et al. 2010a). Other species may have more subtle effects when introduced to islands as a conservation measure, but these are at present unknown. For example, the effects of introduced species of kiwi (*Apteryx* spp.) on island invertebrate communities have not been assessed, even though they have been introduced to some islands where other restoration goals may be jeopardised.

For less mobile species, such as invertebrates and reptiles, many questions remain about how criteria for success should be applied to translocations. For all species, there is still much to be learned about the appropriate genetic criteria for success. For example, little is known about the long-term genetic and fitness implications of translocations relative to propagule size and composition. Furthermore, there have been few studies of the short- and long-term success of captive-reared *versus* wild-caught populations.

Objective 5: Improving ecosystem composition

Ecosystem structure is influenced by the composition of species, functional groups, life-history stages, trophic diversity, and the effects of key elements such as ecosystem engineers that modify habitat structure and keystone species that influence community composition (Lee et al. 2005). The global reviews identified several research questions around the effects of removing invasive species and subsequent implications for ecosystem restoration. Key issues were whether ecosystems can be restored and how to measure the extent to which restoration is successful (Table 1).

Experiences in NZ indicate that when introduced mammals are removed from islands, biotic communities can recover through four pathways: recolonisation from outside the island; reappearance of species reduced to such low densities they were previously undetected; recovery of species known to be present, but reduced in abundance; and reintroduction of extirpated species, which are unlikely to recolonise unaided. Aorangi and Korapuki Islands (see also Towns et al. 2009b) provide case studies that illustrate where different approaches to these processes may apply (Box 5). Both examples involved the removal of introduced mammals to restore seabird-driven island ecosystems typical of specified island groups, but with restoration achieved in different ways. Despite the previous presence of pigs, no native species have been reported as lost from Aorangi Island, so a hands-off process of natural recolonisation and recovery should enable the redevelopment of assemblages and ecosystem processes indistinguishable from other islands without introduced mammals (e.g. Fukami et al. 2006). In contrast, comparisons with its neighbouring islands indicated that Korapuki apparently has probably lost many species (Towns 2002b), including half the lizard fauna (Towns 1991). Restoration of biotic communities that include these species has required direct reintroductions, with the attendant problems with translocations of small populations (Objective 4 above).

Lasting effects of invasive species on ecosystem function are widely reported (e.g. Simberloff 1990; Bellingham et al 2010b). When invasive species are removed, some native species that influence ecosystem function may recover over time, as was illustrated by the reappearance and spread of honeydew scale insects on Korapuki Island after the removal of kiore and rabbits (*Oryctolagus cuniculus*; Box 5). Honeydew scale insects are poor dispersers and have been lost from many islands with potential consequences for ecosystem function (Towns 2002a; Gardner-Gee & Beggs 2009). Other functions will be permanently lost if key species became extinct. Such is the case in the Chatham Islands, which lost an array of endemic terrestrial birds after human settlement (Tennyson & Martinson 2006). Related species may provide replacements (Atkinson 1988), but circumstances where this approach might apply have yet to be identified and debated.

Islands from which native species have been lost may also lack subtle interactive components of ecosystems. For example, mycorrhizal associations that influence succession may have been disrupted on deforested island systems. Furthermore, adding species to systems may exacerbate interactive effects, raising the question of whether translocations need to be informed by theoretical assembly rules (e.g. Atkinson 1990). Assumptions about past composition could be reduced if palaeoecological studies were able to confirm pre-disturbance community composition. Such data can be used to determine the origins of plant species (van Leeuwen et al. 2008), or to identify the plant community composition before islands were deforested (Prebble & Wilmshurst 2009). Although the value of palaeoecological evidence has been stressed (e.g. Towns & Ballantine 1993; Miskelly 1999), such approaches have rarely been used to guide restoration activities in NZ.

Objective 6: Improving ecosystem representation

Preserving the widest possible range of ecosystem environments should maximize evolutionary potential (Lee et al. 2005). Internationally, this was only seen as an important issue by Sutherland et al. (2009), although it was a topic of little direct relevance to the other reviews (Table 1).

The distribution of island reserves in NZ is an historical accident. Between 75% and 100% of island area to the north and south of NZ is in public ownership, compared with < 50% adjacent to the north-eastern North Island and in central NZ around Cook Strait (Towns & Ballantine 1993), and <10% in the Chatham Islands. Fortunately, the island reserves include most centres of endemism (hotspots), which are also largely at the northern and southern extremes of the NZ archipelago. By comparison, the Chatham Islands hotspot has few reserves, although the area under private protection is increasing (Munn et al. 2008).

Serendipity also figures in the way islands are managed, and this is the area where changes are possible. The most biologically significant islands are Nature Reserves that are often in particularly remote locations, which should ensure that maximum ecological integrity is attained and protected. These include the most isolated southern locations, which are now part of the Southern Islands World Heritage Site in recognition of their outstanding biological significance (Chown et al. 2000). A second large group of islands off southwestern South Island is within Fiordland National Park, where they are part of Te Wahipounamu World Heritage Site.

By comparison, islands in public ownership close to large population centres have often been designated for recreation. As our case study demonstrates (Box 6) the biological potential of these reserves has until recently received little consideration.

A systematic approach that provides for a range of alternative management strategies on islands urgently needs national application (e.g. Atkinson 1990), especially if this also facilitates the protection or restoration of islands outside administration by government agencies. Little is known about poorly represented ecosystems on islands. For example, some islands of sedimentary origin have stream and wetland systems that are rare on islands of volcanic origin.

Objective 7: Climate change and variability

Along with biological invasions, climate change is another significant component of human-caused global environmental change (Vitousek et al. 1997). Nonetheless, climate change did not figure in any of the global research areas identified for invasive species (Table 1), despite potential indirect interactions between the spread of invasive species and environmental change (Vitousek et al. 1997).

In NZ, along with increased average temperatures, global climate change may increase the frequency of extreme climatic events. Their effects can only be predicted if the characteristics of existing environments and the way these environments change over time and in response to extreme climatic events are understood (Lee et al. 2005). A key influence is NZ's position across the West Wind Drift, a wide oceanic surface current. In the northern NZ region, this current brings warm, subtropical waters. In the southern South Island, these warm waters converge with cooler, less saline waters from sub-Antarctic regions to form the Subtropical Convergence (Cubitt & Molloy 1994). The extraordinary range and diversity of seabirds reflects the influence of these currents, the strength of which varies, particularly in response to the El Niño–Southern Oscillation (ENSO). For example, breeding success and clutch sizes of red-billed gulls (*Larus novaehollandiae scopulinus*) on Kaikoura Peninsula is related to the availability of the planktonic euphausid *Nyctiphanes australis*. The relative abundance of *N. australis* is directly proportional to the Southern Oscillation Index (SOI), which when high (the La Niña condition) suppresses the intrusion of warm water relatively low in nutrients (Mills et al. 2008). Similar relationships between tītī productivity and the SOI have been reported (Lyver et al. 1999). More extreme effects can result from longer term shifts in the characteristics of these currents, and this may be one effect of current climate change. However, for other species, such as wandering albatross (*Diomedia exulans gibsoni*; Box 7), relationships between the SOI and productivity are weak. Nonetheless, fluctuations in productivity are most likely linked to marine food chains somewhere in the albatrosses' huge foraging range within the Tasman Sea and Southern Ocean (G. Elliott & K. Walker unpubl.). Satellite tracking of seabirds has the potential to reveal much about the foraging ranges of NZ seabirds, but it remains unclear whether this will help to predict species vulnerable to changes in marine systems far beyond the NZ Exclusive Economic Zone.

Changes in the size and productivity of seabird colonies, such as those reported for rockhopper penguins (*Eudyptes chrysocome*; Box 7), were only discovered because data had been collected over long periods. However, it remains unknown whether such variations are more common in extreme environments, to what extent they affect terrestrial ecosystems, or whether changes in seabird populations provide an early indicator of subtle effects that will eventually have wider consequences. Such consequences could include range declines of native terrestrial species or range expansions for invasive species. Furthermore, there has been no attempt as yet to define systematically where environmental data should be gathered and for what species or systems. In the northern hemisphere, the potential translocations of species through "assisted immigration" as a means of avoiding climatically induced range declines has been hotly debated (e.g. Ricciardi & Simberloff 2009). In NZ, translocations have long been used to manage threatened species such as kakapo (e.g. Ballance 2007). The issues raised are discussed here under objective 4.

Objective 8: Sustainable use of island ecosystems

In NZ, some terrestrial indigenous species of birds are harvested and there are agreements for the cultural harvest of seabirds (Lee et al. 2005). By comparison, native species are widely harvested in other countries, but only four research questions relating to sustainable use were identified in the focal global reviews (Table 1).

On some NZ islands, there is growing pressure for resumption of customary harvests by Māori of seabirds and also to increase public access for recreation and tourism.

Harvesting and tourism are both conducted on islands near Stewart Island/Rakiura (Box 8), with potential conflict between these two activities largely resolved through differences in location and land tenure. For example, under the Tītī Island Regulations 1978 Rakiura Māori have rights to harvest tītī chicks on islands adjacent to Rakiura with provisions to ensure survival of the species and conservation of stocks. At present, average harvest intensities have little effect on future population trajectories, although unsustainable harvests are probably causing local declines within a few *manu* (family harvesting areas; Moller et al. 2009). However, harvesting combined with the effects of introduced predators (e.g. weka) appears to be responsible for declines of the populations of tītī on some islands (Newman et al. in press). These population trends have been confirmed using long-term harvest diaries provided by muttonbirders and historical scientific studies on non-harvested islands (Clucas in press).

In contrast, on Ulva Island (267 ha), which is also adjacent to Rakiura, sustainable use is focused on nature tourism within Rakiura National Park. The island has been so successful as a showcase for biodiversity, it is now listed by the NZ Automobile Association as one of the “101 Must-Do’s for Kiwis” (McCrystal 2007). Visitors to the island are able to view numerous native species, including forest birds reintroduced (translocated) to the island after the removal of rats.

The practice of translocating species for conservation purposes raises cultural issues for some iwi and informed non-Māori. Some of these concerns involve: (i) lack of knowledge over the state of “source” populations of a species being translocated; (ii) movement of species around the country outside of their traditional regions, (iii) mixing species' *whakapapa* (genealogies), and (iv) the effect of releasing species into ecosystems where they may not have previously existed. The concerns also add a local cultural dimension to Objectives 4 and 5 (above). One iwi saw their islands being used as "supermarkets" to support restoration projects around the country (P.O'B.L pers obs), while their questions over sustainability remain to be addressed. Even so, the use of island populations for translocations has been supported by iwi (e.g., by Ngāti Awa with respect to translocation of grey-faced petrels (*Pterodroma macroptera gouldi*) to Cape Kidnappers, Hawkes Bay). Increasingly, translocations are conducted between Māori tribes (iwi-to-iwi) since the species' being moved are often culturally significant. This means that relationships between iwi and the ongoing responsibilities of an iwi for its taonga (treasures) are important considerations of any translocation.

These contrasting examples illustrate the challenges of meeting different social expectations for island management. Conflicts could be reduced if the potential range of management objectives were identified for each island within the wider national context. For each site, it will be necessary to determine how the islands can be managed sustainably to meet recreational, biodiversity, economic and cultural goals. Furthermore, island systems may provide ecosystem services, such as improved soil fertility as a result of the activities of seabirds and community involvement in conservation activities. The full range of services provided by islands has yet to be formally identified. Furthermore, the values placed on islands and their resources by different sectors and ethnic groups remain unknown.

Objective 9: Community participation in conservation

The above examples illustrate that sustaining indigenous biodiversity will generally depend on the support, co-operation and participation of all sectors of local communities (Lee et al. 2005). Collectively, three of the global reviews raised a wide range of research questions relating to community participation (Table 1), which perhaps emphasizes current weak links between natural and social sciences.

Eradications of introduced species and restoration of island ecosystems around NZ are now gaining considerable international attention (Simberloff 2002; Krajick 2005; Rauzon 2007). Many of these restoration projects are aimed primarily at conservation advocacy through participation, as is exemplified by Tiritiri Mātangi Island (Box 9). A similar approach has been followed on many other islands by a variety of community groups. Importantly, it has also led to action on private land. For example, Ipipiri (eastern Bay of Islands), comprises 18 islands and islets (a total of 604 ha) in public and partial or total private ownership. Here, “Project Island Song” aims to remove stoats (*Mustela erminea*) and three species of rats from all of the islands and reintroduce native species using projects such as the one on Tiritiri Mātangi as a model (R. Elliot pers. comm.). The periodic dispersal from the mainland of stoats and Norway rats (*Rattus norvegicus*) to the islands since eradications took place in 2009 provides a challenge for this project, as does the diversity of groups involved: a community group (Guardians of the Bay of Islands), two Māori hapū (Patukeha and Ngāti Kuta), private land owners, tourism operators, the District Council and DOC (A. Walker pers. comm.). Such groups are also challenged by the technical requirements of island restoration and may have limited ability to collect and analyze data. Institutional help through web-based training and data storage would help alleviate these difficulties (D. Breen pers. comm.).

The range and complexity of such initiatives demonstrates growing interest of communities in hands-on conservation. However, beyond counting the number of projects, there have been few formal measures of their social benefits or contribution to conservation of biodiversity (Towns et al. 2009b). In part, this situation reflects the lack of research on how biodiversity and social goals should be defined and measured. Furthermore, although engagement of the public involves partnerships with DOC, there have been no analyses of their effectiveness or whether the relative expectations of the partners are being met (M. Wouters pers. comm.). The nature of partnerships between DOC, iwi and community groups also requires consideration. Māori have a special relationship with the islands and their taonga, which is recognised under the Treaty of Waitangi and the Conservation Act, 1987. This means that the views of iwi as a Treaty partner should effectively be given the status of a government ministry rather than considered those of another community group. This issue raises questions of how the aspirations of such diverse stakeholders should be defined and realized.

Discussion

The needs assessment (Table 2), which was used to identify key issues and specific research questions, revealed 44 questions that, if resolved, could assist with the opportunities and challenges for managing biodiversity on NZ islands. A regional approach such as this can be most effective when developing conservation strategies (Anderson et al. 2009). However, about a third of these questions (14) were also identified in some form within the 83 questions derived from global reviews. Their resolution in NZ could thus have international implications. Questions of global relevance include those relating to the maintenance of ecosystem processes: how should we measure resilience in island ecosystems; how are they affected by external influences such as climate and marine bycatch; and can environmental indicators be used to measure long-term change (Rands et al. 2010)? Similar global issues arise under the objective of reducing non-native spread and dominance, with the eradication of invasive species and ecological restoration now growing international activities (Veitch & Clout 2002; Veitch et al. in press). They include questions such as how do invasive plants and animals interact, how do we avoid the unintended effects of non-native species through inappropriate sequences of eradications (e.g. Zavaleta 2002; Rayner et al. 2007), and how should new incursions of species difficult to detect such as ants and mice be detected on arrival? Likewise, questions about the long term implications of small numbers of founders, severe bottlenecks and translocations of small populations are still widely studied and debated by geneticists (e.g. Jamieson et al. 2008). Other questions are global by virtue of the biology of species of interest. Particular examples are those relating to productivity of seabirds and their responses to global climate and oceanic conditions far beyond their nesting areas in NZ.

Two major research fields accounted for >60% of our questions. The first involves understanding ecosystem processes, temporal trends in biotic communities, and the way they respond to the manipulation of invasive species and environmental change. The second involves many questions around the social effects of ecosystem management on islands and emphasises the lack of co-ordinated approaches between natural and social sciences to address such issues. For example, the question of whether seabirds can be harvested sustainably seems extraordinarily difficult to answer (Moller 2006) because of the social and ecological complexities involved. This example also illustrates how conflicts could arise if the Māori ethic of 'conservation for sustainable use' seems to other sectors of the community to run counter to their own ethic of conservation for preservation. Furthermore, traditional management of many islands included frequent use of fire to clear the land for cultivation of crops such as kūmara (*Ipomoea batatas*; Bellingham et al. 2010a). Some Māori owners of islands are intent on reinstating these traditional management regimes. Novel approaches to the use of mātauranga (Lyver and Moller 2010), the overlay with scientific method, and wider community involvement will be required if apparently divergent views are to be resolved.

We also asked how island management provides social and economic benefits. For example, understanding the roles of ecosystem services on islands are fundamental to progress with management of biodiversity on larger inhabited islands and those with high exposure to public use (Morrison in press). However, the kinds of services provided, and how their benefits should be measured, remain poorly studied (e.g. McAlpine & Wotton 2009; Rands et al. 2010). Without much greater understanding of these areas, conservation managers may struggle to combine the seven biologically based objectives needed to achieve ecological integrity with the two socially based objectives.

Answers to some of our questions will need very long-term commitments to data gathering and analysis. Without such commitments, much of what we need to know will have to remain based on conjecture. The success of this research strategy will thus be assessed from two measures: whether funding agencies allocate assistance on the basis of the questions identified, and whether the research undertaken provides answers that demonstrably make a difference to the conservation of island biodiversity.

Box 1: *Objective 1. Maintaining ecosystem processes*

Location: Middle Island (13 ha); Mercury Islands (36^{o} 38´S, 175^{o} 52´E)

Middle Island, which has never been invaded by introduced mammals, and has forest modified by 7 species of seabirds, especially diving petrels (*Pelecanoides urinatrix*) with burrow densities of c. 10 000 ha^{-1}. The flora comprises 96 species, of which 25 are non-native, although none are considered sufficiently threatening to require control or eradication (Atkinson 1964; Cameron 1990; Towns & Atkinson 2004). The fauna includes 22 species of land snails; the only natural population of the Mercury Island tusked weta (*Motuweta isolata*); tuatara (*Sphenodon punctatus*); 10 species of lizards; and a resident land bird fauna of 14 species, 4 of which are non-native (Whitaker 1978; Southey 1985; Towns 1991; Towns & Atkinson 2004). There are no native mammals but there may once have been coastal populations of fur seals. Long-term or intensive studies of have included soils and vegetation (Atkinson 1964), tusked weta (Stringer & Chappell 2008), reptiles (Whitaker 1978; Southey 1985; Towns 1991), and the effects of seabirds on food webs (Towns & Atkinson 2004; Fukami et al. 2006; Towns et al. 2009a).

Emergent questions: Do different species of seabirds vary in their effects on ecosystem processes? At what rate do relatively unmodified island systems change over time?

Box 2: *Objective 2. Reducing exotic spread*

Location: (a) Raoul Island (2938 ha); Kermadec Islands (29^{o} 16´ S, 177^{o} 55´ W)

After early colonisation by Polynesians, the island was used by whalers and settlers who attempted to establish farms. These efforts and 20^{th} century shipwrecks were accompanied by invasions and escapes in approximate chronological order by kiore, goats (*Capra hicus*), cats (*Felis catus*), pigs (*Sus scrofa*), and Norway rats.

Vegetation on the island became heavily modified by goats with the near extinction of endemic plants such as *Hebe breviracemosa* (Sykes 1977). At least five species of seabirds and three species of land birds declined due to harvesting (initially) followed by predation from rats and cats (Veitch et al. 2004). Eradications have been completed for pigs (1966), goats (1972–1984), rats (2002) and feral cats (2004) (Parkes 1990; Towns and Broome 2003). Settlement also marked by the spread of 28 species of non-native plants, 7 of which now eradicated. Some species of plants suppressed by goats proliferated once goats removed (e.g. Mysore thorn; *Caesalpinia decapetala*) and have been under continuous control since 1974 (West 2002). Introduced invertebrates include a large tropical cockroach (*Periplaneta brunnea*) (Gordon 2010), and highly invasive big-headed ants (*Pheidole megacephala*). There has been natural dispersal from New Zealand by at least nine species of introduced European birds, with blackbirds (*Turdus merula*), song thrushes (*T. philomelos*), and starlings at times the most common forest birds on the island (Veitch et al. 2004).

Emergent questions: What are the effects of invasive species on ecosystem composition and processes? How are these effects changed when large herbivores and predatory mammals are removed and over what time scales? What are the effects of non-native birds on island systems? Do social insects have detrimental effects on islands and can they be removed? Are there interactive effects between invasive plants?

Location: (b) Marotere (Chickens) Islands Nature Reserves (35° 54´ S, 174° 45´ E)

In January 2009, rat prints were recorded in tracking cards set for routine checks on neighbouring rat-free Lady Alice and Whatupuke Islands. One ship rat was subsequently caught in a live trap on Whatupuke Island and another in a snap trap on Lady Alice Island. Delimiting responses using tracking cards in tunnels, rat sensitive dogs, traps and a live, caged, lure rat only detected sign from tracking dogs at the capture site on Lady Alice Island. Total monitoring response to the incursion involved 26 395 tracking nights and 12 086 trap nights on Lady Alice Island plus 23 506 tracking nights and 16 751 trap nights on Whatupuke Island (Hawkins 2009).

Emergent questions: What are the most cost-efficient methods for detecting incursions of invasive mammals?

Box 3: *Objective 3. Effects of environmental pollutants*

Location: Poor Knights Islands Marine Reserve (35^{o} 28´ S, 174^{o} 45´ E)

About 5 tonnes of oil released from the cargo vessel Rotoma produced a slick 2.5 km by 6 km of light oil, heavy black oil, and detergent that washed into the Poor Knights Islands Marine Reserve in December 1999. The oil washed up on the shoreline and accumulated in caves around Aorangi Island Nature Reserve, coating encrusting coralline algae, barnacles, and bryozoans on cave walls. At least 10 seabirds (species not specified) were killed in the oil, and one was removed alive. Encrusting oil on cave walls that are normally exposed to strong wave action was removed by water blasting and mopping, but fragile surfaces covered by algal turf were not cleaned. The islands are the only nesting site for Buller's shearwaters (*Puffinus bulleri*), which form aggregations offshore of up to 10 000 birds at dusk before returning to burrows on the islands. It is unknown whether oil affected birds in these aggregations, whether oil was carried into burrows, or whether contaminated birds drowned at sea (Northland Regional Council 2000; 2003; Babcock 1999; Vivequin 1999).

Emergent questions: What are the risks and effects of petrochemical spills on seabird-driven island ecosystems in New Zealand?

Box 4: *Objective 4. Preventing extinctions and declines*

Species: Tuatara

This is a large reptile species once widespread through the main islands of NZ and on offshore islands. All mainland populations and seven (19%) of the 37 island populations were extinct by the beginning of the 20^{th} century (Cree & Butler 1993). Of 26 north-eastern populations, 9 (34%) on islands inhabited by kiore showed impaired or failed recruitment, with some populations reduced to a few individual adults (Daugherty et al. 1992; Cree et al. 1995a, b). Artificial incubation of tuatara eggs increased hatching success from <50% (wild) to 85.7–92.2% (captive) (Thompson et al. 1996). 'Head-started' juveniles were released at 3–5 years of age onto islands cleared of all species of rats (Nelson et al. 2002; Cree et al. 1995b). Three tuatara populations compared before and after kiore were eradicated showed increased recruitment of juveniles, increased local population density and improved body condition of adults after kiore were removed. A fourth population where kiore remained showed evidence of decline by attrition leading to likely eventual extinction (Towns et al. 2007). Like turtles, crocodilians and some lizards, tuatara have temperature-dependent sex determination (TSD), with an excess of females produced at 18^{o}C and 20^{o}C, and an excess of males at 22^{o}C; translocated populations from artificially incubated eggs may have introduced unfavourable sex bias (Cree et al. (1994).

Emergent questions: What are the genetic effects of fragmented populations and can they be reversed? Do animals raised in captivity have reduced fitness compared with those born in the wild? What are the long term effects on populations that have survived after sustained predation? How do species with environmentally constrained reproductive systems respond to climate change?

Box 5: *Objective 5. Improving ecosystem composition*

Location: (a) Aorangi Island (110 ha); Poor Knights Islands (35^{o} 48´ S, 174^{o} 45´ E) Inhabited by Māori until 1823, most forest vegetation was removed from Aorangi for cultivation and resident Buller's shearwaters (*Puffinus bulleri*) were harvested for food and trade. Near the end of the 18^{th} century, pigs were introduced and became feral when Māori moved from the island after *tapu* (sacred covenant) was placed over it. The pigs, which removed most palatable vegetation and preyed upon petrels and prions, were eradicated in 1936 (Atkinson 1988; Hayward 1993). Low mixed forest then regenerated and at least five species of burrowing seabirds survived or recolonised. Buller's shearwaters increased from a few hundred pairs in 1938 to estimated 200,000 pairs by 1983, three other species of early colonising seabirds were then displaced and a fourth, fairy prion (*Pachyptila turtur*), became confined to nesting in crevices (Harper 1983). All 8 species of resident reptiles survived the pigs and became as abundant as on neighbouring islands (Whitaker 1978). Surveys in the 1990s, indicated that no species of plants had become extinct (de Lange & Cameron 1999). At least 44 species of threatened plants and animals are now present (Towns et al. 2009b).

Emergent questions: Can natural recovery of islands after modification by people and introduced animals induce pre-disturbance systems? How can the composition of pre-disturbance communities be determined without historical records?

Location: (b) Korapuki Island (18 ha); Mercury Islands (36^{o} 39´ S, 175^{o} 50´ E) This island was invaded by kiore (unknown when), regularly burned until about 100 years ago, after which rabbits were released. Nonetheless, seven species of burrowing seabirds survived, dominated by little blue penguins (*Eudyptula minor*), grey-faced petrels, and fluttering shearwaters (*Puffinus gavial*; Hicks et al. 1975). The kiore were eradicated in 1986, and rabbits in 1987 (McFadden & Towns 1991; Towns 1988). An expanding subcanopy of coastal shrubs then developed under the canopy of pōhutukawa (*Metrosideros excelsa*), and coastal flax (*Phormium tenax*) became overtopped by shrubs and small trees. Species of canopy trees to reappear as seedlings included milktree (*Streblus banksii*) and tawapou (*Planchonella costata*; Towns et al. 1997; Atkinson 2004; I. Atkinson pers comm.). Large invertebrates also reappeared and spread along with honeydew scale (*Coelostomidia zealandica*), and resident populations of skinks, geckos and diving petrels (G. Taylor pers. comm.; Towns 1996; Towns et al. 1997; Towns 2002a; Towns 2002b). The aim of management is restoration of a seabird-reptile-invertebrate-plant system typical of the archipelago (e.g. Middle Island above; Towns & Atkinson 2004). Successful reintroductions from within the Mercury Island archipelago have included tree weta (*Hemidiena thoracica)*, large darkling beetle (*Mimopeus opaculus*), robust skink (*Oligosoma alani*), Whitaker's skink (*O. whitakeri*) and Suter's skink (*O. suteri*). Released species without confirmed success include tusked weta (*Motuweta isolata*) and marbled skink (*O. oliveri*). Planned reintroductions include tuatara (present as subfossils), ground weta (*Hemiandrus* sp.), and the large spider *Cambridgea mercurialis* (Towns & Atkinson 2004).

Emergent questions: How do island food webs respond when systems shift from consumption led (introduced predators) to subsidised by nutrients via seabirds? What are the key drivers of ecosystem processes on islands and do they change with island size and location? How can progress towards restoration targets be measured within changing systems? What are appropriate numerical and genetic criteria for successful reintroductions?

Box 6: *Objective 6. Improving ecosystem representation*

Location: Inner Gulf Islands Ecological District (36^{o} 45´ S, 175^{o} 00´ E)

The Ecological District comprises islands largely of sedimentary Waitemata sandstone weathered to gentle rolling topography, often with sandy beach systems unusual on northern NZ islands Hayward (1986). The larger islands have all been cleared of forest and farmed. Seven islands are in public ownership (DOC), with subsequent reforestation of Motuihe, Motuora, Motutapu and Tiritiri Mātangi Islands managed by community groups aiming to release native birds with a high public profile (Auckland Conservancy 1995). The risk remains that if the wildlife management focus is widely applied it could compromise benchmark ecosystems representative of the district. One community group (Motuora Island) now has an ecosystem based restoration plan for the island (Gardiner-Gee et al. 2007).

Emergent question: How should the need for representativeness be reflected by management?

Box 7: *Objective 7. Climate change and variability*

Species: Seabirds in southern oceans

Rockhopper penguins breed on islands near the Antarctic Polar Front and the Subtropical Convergence of the South Atlantic and South Indian Oceans (Marchant & Higgins 1990). Campbell Island was a regional stronghold for the species in 1942 with about 1.6 million birds. The colonies declined in size by 94% over next 45 years, particularly between 1945 and 1955 when mean summer sea temperature rose from 9.1^{o}C in 1944 to 9.6^{o}C in 1954. These fluctuations in the size of penguin colonies appeared related to sea water temperature leading to changes in the penguin's food supply and could not be attributed to any effects on land (Cunningham & Moors 1994; Hilton et al. 2006). Similarly, numbers of Gibson's wandering albatross on Adams Island (Auckland Islands) decreased by 63% since 1973, most likely through bycatch in the southern ocean long-line fishery (Murray et al. 1993). Mitigation measures since 1992 reduced the incidental take of albatrosses around NZ but there was a subsequent mass mortality of up to 20% adults in 2005, as well as reduced nesting success and increased proportions of non-breeding adults. These were most likely in response to environmental effects of unknown origin (Walker & Elliott 1999).

Emergent questions: What is the frequency and extent of natural change in seabird populations and are these changes accelerating? What effects do ocean temperature changes have on seabird productivity and distribution?

Box 8: *Objective 8. Developing sustainable use*

Location: Islands near Stewart Island (47^{o} 05´ S, 168^{o} 05´ E)

On the Tītī Islands, research by Rakiura Māori and the University of Otago (*Kia Mau Te Tītī Mo Ake Tōnu Atu* - Keep the Tītī Forever Project) into tītī ecology and population dynamics indicated that harvest intensity across all Tītī Islands (13% of chicks produced in NZ region) appears sustainable, except where muttonbirders exert higher than average harvest pressure (Kitson 2004; Newman & Moller (2005); Moller et al. 2009). Tītī abundance declined over the past 30 years, with greatest declines where the birds are not harvested (Lyver et al. 1999; Lyver 2002; Scott et al. 2008). Fisheries bycatch may be a factor, with loss of one adult through bycatch equating to the harvest of 6-8 chicks by Rakiura muttonbirders (Moller et al. 2010). Population trends for large burrowing petrels are difficult to obtain; long data series (>50 years) on the effects of removing chicks are needed because of longevity of the adults (Moller 2006). Furthermore, productivity appears sensitive to events at sea, birds may migrate between harvested and unharvested populations, seabird density and the effects of harvest may be site-specific and influenced by topography and vegetation of the harvest island Newman et al. (2009).

Ulva Island has been free of introduced mammals after Norway rats were eradicated in 1997 (Thomas & Taylor 2002). Prolific bird life includes kākāriki (*Cyanoramphus n. novaezelandiae*) and kiwi (*Apteryx australis lawyri*), supplemented by translocated species including South Island saddleback (*Philesturnus carunculatus*), and mohua (*Mohoua ochrocephala*). Live kākāpō are displayed during open days. The island and adjacent Te Wharawhara Marine Reserve receive >20 000 visitors per year, with about 25% using guided walks and visits provided by 15 concessionaires (private businesses; A. Roberts pers. comm.).

Emergent questions: What are the key stressors on populations of seabirds on NZ islands and which ones can be managed? What are the effects of fisheries on marine food webs and how do these affect seabird populations? What is the role of mātauranga in aiding research on islands? What are the social and economic benefits of invasive species eradications from islands?

Box 9: *Objective 9. Engaging communities*

Location: Tiritiri Mātangi Island (196 ha); Hauraki Gulf (36° 36´ S, 174° 53´ E)

This island was farmed from the early 20th century until 1971, leaving 24 ha (11%) in forest and the remainder in rank pasture and early successional ferns and scrub (Esler 1978). The only remaining introduced mammalian predator (kiore) was eradicated in 1993 (Rimmer 2004). Tiritiri Mātangi is now public land (DOC) managed as an open sanctuary developed through community participation, with threatened and endangered birds accessible to the public (Craig 1990; Bellamy et al. 1990; Auckland Conservancy 1995; Hawley 1997). Forest regeneration was assisted by volunteers who planted 280 000 trees into the rank pasture, mainly during 1984–1994 (Rimmer 2004). One species of threatened plant, three species of reptiles and 11 species of birds have been released onto the island. Of the birds, tomtits (*Petroica macrocephala toitoi*) and brown teal (*Anas aucklandica*), either flew off the island or succumbed to avian predators (R. Renwick pers. comm.). Three other species, takahē (*Porphyrio mantelli*), kōkako (*Callaeas cinerea wilsoni*) and hihi (*Notiomystis cincta*), are intensively managed as part of threatened species programmes (Rimmer 2004). Volunteers are organized as the Supporters of Tiritiri Island Incorporated Society, which has a strong educational focus, supports research by tertiary institutions, produces and sells resource kits aimed at school children, assists with guiding tours, raises funds to support species introductions and threatened bird management, and runs a shop and information centre (M. Galbraith pers. comm.).

Emergent questions: What motivates members of communities to volunteer for work on islands? What are the social and economic effects of island restoration? Is island restoration viewed differently by Māori, Pākehā and other ethnic groups? What expectations do community groups and Māori have of public agencies that manage islands? How can community groups be supported to use scientific/strategic monitoring?

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Table 1. Research questions within objectives for ecological integrity provided by Lee et al. (2005) identified from global reviews of issues relating to management of non-native species and conservation of biodiversity based on Byers et al. (2002) and Sutherland et al. (2009; which is marked *) in column 1; island invasive species (Veitch et al. in press) in column 2; and seabird island biology (Mulder et al. 2011) in column 3.

Integrity objective	Management of non-native species; conservation of global biodiversity	Island invasive species	Seabird island biology
1. Maintaining ecosystem processes			Does seabird diet influence nutrient composition of guano? How do seabirds affect terrestrial food webs? What are the indirect effects of seabirds on consumer food webs through modification of vegetation? Under what circumstances do seabird

			effects become dominated by other abiotic influences? Do the nutrient subsidies from seabirds influence adjacent marine environments?
2. *Reducing exotic spread and dominance*	Why do many invasions fail or have minimal effects? How do non-indigenous species alter ecosystem properties? What characterises sites with greatest vulnerability to invasive species? How should the impacts of individual invasive species be assessed?	What are the problem species? How should eradications be planned (operational)? How should eradications be conducted (tactical)? What are the results of eradication attempts? How can reinvasions and new incursions be prevented (biosecurity)? What are unpredicted outcomes of	Can distributional data for introduced predators effectively predict their global effects on seabird populations? What traits make plants vulnerable to introduced animals? What determines the dominance of introduced species of rats? Can detrimental downstream effects of eradications be predicted (e.g. invasive plant rebounds)?

	How do invasive species behave over time? What limits the spread of non-indigenous species? What happens between establishment of a non-native species and recognition of an invasion? What habitats are particularly vulnerable to invasion? What are the characteristics of invasive species? How can assessments of harm be improved? What control strategies are the	eradications of invasive species? How do resident species respond to eradications? What contribution to natural capital can be obtained from eradicating invasive species?	Can declines of biotic communities be assigned to direct and indirect effects (e.g. pollination)? Does the rate of invasive species establishment vary by climatic region or type? Can eradications of rodents be achieved at similar scales across climatic regimes? Are any groups of seabirds particularly prone to the effects of introduced predators? What are the ecosystem consequences of small introduced omnivores such as ants and mice?

	most effective? *How should authorities manage non-native species?		
3. Environmental pollutants			Do ocean contaminants bioaccumulate in terrestrial island species?
4. Preventing declines and extinctions	*To what extent does management of iconic species have wider effects?		What are the external determinants of seabird survivorship and productivity?
5. Ecosystem composition	What happens to native species or communities when invasive species are controlled or eradicated? *How do we determine pre-disturbance conditions in order to		Do plant-soil interactions reflect effects of different species of seabirds? How do the dynamics of nutrients in soils change by location? How does plant productivity vary with seabird density across seabird island

	inform restoration? *Where are the greatest biodiversity and social benefits from restoration? *Does restoration of natural disturbance regimes improve conservation effectiveness? *How does across-ecosystem conservation influence biodiversity?		systems? How do plant growth forms vary geographically across island systems? What are the varying effects of seabird nest densities on plant community composition? At what plant life stages do seabirds have greatest effects? Are there legacy effects of previous landuse reflected in soil chemistry? Can whole ecosystems be restored and what are the criteria for success?
6. Ecosystem representation	*How effective are different classes of reserves at protecting biodiversity and providing		

	ecosystem services? *What are the social costs and benefits of protected areas? *How does management of a site affect biodiversity and society beyond the site's boundaries?		
7. Climate change and variability	*What biodiversity is most vulnerable to climate change? *How is resilience to climate change affected by human activity? *How much carbon is sequestered by different ecosystems?		How useful are seabirds as indicators of global climate change? What aspects of island ecosystems other than seabirds provide useful measures of climate change? How can monitoring of island ecosystems be standardised to enable cross-system comparisons?

8. Sustainable use	*Are there critical thresholds where loss of species or communities disrupts ecosystem functions or services? *How can fisheries effectively mitigate their effects on non-target species?		Has marine harvesting had food web effects that cascade into seabird populations? Have mitigation measures against loss of seabirds to marine harvesting provided measureable responses by seabirds?
9. Community participation in conservation	*What are the conservation impacts of improved education, employment and reproductive choice? *What factors shape human attitudes to wild animals, especially those that induce human-wildlife conflict?	How can scope of eradications be broadened esp. for inhabited islands? How best can regional strategies against invasive species be developed? How should community involvement/acceptance of invasive species eradication be approached? How can communities be aided with	What motivates community groups to commit time to island conservation? How can enterprise-based conservation be developed for islands and what are the criteria for success? What is the social background of participants in island restoration? How successful is the educational

	*How does public involvement (especially marginalised groups) in decision-making influence conservation outcomes? *What are the social impacts of conservation activity? *How can recognition of customary rights improve conservation outcomes?	understanding/participating in removal and prevention of invasions? How should the social benefits of invasive species eradications be defined? How should best practice against biological invasions be provided and distributed?	motive for participation in island conservation? To what extent can community groups monitor ecosystem recovery on islands? What are the relative expectations of agencies and the public for the social outcomes of restoration activities? What are the origins of opposition to eradications of invasive species? What are the relative social outcomes of public engagement versus stakeholder participation in island conservation?

Table 2. Research questions that relate directly to the conservation of New Zealand islands sorted into objectives for ecological integrity (Lee et al. 2005), based on needs assessment, and with relevant questions derived from global analyses identified in bold.

Integrity objective	Current situation	Ideal position	Key Questions
Changes in indigenous dominance			
1. Maintaining ecosystem processes	Islands spread over 3 000 km, with some largely unmodified Increasing range of sites cleared of invasive species Patchy and poor data on ecosystem composition and function	Measure change in ecosystems Understand external effects on ecosystems Determine how island systems differ from mainland	**What external influences affect ecological integrity?** How resilient are island ecosystems relative to island size? How do marine subsidies affect island ecosystems and is there nutrient flow back into marine environments? Do island ecosystems benefit from adjacent marine reserves?

			Do island ecosystems have characteristics absent from mainland patches of equivalent size?
2. Reducing exotic spread and dominance	Increasing range of invasive plants, some of which effectively controlled Capacity to eradicate all introduced mammals (except mice) from large islands Poor data on ecological effects of introduced birds Poor data on ecological effects of most introduced invertebrates Patchy ability to detect and destroy incursions of rodents	Eradicate or control introduced plants that threaten ecological integrity Eradicate invasive vertebrate species without unwanted collateral damage Detect incursions (invasive species at low density) Understand effects of invasions by non-mammalian species (invertebrates and birds)	**How do invasive plants and animals interact and can unintended effects be avoided?** **How do invasive plants and animals behave in changing environments (e.g. in the course of forest succession; release from herbivory)?** **How can complex interactions be modelled for competing invasives?** What are the effects of invasive species on ecosystem processes and how do these change when invasive species are

	Vulnerable to invasions by invertebrates	Achieve eradications from large and complex sites that are inhabited by people Provide effective responses to incursions by invasive mammals Have the ability to detect and eliminate invasive invertebrates and other unwanted organisms	removed? How effective are biological control agents on islands? What baits and lures attract rodents at low densities? What are the most cost-effective methods for detecting incursions of invasive species? How should social and economic benefits of eradications be measured?
3. *Environmental pollutants*	Numerous island sites, some with very high ecological integrity, that straddle or are adjacent to shipping lanes Increased marine oil exploration	Have confidence that offsite activities do not detrimentally affect terrestrial systems	**Do ocean contaminants bioaccumulate in terrestrial species or ecosystems**? What are the least environmentally damaging methods for managing the effects of petrochemical spills and mining

	Increased prospecting for seabed minerals Increased pressure to extract terrestrial mineral resources on protected land		in the New Zealand environment?
Changes in species occupancy			
4. Preventing declines and extinctions	Major proportions of biota threatened (and 40% of birds extinct) Successful reintroductions of numerous species on islands Management on islands of mainland species (birds) under threat	Understand interactive effects of recolonising species on islands after invasive species eradication Have long-term self-sustaining populations of translocated species	How do native species interact on islands without invasive species (no longer observable on the mainland)? What are the long term effects of small founder populations (of translocated species)? How does low genetic diversity affect long term fitness?

			What are the practical outcomes of managing genetic drift?
5. *Ecosystem composition*	Have many decades of successional change following burning and farming on numerous islands Seeing the long term effects of invasive species removals undertaken many decades ago Undertaking restoration projects on increasingly large and complex islands	Predict successional pathways and provide informed models for island revegetation Provide restoration models for previously modified islands Demonstrate the effectiveness of restoration activities	**What are the ecosystem effects of predator removals in complex systems?** **How can the accuracy of restoration goals be increased?** **How can restoration of composition and functional relationships be demonstrated?** **Can ecosystems benefit from the management of high profile species (e.g. charismatic or flagship and umbrella with assumed benefits to other species)?** What are the implications of species substitutions for extinct taxa?

			What are appropriate numerical and genetic criteria for successful reintroductions? How do lessons learned from restoration on islands relate to the mainland?
Changes in environmental representation			
6. Ecosystem representation	Numerous islands as reserves and private restoration projects Most sites with high ecological integrity well offshore More accessible islands managed for recreation; patchy representation of high integrity sites	Develop protection and restoration goals that improve biogeographic range of island types and sizes with high integrity Have a comprehensive understanding of the biological diversity on islands (at least in	How useful are islands for testing models of representativeness at different organizational levels? What are the relative biodiversity contributions made by islands in different archipelagos? Can islands/archipelagos be ranked according to irreplaceablity?

	Very patchy knowledge of species composition for some communities (e.g. invertebrates)	public lands)	
7. Climate change and variability	Manage islands that cover a far greater latitudinal range than does mainland New Zealand Manage sites of greatly varying size and topography and thus vulnerability to environmental stress Have evidence that some island species respond to off-site environmental change (e.g. rock-hopper penguins)	Be able to predict the identity and effects of stressors on island ecosystems	**How do island ecosystems shift in response to changes in climate and in the marine environment?** How do species that utilise island environments respond to climate change**?**

Effects of use by people			
8. Sustainable use of island ecosystems	Increasing array of islands without invasive mammals which are increasingly attractive to visitors Increasing mobility and conservation awareness of New Zealanders Increasing proportion of GDP from tourism Re-establishment of customary seabird harvests	Enable high public visitation to key showcase sites Improve public understanding and enjoyment of New Zealand biodiversity Increase interest in participating in island management Understand the social and economic importance of island biodiversity Understand other ecosystem services provided by island biodiversity	**What effects do marine bycatch and customary harvest of seabirds have on island ecosystems?** Is there conflict between recreational use and biodiversity management and how can it be resolved? What business opportunities stem from island management? What ecosystem services are provided by island species and are these different from the mainland? Are there carbon offset implications of island restoration projects? What are the comparative implications for

		Understand effects of customary harvests	carbon sequestration of unmodified islands, recovering sites and islands with invasive mammals?
9. Community participation in conservation	Increasing numbers of community led conservation projects Island conservation partnerships with iwi and private land owners Localised initiatives but no whole-island projects on occupied islands	Complete removals of selected invasive species from large islands (e.g. Great Barrier, Stewart) Have sufficient public support for island conservation for unwanted species invasions to be rare and rapidly detected Have sufficient public support to ensure funding of eradications, commitments to restoration and sophisticated	**What factors shape societal attitudes to invasive species and their management?** **What influences views of customary rights and how can traditional knowledge and practices complement current conservation practice?** **What motivates community groups to commit to island restoration?** Can interactive databases be developed for community involvement? How do community values change in response to conservation activity?

		biosecurity systems Have mechanisms for adaptive management of community projects (and cross-system comparisons)	What are the social outcomes of biodiversity management? How can social, economic and biodiversity outcomes be quantified?