Selection of potential indicator species for measuring and reporting on trends in widespread native taxa in New Zealand

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Abstract

The New Zealand Department of Conservation (DOC) has recently developed an Inventory and Monitoring Framework to measure progress towards biodiversity targets. It adopts the use of a hierarchical and integrated indicator framework and encapsulates three targeted national outcomes: indigenous dominance, species occupancy, and environmental representation. Indicator 5.1, 'Composition', within the species occupancy outcome includes elements that can collectively be thought of as an indicator of trends in widespread native taxa. We used a process based on expert elicitation to identify and select a suite of native taxa to contribute to reporting under Indicator 5.1. Using eight selection criteria reflecting biological and geographic attributes, a panel of 18 experts selected 106 taxa as a minimum set to adequately represent the full range of taxonomic groups, pressures and habitat types found in New Zealand. We recommend phased implementation of monitoring programmes for selected taxa, with priority given to taxa that both exhibit population responses to specific (as opposed to multiple) pressures and are relatively achievable to monitor.

Keywords: biodiversity, environmental reporting, expert elicitation, freshwater, marine, monitoring, terrestrial.

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1. Introduction

International conservation goals, such as those described in the Convention on Biological Diversity Agreement (Secretariat of the Convention on Biological Diversity 2005), set the context for national biodiversity inventory and monitoring programmes. The United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC) advocates the use of an indicator framework to measure progress toward biodiversity targets (UNEP-WCMC 2009). Specifically, the suggested approach involves using a small set of broad headline indicators underscored by more specific sub-indicators/measures in order to communicate trends in greater detail (UNEP-WCMC 2009).

A wide range of indicator concepts, from ecosystem health indicators to composition and population trend indicators are applied to measuring biodiversity (Caro & O'Doherty 1999; Hoare et al. 2010). Measuring a carefully selected subset of biodiversity indicators enables broad trends in environmental conditions and progress toward biodiversity goals to be established. It can also increase awareness of environmental issues and be applied to environmental policy decisions (Hammond et al. 1995). Conservation agencies require an effective measurement and reporting system in order to adequately account for progress toward biodiversity goals (Lee et al. 2005).

Until recently, application of indicator concepts to national reporting in New Zealand has not followed the recommended practice. Long-term monitoring data have not traditionally been collected with an integrated indicator framework in mind (Parliamentary Commissioner for the Environment 2010), so reporting agencies construct indicators opportunistically based on data availability (MfE 2007; Statistics New Zealand 2009). For example, although current State of the Environment reporting in New Zealand attempts to use a suite of indicators to measure the condition of, and trends in, the environment (MfE 2007), quantitative species reporting has, to date, has been limited to trends in a handful of threatened species, selected *a postori*, for which trend data exist (Hoare et al. 2010). Hoare et al. (2010) and Walpole et al. (2009) advocate for objective selection of, and data collection for, a range of indicator species that encompass representation of (1) taxonomic diversity, (2) ecosystem types, (3) key environmental pressures and (4) threat status.

The New Zealand Department of Conservation's (DOC's) recently developed Inventory and Monitoring Framework for monitoring biodiversity and reporting on its status and trend follows this model (Lee et al. 2005; Allen et al. 2009a, b). Selection of indicators to achieve a comprehensive picture of New Zealand's biodiversity and the threats that it faces relies on representation of the different levels of biodiversity and their amalgamation for high-level reporting (Lee et al. 2005). While managers, policy analysts, and researchers have agonised over selecting indicators for decades, national and international pressures for their use only increase (UNEP-WCMC 2009; Walpole et al. 2009).

The Inventory and Monitoring Framework includes a hierarchical and integrated indicator framework for performance assessment (Lee et al. 2005; Allen et al. 2009a, b). It encapsulates three targeted national outcomes: (1) indigenous dominance, (2) species occupancy, and (3) environmental representation which together comprise nine objectives, 24 indicators and 61 measures derived from quantitative data layers (Lee et al. 2005). These elements, indicators and measures will provide information about national trends in ecological integrity. For example, the species occupancy element includes objectives pertaining to (1) preventing declines and extinction and (2) maintaining ecosystem composition. Three of the four elements within Indicator 5.1, 'Composition', ('Demography of widespread animal species', 'Representation of plant functional types' and 'Representation of animal guilds'; Lee et al. 2005) can collectively be thought of as an indicator of trends in widespread native taxa.

Common, widespread species are critical to the structure, biomass and function of most ecosystems (Gaston & Fuller 2008; Elliott et al. 2010). As such, establishing trends in widespread native taxa is an important component of the suite of biodiversity indicators identified in the Inventory and Monitoring Framework. Each species selected and monitored under this objective is intended to act as a 'population indicator species' (a species whose trends can be used as an index of trends in other species; Hoare et al. 2010).

Long-term datasets perform a critical role in evaluating changes in biodiversity, as a result of both natural change and anthropogenic activities (Magurran et al. 2010; Silvertown et al. 2010). Long-term monitoring of widespread taxa can provide both an early warning of emerging threats and a baseline for measuring the effectiveness of conservation management (Gregory et al. 2005; O'Brien et al. 2011). For example, monitoring of common farmland birds in Europe over two decades demonstrated dramatic declines associated with agricultural intensification and was used to instigate policy changes in farming practices (Gregory et al. 2005).

In this report we: (1) describe the process by which we identified and selected a representative range of native taxa to contribute to reporting under Indicator 5.1 in the national Inventory and Monitoring Framework (Lee et al. 2005), (2) provide a list of taxa and groups that together would form a comprehensive suite of widespread indicators, and (3) describe additional work required to make widespread indicators selected for implementation most useful for reporting and policy decisions.

2. Methods

2.1 Overview of selection process

Expert elicitation is a technique used to synthesise the opinions of 'experts', defined here as researchers and/or managers with > 10 years experience working on a particular taxonomic group. It is increasingly being used in the conservation sector to guide decision making, particularly in data-poor scenarios (Donlan et al. 2010).

We used a national experts' workshop to identify a broad suite of potential widespread[1] indicator taxa (or groups of ecologically equivalent taxa) to provide coverage of terrestrial, freshwater and marine taxonomic groups, key pressures contributing to biodiversity declines, broad habitat types and functional roles. The experts then scored each potential indicator taxon against eight key selection criteria that captured both biological and geographic criteria based on principles agreed on in the species indicator literature (Table 1; Stork & Samways 1995; Caro & O'Doherty 1999; Hutcheson et al. 1999; Hilty & Merenlender 2000). We selected a shortlist of the highest scoring taxa within each combination of taxonomic group, pressure and habitat type (for definitions, see sections 2.5 and 2.6), and checked that the selected taxa covered a range of functional roles within ecosystems.

In addition to information about key selection criteria for each potential indicator taxon, we compiled information[2] about: (1) the range of pressures a taxon was affected by, (2) its geographic distribution, (3) its threat status (based on Townsend et al. 2008), (4) the existence of historical monitoring data, (5) the existence of managed populations (and their locations and types of management) and (6) whether the taxon is recognised as having cultural uses. We also asked

[1] We define 'widespread' relative to pressures and ecosystems. That is, a species that occurs (or occurred) widely throughout an ecosystem type and is affected by a particular pressure throughout its range is eligible for inclusion, even though it might not be widespread across the country. For example, Otago skinks, *Oligosoma otagense*, were considered as an indicator of predation in tussock grasslands, because they were formerly widespread in the schist rocks that are prevalent in the Central Otago area (Houghton, C.; Linkhorn, R. 2002: Population decline in the skinks *Oligosoma otagense* and *O. grande* at Macraes Flat, Otago. Department of Conservation, Wellington. 26 p.).

[2] These data are available on request from the first author.

experts to identify knowledge gaps that limited the selection of widespread indicator taxa, primarily about the existence of suitable monitoring techniques and causal links between population trends and pressures. All data were collated in a Microsoft Excel spreadsheet. This additional information will provide context for designing sampling schemes and for reporting and interpreting trends.

2.2 Candidate pool of taxa considered as potential indicators

We developed a candidate list of bird, fish, herpetofauna (reptile and amphibian), mammal, invertebrate and vascular plant taxa. For bird, freshwater fish, reptile, amphibian, bat and marine mammal taxa, experts considered the full New Zealand lists in the first instance. However, data were only collated for those taxa that were considered widespread, including threatened species that still had widespread distributions. Some localised taxa were combined with ecological equivalents to form taxonomic subgroups if, together, they were considered useful indicators of widespread pressures. The vascular plant list is considerably longer and the full range of marine fish and invertebrate taxa present in New Zealand has yet to be documented. Therefore, for these groups, experts identified a pool of candidate taxa based on their knowledge of taxa with relatively well-known biology. Taxonomic groups for which basic biological knowledge is poor (e.g. bryophytes) were not considered as indicators because they did not meet the selection criteria (Table 1).

Table 1. Criteria used in the selection of widespread native taxa to act as indicators as part of New Zealand's national indicator framework. Criteria were developed with reference to the principles recommended by Stork & Samways (1995), Caro & O'Doherty (1999), Hutcheson et al. (1999) and Allen et al. (2009b).

ATTRIBUTE	EXPLANATION
Biological	
Well-known biology	Understanding the factors influencing a population indicator is important for understanding its relationship with a particular threat process and its potential ability to indicate trends in other populations.
Relatively high abundance	High abundance is useful for achieving a statistically robust, cost-effective sample.
Easy to locate, identify and monitor in the field	Species that can be monitored relatively easily and reliably give confidence in data and are likely to be more cost-effective than alternatives.
Clearly measurable	It is important to be able to repeatedly collect relevant demographic data for the indicator species (e.g. abundance, size, growth, structure or frequency) in order to evaluate population trends.
Geographical	
Resident within the ecosystem of interest prior to environmental change	Resident species are subject to sustained environmental pressure and will usually make the best indicators. However, migratory species may be useful in specific situations.
Sensitive to environmental change within the period of measurement	A species should be sensitive, though not hypersensitive, to environmental change and respond rapidly and predictably to it. This enables a population to act as an early warning of disturbance and inform decisions about mitigation of a threat.
Occurs on a scale relevant to the threat process	The scale on which a species occurs (mobility, home range size) should be considered relative to the threat process.
Widespread	The chosen indicator species should be widespread (as opposed to localised) within a broad habitat type in order to indicate processes operating throughout the area.

Summarised traits information was used to inform initial selection of taxa as potential indicators, where available. For example, plants identified as being palatable to possums and ungulates (Allen et al. 2009b; Mason et al. 2010), based on dietary studies (Nugent et al. 1997; Forsyth et al. 2002), were used in the identification of a candidate list of potential plant indicator taxa. Similarly, life history traits that are associated with vulnerability to predation (Whitaker 1978; O'Donnell et al. 1996; Towns et al. 2003; Hoare et al. 2007) were considered in the identification of a list of potential reptile and bird indicators.

2.3 Composition of the expert group

The national workshop to identify and evaluate taxa as indicators of trends in widespread species comprised 18 DOC staff[3] with a national overview for at least one taxonomic group being considered. Workshop participants were invited by the authors for their specialist knowledge of birds and bats (n = 5 participants), freshwater fish and invertebrates (n = 2), herpetofauna (n = 3), marine fish, invertebrates and mammals (n = 2), terrestrial invertebrates (n = 3) and vascular plants (n = 3). Several members of the group had expertise across different areas and were frequently consulted by more than one group when scoring taxa (see below).

2.4 Scoring of candidate taxa

Experts scored each taxon for each of the eight attributes described in Table 1. Each attribute was scored between zero (the taxon scored extremely poorly in relation to the attribute) and three (it scored highly). For example, a taxon with very well known biology scored three, and one with no knowledge scored zero). Scoring was done by consensus within the group considered to have expertise for that taxon. Scores were summed for each taxon (maximum = 24) and the scores were used to compare the relative performance of taxa as potential indicators.

2.5 Habitat types

In the data collection phase, taxa were categorised according to whether they primarily occurred in one of 11 broad habitat types. Habitat types considered were: alpine, coastal, forest, shrubland or tussock grassland (terrestrial); estuaries, lakes, rivers or wetlands (freshwater); and coastal (to 30 m deep) or deep water (> 30 m deep) marine. Broad habitat types were used (as opposed to finer resolution habitat classification) to guide experts to consider taxa that inhabit a range of ecosystems and ensure representation (see Hoare et al. 2010).

2.6 Pressures

Taxa were classified according to their vulnerability to one of five of the major pressures that are contributing to declines in biodiversity in New Zealand[4]: competition, predation, herbivory, human impacts and habitat modification. Competition, particularly between native vascular plants and introduced weed species (e.g. de Lange et al. 2010), but also between exotic and native animals (e.g. Bonnett & McIntosh 2004), has changed the indigenous dominance and community

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[3] Participants at the workshop were DOC staff because DOC has both primary responsibility for national biodiversity monitoring and reporting in New Zealand and expert knowledge that covers the range of taxonomic groups (and their geographic spread) being considered as indicators of trends in widespread native taxa.

[4] A primary pressure was identified for each potential indicator for categorisation purposes, even though multiple pressures may affect any one taxon. Taxa with a strong response to an individual pressure were given preference to those with a response more likely to be related to multiple pressures where several taxa scored equally well within a taxonomic group, pressure and habitat type category.

composition throughout New Zealand. Predation by introduced mammalian predators is one of the major causes of decline of species in forests, freshwater and coastal ecosystems in New Zealand since the arrival of humans (Atkinson 1989; Dowding & Murphy 2001; Allibone et al. 2010; Innes et al. 2010) and affects most major animal groups (Ramsay 1978; Sherley et al. 1998; Pryde et al. 2005; Hoare et al. 2007; Allibone et al. 2010; Innes et al. 2010). Similarly, introduced mammalian browsers have had a profound impact on native vegetation, reducing foliar cover, contributing to canopy dieback and regeneration failure, and threatening some particularly palatable species (Nugent et al. 1997; Forsyth et al. 2002; Allen & Lee 2006; Mason et al. 2010). Habitat modification, including the clearance and fragmentation of indigenous cover, fire and conversion of forests to plantations, is a major threat particularly for species inhabiting threatened environments (McGlone 1989; Eikaas et al. 2005; Walker et al. 2006; Ausseil et al. 2010). Human impacts cover a range of other human activities including pollution, barriers to migrations, disturbance (e.g. recreation) and harvesting (e.g. Hickey & Clements 1998; Dopson et al. 1999; Walls 1999; Joy & Death 2001; Thompson 2010).

A range of other pressures were considered but not included in our selection, largely because their influences are local or associated with small populations (e.g. hybridisation and disease; Tompkins 2007; Ortiz-Catedral et al. 2009), or the relationship between the perceived pressure and species trends is not well understood (e.g. Halloy & Mark 2003).

2.7 Final selection of potential indicator species

In narrowing down our selection of indicators, we gave priority to achieving representation of taxonomic group, environment, pressures and functional role, in accordance with recommendations of the United Nations Environment Programme (UNEP-WCMC 2009). In this way, individual indicators can be grouped for analysis to enable the identification of trends and priorities for action at meaningful scales.

We chose the highest scoring taxa in each representation category (i.e. combination of taxonomic group, environment, pressure) to provide a short-list of preferred taxa. Functional role was used as a *post hoc* check to ensure that all functional roles (primary producer, primary consumer, mid-trophic consumer, top predator and pollinator and seed disperser) were represented. As a result, several taxa were added to the final selection to achieve representation, even though they did not score as highly as some other taxa (which were excluded on the basis that that particular ecosystem, threat and taxonomic group was already sufficiently represented).

3. Results

A panel of 18 experts at a national workshop identified 251 taxa (usually at species level, but some subspecies were identified) and 50 groups of ecologically equivalent taxa as being worthy of consideration as widespread native indicator taxa. Of these, and based on the eight selection criteria described above, 80 taxa and 26 groups of ecological equivalents were identified as a minimum set of taxa to adequately represent the full range of taxonomic groups, pressures, habitats and functional roles (see Table 2; note that some taxa or groups are represented in more than one habitat or environment type).

Of the 106 taxa or groups of ecologically equivalent taxa identified as a minimum set of indicators, 35 occur in the freshwater environment, 18 in the marine environment and 56 in the terrestrial environment (Table 2). Taxonomic groups represented are: bats (2 taxa), birds (26 taxa or groups), freshwater fish (4 taxa), freshwater invertebrates (1 taxon), herpetofauna (12 taxa or groups), marine fish (4 taxa), marine invertebrates (9 taxa), marine mammals (2 taxa), vascular plants (38 taxa; of which 24 were terrestrial and 14 aquatic) and terrestrial invertebrates (8 taxa or groups; Table 2). The following broad ecosystem types are represented: alpine (6 taxa or groups), coastal terrestrial coastal marine (13 taxa or groups), deepwater (5 taxa or groups), estuaries (12 taxa or groups), forest (26 taxa or groups), freshwater (17 taxa or groups), rivers/gravels (8 taxa or groups), shrubland (10 taxa or groups), tussock grasslands (4 taxa or groups; Table 2). Functional roles of taxa or groups selected include: ecosystem engineers (13 taxa or groups), mid-trophic species (37 taxa or groups), pollinator and/or seed disperser (12 taxa or groups), primary consumer (7 taxa or groups), primary producer (30 taxa or groups) and top predator (7 taxa or groups).

4. Discussion

The ability to evaluate the responses of individual species to anthropogenic disturbance and report on the effectiveness of conservation policy is a key issue for ecologists and conservation managers. The approach we have developed has provided an objective basis for the selection of widespread native taxa representative of the major taxonomic groups for each of the key five pressures (predation, herbivory, competition, human impact, and human modification) influencing the viability of biodiversity within terrestrial, freshwater and marine environments in New Zealand. Implementing long-term monitoring at a national scale would enable trend reporting (e.g. State of the Environment reporting) for a representative range of taxa. However, we emphasise that establishing the relationships between selected indicator taxa and the broader suite of species for which they can act as indicators is necessary in order to maximise utility of the data.

4.1 The value of including widespread species as indicators in a national biodiversity monitoring system

Elliott et al. (2010) highlight the growing concern about the status of common widespread species and the need for nationwide bird monitoring programmes in New Zealand. Initial declines in common species may be difficult to detect, but can equate to large losses of individuals and ecosystem integrity. In their work, analysis of a 30-year point-count monitoring dataset of forest birds in an unmanaged temperate forest in New Zealand revealed a significant change in the bird community structure in which five common native species (bellbird, *Anthornis melanura*; rifleman, *Acanthisitta chloris*; grey warbler, *Gerygone igata*; tomtit, *Petroica macrocephala* and tūī, *Prosthemadera novaeseelandiae*) declined in abundance.

Table 2. Taxa and groups that would form a comprehensive suite of widespread indicators as part of the New Zealand Inventory and Monitoring Framework.

ENVIRONMENT	TAXONOMIC GROUP	HABITAT TYPE	PRESSURE	SPECIES	COMMON NAME
Freshwater					
	Birds	Estuaries	Human impact	*Anarhynchus frontalis*	Wrybill
				Anas rhynchotis	New Zealand shoveler
				Haematopus ostralegus	South Island pied oystercatcher
			Predation	*Anas chlorotis*	Pāteke
		Freshwater	Habitat modification	*Anas rhynchotis*	New Zealand shoveler
				Aythya novaeseelandiae	Scaup
			Human impact	*Egretta alba*	White heron (kōtuku)
		Rivers/gravels	Human impact	*Larus bulleri*	Black-billed gull
			Predation	*Anarhynchus frontalis*	Wrybill
				Charadrius bicinctus bicinctus	Banded dotterel
				Larus bulleri	Black-billed gull
	Freshwater fish	Freshwater	Habitat modification	*Galaxias argenteus*	Giant kōkopu
			Human impact	*Anguilla dieffenbachii*	Longfin eel
				Galaxias maculatus	Inanga
			Predation	*Galaxias brevipinnis*	Kōaro
	Freshwater invertebrates	Freshwater	Habitat modification	*Hydridella menziesii*	Freshwater mussel
	Herpetofauna	Freshwater	Habitat modification	*Oligosoma chloronoton*	Green skink
				Oligosoma polychroma	Common skink
	Marine fish	Estuaries	Human impact	*Rhombosolea plebeia*	Flounder
	Marine invertebrates	Estuaries	Habitat modification	*Amphibola crenata*	Mud snail
				Austrovenus stutchburyi	Cockles
				Cominella glandiformis	mud whelk
			Human impact	*Austrovenus stutchburyi*	Cockles
	Plants	Estuaries	Habitat modification	*Mimulus repens*	Māori musk
				Suaeda novae-zelandiae	
				Zostera muelleri	Seagrass
			Human impact	*Ruppia* spp.	Horsehair weed
		Freshwater	Competition	*Carex tenuiculmis*	Sedge
				Epilobium pallidiflorum	Willowherbs
				Nitella and *Chara* spp.	Charophytes
			Habitat modification	*Carex secta*, *Carex virgata*	Wetland carex
				Lycopodiella serpentina	Club moss

Continued on next page

Table 2 continued

ENVIRONMENT	TAXONOMIC GROUP	HABITAT TYPE	PRESSURE	SPECIES	COMMON NAME
				Trithuria inconspicua	Hydatella
			Herbivory	*Aciphylla traversii*	Chatham Island speargrass
		Rivers/gravels	Competition	*Muehlenbeckia axillaris*	Pōhuehue
				Muehlenbeckia ephedroides	Pōhuehue
				Raoulia spp.	Scabweeds
	Terrestrial invertebrates	Rivers/gravels	Habitat modification	*Boldenaria* spp.	Boulder copper butterfly
			Predation	*Brachaspis robustus*	Robust grasshopper
Marine					
	Birds	Coastal marine	Habitat modification	*Larus novaehollandiae scopulinus*	Red-billed gull
			Human impact	*Daption capense capense*, *Macronectes* spp.	Cape pigeon, giant petrel
				Eudyptula minor	Little penguin (kororā)
				Puffinus carneipes	Flesh-footed shearwater
		Deepwater	Human impact	*Diomedea antipodensis*, *D. gibsonii*	Wandering albatrosses
				Pterodroma macroptera gouldi	Grey-faced petrel
				Thalassarche spp.	Mollymawks
	Marine fish	Coastal marine	Human impact	*Pagrus auratus*	Snapper
				Parapercis colias	Blue cod
		Deepwater	Human impact	*Trachurus novaezelandiae*	Jack Mackerel
	Marine invertebrates	Coastal marine	Human impact	*Evechinus chloroticus*	Kina
				Haliotis iris	Pāua
				Jasus edwardsii	Rock lobster
				Mytilus galloprovincialis	Blue mussel
				Pecten novaezelandiae	Scallops
				Perna canaliculus	Green-lipped mussel
	Marine mammal	Coastal marine	Human impact	*Cephalorhynchus hectori*	Dolphins
		Deepwater	Human impact	*Arctocephalus forsteri*	New Zealand fur seal (kekeno)
Terrestrial					
	Bat	Forest	Predation	*Chalinolobus tuberculatus*	Long-tailed bat
				Mystacina tuberculatus	Lesser short-tailed bat
	Birds	Alpine	Predation	*Xenicus gilviventris*	Rock wren
		Coastal	Human impact	*Charadrius bicinctus bicinctus*	Banded dotterel
				Eudyptula minor	Little penguin (kororā)
				Pterodroma macroptera gouldi	Grey-faced petrel
				Sterna striata	White-fronted tern

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Table 2 continued

ENVIRONMENT	TAXONOMIC GROUP	HABITAT TYPE	PRESSURE	SPECIES	COMMON NAME
			Predation	*Charadrius bicinctus bicinctus*	Banded dotterel
				Eudyptula minor	Little penguin (kororā)
				Haematopus unicolor	Variable oystercatcher
				Pterodroma macroptera gouldi	Grey-faced petrel
				Sterna striata	White-fronted tern
				Procellaria parkinsoni, *Procellaria westlandica*, *Pterodroma cookii*, *Pterodroma macroptera gouldi*, *Pterodroma magentae*, *Puffinus gavia*, *Puffinus huttoni*, *Puffinus griseus*	Tube-nosed seabirds
		Forest	Competition	*Nestor meridionalis*	Kākā
			Predation	*Acanthisitta chloris*	Rifleman
				Anthornis melanura melanura	Bellbird (kōpara)
				Hemiphaga novaeseelandiae	Kererū
				Nestor meridionalis	Kākā
				Petroica australis	Robin
				Prosthemadera novaeseelandiae novaeseelandiae	Tūī
		Shrubland	Predation	*Acanthisitta chloris*	Rifleman
	Herpetofauna	Alpine	Predation	*Woodworthia* “Southern Alps”, *W.* “Mt Arthur”, *W.* “Southern mini”	Alpine geckos
		Coastal	Predation	*Woodworthia maculatus*, *W.* “Marlborough mini”, *W.* “Canterbury”	Coastal geckos
		Forest	Habitat modification	*Leiopelma hochstetteri*	Hochstetter’s frog
			Predation	*Oligosoma aeneum*	Copper skink
				Oligosoma infrapunctatum	Speckled skink
				Oligosoma ornatum	Ornate skink
		Shrubland	Predation	*Dactylocnemis* group	Pacific gecko
				Woodworthia “pygmy”, *W.* “Cromwell”	Shrubland geckos
				Naultinus group	Green geckos
		Tussock grasslands	Predation	*Woodworthia* “Otago large”	Otago large gecko
				Oligosoma otagense	Otago skink
	Plants	Alpine	Herbivory	*Anisotome haastii*	Mountain carrot
				Ranunculus spp.	Large alpine ranunculi
		Coastal	Habitat modification	*Pimelea villosa*, *Pimelea lyallii*	Pimelea species

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Table 2 continued

ENVIRONMENT	TAXONOMIC GROUP	HABITAT TYPE	PRESSURE	SPECIES	COMMON NAME
			Herbivory	*Coprosma acerosa*	Sand coprosma
				Euphorbia glauca	Sand spurge
				Metrosideros spp.	Pōhutukawa and rātā
		Forest	Herbivory	*Asplenium* spp.	Asplenium ferns (pikopiko)
				Brachyglottis kirkii var. *kirkii*	Kirk's Tree Daisy
				Dysoxylum spectabile	Kohekohe
				Fuchsia excorticata	Kōtukutuku
				Griselinia spp.	Broadleaf
				Peraxilla spp., *Tupeia* spp., *Alepis* spp.	Pirita, korukoru, tāpia, (mistletoes)
				Pittosporum kirkii	Kirk's pittosporum
				Pseudopanax colensoi, *Pseudopanax arboreus*	Large-leaved pseudopanax
				Ptisana salicina	King fern, para
				Schefflera digitata	Seven-finger
				Coprosma lucida, *Coprosma grandifolia*, *Coprosma robusta*	Large-leaved coprosmas
		Shrubland	Competition	*Carmichaelia crassicaulis crassicaulis*	Coral broom
				Olearia fragrantissima, *Olearia hectorii*, *Olearia gardneri*	Small-leaved olearia
			Herbivory	*Carmichaelia nana*, *Carmichaelia corrugata*, *Carmichaelia vexillata*	Palatable native brooms
				Ileostylus micranthus	Green mistletoe
				Melicytus spp.	Porcupine shrubs
				Pittosporum turneri	Tentpole tree
		Tussock grasslands	Herbivory	*Chionochloa flavescens*, *Chionochloa macra*, *Chionochloa pallens*, *Chionochloa rigida*	Snow tussocks
	Terrestrial invertebrates	Coastal	Habitat modification	*Latrodectus katipo*	Katipō (spider)
		Forest	Predation	*Hemideina* spp.	Tree wētā
				Powelliphanta spp.	Giant landsnails
		Shrubland	Predation	*Deinacrida elegans*	Bluff wētā
		Tussock grasslands	Predation	*Hadramphus tuberculatus*	Knobbled weevil

In the past, because of the lack of long-term monitoring of widespread native taxa in New Zealand, declines in formerly widespread taxa (e.g. kākā, *Nestor meridionalis*; mōhua, *Mohoua ochrocephala* and long-tailed bats, *Chalinolobus tuberculatus*) have gone undetected to the point that they were endangered before the need for management intervention was identified (Gaze 1985; O'Donnell & Rasch 1991; O'Donnell 2000). For example, up until the 1990s, long-tailed bats were considered 'common and widespread' (Daniel & Williams 1984; Daniel 1990). However, when surveys of a range of sites where long-tailed bats had been present in the 1970s and 1980s were conducted, O'Donnell (2000) either failed to find long-tailed bats or recorded bats in low numbers, despite considerable survey effort. Long-tailed bats are now considered Nationally Endangered under New Zealand Threat Classification criteria (O'Donnell et al. 2010) and in need of management intervention to protect remaining key populations (O'Donnell 2010; O'Donnell et al. 2010).

Similarly, more intensive monitoring of single species has repeatedly demonstrated that new or previously unanticipated threats are found periodically, and that they would go undetected without longer-term monitoring programmes. For example, the impact of rats on the viability of mōhua (Dilks et al. 2003) or the influences of competition with wasps (*Vespula vulgaris*) and brushtail possums (*Trichosurus vulpecula*) on food availability for kākā (Wilson et al. 1998). Although there has been some perception that common birds may have reached equilibrium with the new threats introduced to New Zealand by humans (King 1984), it has been shown repeatedly that commonness is not a good indicator of the resistance of species to further change (Siriwardena et al. 1998; Elliott et al. 2010). Without early warning of significant population declines in potentially vulnerable taxa, investment in the recovery of threatened and at risk species becomes increasingly expensive.

4.2 Alternative approaches to selection of indicators

We used an expert-driven process for the selection of widespread species to report on trends in composition. Expert opinion on the relative magnitude of anthropogenic threats to native taxa are used elsewhere for conservation planning and reporting on status of threatened species because they provide a measure of consensus on the magnitude of those threats among researchers and conservation managers (e.g. Gregory et al. 2005; Joseph et al. 2008; Townsend et al. 2008; De Lange et al. 2009; Joseph et al. 2009; Miskelly et al. 2009; Donlan et al. 2010; Hitchmough et al. 2010).

An alternative approach would have been to use quantitative measures under each selection criterion to score taxa for indicator suitability rather than an expert-driven approach (e.g. Tulloch et al. 2011). However, we considered that sufficient data were not available across all taxa to allow this approach. Similarly, a number of studies have demonstrated the value of including ecological trait information as an indicator of shared responses to environmental changes (Mason et al. 2010; Williams et al. 2010). For example, Mason et al. (2010) demonstrated that exclusion of ungulate herbivores from New Zealand forest ecosystems has caused a qualitatively consistent shift in functional composition towards foliar traits relating to palatability at a national scale and across a range of environments. In this study, with the exception of birds, herpetofauna and a selected number of plant species, there was insufficient knowledge or access to traits data across the complete range of native taxa and how specific anthropogenic threats interact with their biology to use a quantitative approach. In our process, ecological traits represent only one component guiding selection; the expert group also needed to assess the appropriateness of the taxonomic units against other criteria such as well known biology, ease of monitoring and geographic distribution (Table 1).

A range of other criteria were considered for inclusion in our selection process, but were discounted for various reasons. Existence of historical monitoring data is sometimes considered as important for choosing indicator species. We deliberately did not use this as a selection criterion to avoid repeating historical biases in focal species (Gregory et al. 2005; Hoare et al.

2010). However, we identified the existence of historical data for species identified as potential indicators so that they could be used in the design of sampling schemes and as baseline information for selected taxa. This approach is generally accepted in the development of indicators (Everard & Noble 2010).

Cost effectiveness and cultural utility of indicators are key concerns in the development of long-term monitoring programmes, especially considering the need for them to be sustained through funding and priority shifts (Caughlan & Oakley 2001; Lindenmayer & Likens 2010). Although these are not criteria we used explicitly in the identification of widespread indicator taxa (because they diminish credibility in selection of taxa to meet biological objectives; Landres et al. 1988), they are considerations that will be explicitly included in the implementation phase of the programme. Furthermore, we acknowledge that the 'ease of monitoring' criterion that we used includes a cost-based element (Table 1), and that the Inventory and Montioring Framework includes indicators specifically focussed on community involvement and iwi partnerships (Indicators 9.1 and 9.2; Lee et al. 2005).

Short generation time, as a proxy for rapid response to environmental change, is identified as an important attribute of population and health indicator species (Caro & O'Doherty 1999). However, we excluded this criterion *per se* because measuring key demographic parameters (as opposed to relative abundance) of long-lived species can be used to indicate threats. For example, demographic structure of tuatara, *Sphenodon punctatus*, a long-lived (Nelson et al. 2002; Mitchell et al. 2010) reptile in New Zealand, is a sensitive indicator of predation pressure by rodents, because recruitment rates are extremely low in the presence of rodents (Towns et al. 2007). Similarly, male-biased sex ratios in kākā, *Nestor meridionalis*, a forest parrot in New Zealand, can be used to indicate predation pressure on nesting females (Greene & Fraser 1998). We feel that the intent of the short generation time criterion is captured by the 'sensitive to environmental change within the period of measurement' criterion (Table 1).

4.3 Outstanding issues

For many taxonomic groups and habitat types, the potential candidate list to select indicators from was relatively small. Several reasons for this exist: (1) basic biological data are unknown for many taxa, (2) no reliable monitoring techniques exist for some taxa, (3) in many cases there is a poor understanding of the relationships between pressures and species' trends (because no research has been conducted into these relationships), and finally (4) trends in some taxonomic groups may be better captured by community-biodiversity indices (e.g. Macroinvertebrate Community Index for stream invertebrates; Stark 1993) within the 'maintaining ecosystem processes' objective of the Inventory and Monitoring Framework (Outcome Objective 1; Lee et al. 2005).

There were a number of gaps in representation across environment types and pressures. For example, basic biological data and reliable monitoring techniques for many invertebrate and herpetofauna species do not exist; thus we were unable to select them in the indicator suite. Similarly, few taxa met the selection criteria in the marine environment and for habitat types in which previous work has been limited in scope (e.g. alpine habitats). Current research programmes led by DOC's Science and Capability Group are targeting some of these knowledge gaps and will feed into improving selection of indicators in the future. The potential bias toward inclusion of species that respond to well-understood pressures (e.g. Donlan et al. 2010) is acknowledged and accepted in this process.

4.4 Future directions

The next stage of the project involves designing detailed monitoring programmes for implementing the indicators programme for widespread taxa and a phased implementation plan. Our recommendation is to start implementation with a ranked list of taxa within each environment type (terrestrial, freshwater and marine) on the basis of specificity to key pressures (in order to maximise interpretability for national reporting) and achievability (including cost-effectiveness) of establishing a monitoring programme to capture trend information. For each indicator selected, a detailed monitoring programme involving the key attributes to be measured (e.g. field method, sampling design, analytical method and additional data needed for interpretation of trends) needs to be designed. Concurrent design of a reporting system will ensure that information obtained for selected indicators is intuitive and relevant to the public. Extracting value from data collection efforts will require organisational commitment, adequate resources and organisational stability.

Ultimately, time will be the main test of the adequacy of the approach we have adopted. Key questions include: (1) is the suite of indicators chosen adequate? and (2) is there sufficient confidence in the relationships between trends in an indicator species and both the pressure it is expected to respond to and trends in related species subject to the same pressure? A complementary research programme is required to establish monitoring methods to enable proper representation across taxonomic groups and environments and to establish links between key pressures and population trends (and/or demographic parameters) for selected taxa.

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