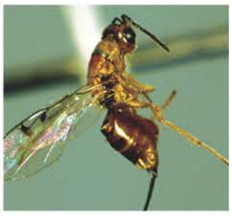
Biodiversity and predator monitoring for *Cape-to-City*, Hawke's Bay Project



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Biodiversity and predator monitoring for *Cape-to-City*, Hawke's Bay Project

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As the client, I felt involved in and consulted on the project from the start.	☐	☐	☐	☐	☐
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The project was delivered on time.	☐	☐	☐	☐	☐
The project met our quality standards.	☐	☐	☐	☐	☐

What impressed you most about this project?

What improvements do you suggest for future projects?

Additional comments?

Contents

Summary

Project and Client

- The *Cape-to-City* project aims to restore indigenous biodiversity across 26 000 ha of productive landscape in Hawke's Bay, through the integrated use of landscape-scale reduction in introduced predator and possum numbers, translocation of iconic species, and habitat restoration. A robust biodiversity monitoring programme is an essential component of the project. This report outlines biodiversity monitoring options for the project, and recommends a design for detecting different levels of biodiversity response. The report fulfils Landcare Research's 2014/2015 contracted Milestone 4.4 with Hawke's Bay Regional Council.

Objective

- Develop a robust biodiversity monitoring programme for *Cape-to-City* that outlines options for measuring responses of introduced predators and indigenous biodiversity to predator control, and considers sampling design issues for detecting various levels of biodiversity response.

Methods

- Monitoring methodologies that are appropriate for *Cape-to-City* were reviewed using the literature and local knowledge.
- Monitoring data from the *Poutiri Ao ō Tāne* project were analysed to determine sample sizes required to detect given levels of change.

Results

- The inclusion of areas with no pest control (non-treatment) is a fundamental requirement for inferring the causative effects of the pest control in *Cape-to-City*.
- The primary tools recommended for monitoring pest numbers are camera traps and tracking tunnels. Road-kill will provide ancillary data. Trap-catch will provide cost-free data, but only from the treatment area.
- Depending on the bird species, modified 5-minute counts in 19 forest patches, counts on 50 ponds and wetlands, and counts along 260 km of country roads are recommended. Bird monitoring should include Cape Sanctuary, as this is the source of a number of emigrating species into *Cape-to-City*. The number of forest patches available for sampling is limited by the shortage of this habitat type in the area.
- Recommended methods for monitoring lizard numbers are artificial retreats and tracking tunnels in open areas, and tracking tunnels and tree wraps in forest patches where rat control is proposed. Power analyses suggest five of each device, deployed along 100 transect lines (50 in each treatment area). Targeted visual searches are recommended for uncommon gecko species where they have been reported in the past.

- Recommended methods for monitoring invertebrates are artificial retreats and track tunnels for ground-dwelling species, weta houses for mid-canopy species in forest patches, and funnel-traps for canopy species in forest patches, deployed along up to 100 transect lines.
- Citizen science will play a critical role in pest and biodiversity monitoring. There are many possibilities for citizen involvement, including structured field surveys and community events, questionnaires, and volunteer involvement in more 'robust' monitoring approaches outlined above.

Recommendations

- As far as possible, undertake equal sampling intensity using the above methodologies in the treatment and non-treatment areas to infer a causative effect of the predator control programme in *Cape-to-City*.
- Recommended sampling intensities should be followed for at least the first 1–2 years of the programme. Depending on the actual magnitude of biodiversity responses measured, it may be possible to modify the sampling intensity in later years.
- The Biological Heritage Science Challenge is likely to include a component on citizen science. Opportunities for collaboration with the *Cape-to-City* project should be encouraged.

1 Introduction

Within the Hawke's Bay region, about 500 000 ha of land is currently under long-term sustained possum control, with the farming community responsible for ongoing maintenance control. The *Cape-to-City* project involves integrating possum control with large-scale control of feral cats, mustelids and hedgehogs across 26 000 ha, with ship rats targeted at specific sites, with minimal or no increase in maintenance control costs. The strategic objective of *Cape-to-City* is to enable indigenous species to co-exist with human habitation, food production and recreation at large scales in this primary production landscape. This is part of the *Te Matau a Maui* Hawke's Bay Project.

The aim is to achieve this objective by targeting possum control more effectively, and by shifting control resources from possums to the wider suite of pests. Conceptually, this resource shift is possible because current monitoring of possums indicates residual-trap-catch rates are generally <2%. This allows possum control costs to be reduced substantially by targeting high-possum-density areas on 5–10% of properties, with minimal loss of economic and environmental outcomes from the existing programme. Significant outcome gains (particularly for biodiversity) are envisaged from integrated control of the additional pest species. Reliable information on biodiversity outcomes relies on the development of a robust monitoring programme that has sufficient power to detect a range of outcome responses. Using the learnings from the *Poutiri Ao ō Tāne* project and other monitoring programmes, we outline the elements of a robust biodiversity monitoring programme for the *Cape-to-City* area. This report fulfils Landcare Research's 2014/2015 contracted Milestone 4.4 with Hawke's Bay Regional Council.

2 Objective

Develop a robust biodiversity monitoring programme for *Cape-to-City* that outlines options for measuring responses of introduced predators and indigenous biodiversity to predator control, and considers sampling design issues for detecting various levels of biodiversity response.

3 Design principles for measuring biodiversity responses to predator control

3.1 Non-treatment and pre-treatment data

The inclusion of areas with no pest control (non-treatment) is a fundamental requirement for inferring the causative effects of pest control (treatment). Without them, other influences such as weather cannot be accounted for. In the case of *Cape-to-City*, measurements of pest and biodiversity dynamics should take place simultaneously in both treatment and non-treatment sites to enable clear interpretation of the impact of control on pest populations and on biodiversity outcomes.

Pre-treatment data, collected from both the treatment and non-treatment sites, adds further strength of inference. This is the so-called 'BACI' design (Before-After Control-Impact), which is a cornerstone of robust experimental design (Smith 2006). However, there is often insufficient time to gather pre-treatment data when there are political or social imperatives to begin the management intervention as quickly as possible. In this situation, non-treatment sites take on even greater importance.

3.2 Top-down versus bottom-up influences

The working premise of the predator control programme is that predation by introduced mammals (also referred to as 'top-down' effects) limits the distribution and abundance of indigenous species. While this is undoubtedly true for vulnerable species, other influences, such as weather, habitat quality, and disease (i.e. 'bottom-up' effects) also play potentially important roles. Given the fundamental importance of habitat suitable for indigenous fauna, we suggest that the spatial extent of different habitat types is quantified throughout the programme to quantify the extent to which changes in habitat (e.g. loss through clearing or gains through re-vegetation and restoration), should they occur, are a contributing factor to the biodiversity response patterns observed. While most, if not all, of the little remaining native vegetation in *Cape-to-City* is 'protected' in some form, and cannot be destroyed, some of the pine forests may be logged during the project. Pine forest is suitable habitat for insectivorous native birds, and for bats. The remote sensing undertaken by Landcare Research in Hawke's Bay may be a useful source of data on vegetation cover.

3.3 Site selection

Although a purely randomized selection of monitoring sites is another cornerstone of robust monitoring, it is not appropriate for *Cape-to-City* because much of the habitat is cleared and unsuitable for indigenous biodiversity. Also, the perimeter of the *Cape-to-City* area (apart from the coast) is prone to immigrating predators, so highest priority should be given to monitoring within the core of the *Cape-to-City* area (i.e. excluding a buffer zone at least 1 km wide). High priority should also be given to monitoring fragmented habitats above a threshold area that is deemed suitable for species recovery. A second priority, if resources are available, is to monitor across the boundary of the C2C area and in small patches of fragmented habitat. Data from this second-order monitoring can be used to test assumptions about the spatial extent of biodiversity benefits from pest control, ultimately helping to build a picture of the connectivity of native biota across landscapes. Sites should therefore be selected strategically to show greatest potential for recovery and, if possible, to map the extent of recovery and connectivity by indigenous species.

We suggest the following steps for selecting sites:

- Map the full range of potential sites based on the above criteria.
- Avoid highly improved green pastures
- Categorise sites according to two broad habitat types: forest and open 'rough' short vegetation with some vertical structure (i.e. rank grass, interspersed scrub, rock, or complex litter layer).
- Select sites randomly from each habitat type, according to the minimum number required to detect a given level of change (see below).

- If it is not possible to monitor a particular site, choose a replacement site randomly.

This site selection process is not applicable to forest birds as there are so few forest fragments remaining in *Cape-to-City* that they all need to be used for monitoring.

3.4 Required number of monitoring sites

Another cornerstone of robust monitoring is having sufficient replication of monitoring sites to detect a given level of change. 'Sufficient' replication depends on two things: the inherent variability of the response variable between monitoring sites; and the magnitude of the response. High variability and a weak response require greater sampling intensity, compared with low variability and a strong response. We analysed the lizard and invertebrate data from Poutiri to quantify these two factors, and used them to model the number of sites required to detect given levels of change (see below). We recommend that these sampling intensities are followed for at least the first 1–2 years of the programme. Depending on the actual magnitude of biodiversity responses measured in *Cape-to-City*, it may be possible to modify the sampling intensity in later years; for example, if the response is dramatic (i.e. large increases in abundance of vulnerable indigenous species), the intensity of sampling could be reduced.

4 Methods for measuring predator responses to control

An immediate indicator of the efficacy of the pest control programme is its effects on pest numbers. Options suitable for measuring predator abundance are outlined below.

4.1 Trap-catch

Because kill-trapping will be the primary control tool in *Cape-to-City*, trap-catch rates will provide an abundant, cost-free, source of data on predator abundance. However, abundance indices that are not independent of the killing method need to be interpreted cautiously. For example, trap-catch measures only those animals captured, not those that refuse to enter traps. A measure of the un-trappable population is needed to infer trap efficacy. Landcare Research scientist, Dean Anderson, has developed a model that estimates residual population size using trap-catch data collected during control programmes (see Norbury & Anderson 2015). This model will be available for use for the *Cape-to-City* project in the near future. Perhaps the biggest problem with trap-catch data is that there is no equivalent in non-treatment areas. Notwithstanding these limitations, trap-catch data come at no extra cost or effort, so the important issue here is interpreting them in a sensible manner.

4.2 Camera traps

Camera traps provide an independent measurement of animal abundance, and show excellent potential for landscape-scale monitoring of pest populations (De Bondi et al. 2010; Bengsen et al. 2011, 2014). Trials undertaken at Poutiri have formed the basis of an optimised monitoring system for *Cape-to-City* (reported in Milestone 2.4 of the 2014/2015 contract with HBRC).

For *Cape-to-City*, occupancy rates of predators could be estimated simultaneously inside and outside the predator-removal area by distributing camera traps widely across the landscape. Occupancy is defined as the fraction of sampling locations within a landscape where a target species is present, and is commonly used in monitoring programmes as an alternative to estimating population size (MacKenzie et al. 2002). This would allow wide coverage of the study area using the 100 cameras available. Bias can be minimised by ensuring similar habitats are sampled in the predator-control and non-treatment areas. Given the number of camera traps available, precise occupancy estimates could be obtained with this approach (Mackenzie & Royle 2005). Predator occupancy could be obtained with only a single deployment of cameras, but the cameras should cover the whole area of interest. Cost could be minimised by placing cameras in areas with easy access.

Another, more intensive, approach is to measure changes in predator densities by concentrating a portion of cameras in grid formations within sections of the control zone as control is sequentially rolled out. This 'rolling grid front' approach would allow predator densities to be estimated within each control section before and after control is implemented, thereby providing a more accurate assessment of control efficacy. Camera trapping trials on Waitere Station in Hawke's Bay have shown that a grid of 40 cameras spaced 500 m apart can estimate feral cat numbers accurately and precisely, and can reliably detect a population reduction after intensive control. Predator populations could be monitored using two grids of 40 cameras, one on each side of the rolling front. This would provide a BACI (Before-After, Control-Impact) experimental design, referred to earlier. If predator control is effective, we would expect to see a reduction in predator numbers in the treated area after control, with no concurrent reduction in the non-treatment area. As the rolling front progresses, the non-treatment area would then become the predator-removal area, and a new camera grid would be established beyond the rolling front. This approach could be used in conjunction with a more widespread deployment of cameras to estimate occupancy at the landscape scale.

An added advantage of camera traps is that they detect a range of other species, including rabbits (Latham et al. 2012) and some native birds. A disadvantage is that every image must be scanned manually to detect presence of animals. This is time consuming. For example, 40 cameras deployed for 3 weeks can take about 3 days to scan. Software is being developed for automatic detection, but in the meantime, manual scanning is required.

For the purposes of using trap-catch and cameras for monitoring, it is important to record the types of lures that are used. Where possible, lures should be used consistently, and if a new lure is tested (e.g. predator odour) it needs to be run concurrently with the current 'standard' lure.

4.3 Track tunnels

Track tunnels also provide an independent measure of predator abundance (Gillies & Williams 2013), although they are not as sensitive as cameras for detecting predators. We recommend standard commercially-available tunnels for detecting rats, mustelids and hedgehogs. We do not recommend large tunnels for cats (Pickerell et al. 2014) as they are prone to damage and wind. Cats will be adequately monitored by cameras. The added advantage of tunnels is that they also detect lizards and invertebrates (see later). Track tunnels were used at Poutiri to monitor both predators and lizards. Five tunnels were spaced 100 m apart along 15 separate transects. While this appeared to be sufficient sampling to detect differences in interception rates of predators, we recommend greater transect numbers to detect lizards and invertebrates (see later).

Tunnels will be deployed for at least 3 weeks before they are monitored (Gillies & Williams 2013). During monitoring, tunnels will be baited with a peanut butter lure (for rodents, and perhaps invertebrates and lizards). Given that other predator species are likely to be more readily detected with cameras, it will save time to not also bait tunnels with a predator lure (although this is preferable).

4.4 Road-kill

Another index of predator abundance is the number of dead individuals along roads (Brockie et al. 2009). This method commonly detects possums, hedgehogs and rabbits. Counts could be undertaken annually along 260 km of rural road suggested in section 5.1.3 for monitoring gamebirds in both the *Cape-to-City* and non-treatment areas (see Map 1 for suggested routes). Surveys could be undertaken by designated volunteers at specific times.

5 Methods for measuring biodiversity responses to predator control

5.1 Birds

5.1.1 General overview

At first glance, birds appear to be one of the best biodiversity indicators within *Cape-to-City* because they are numerous, relatively easy to count, and often quick to respond numerically to any form of management which changes one or more of their demographic parameters. However, only about 15 (30%) of the 50 or so avian species currently living within or alongside the *Cape-to-City* area are limited by predators, and thus are potentially useful for detecting responses to top predator control.

The 15 potentially useful candidate species comprise three introduced species (mallard duck including mallard/grey hybrids, pheasants, Californian quail) and 12 native species (pāteke, whitehead, robin, tomtit, red-crowned kākāriki, kākā, bellbird, tui, kererū, bittern, dabchick, and New Zealand dotterel). In reality, the list is less than 15, because some species are not suitable for monitoring for various reasons. Three native species (kākā, bittern, and NZ dotterel) can be discarded immediately because they are too rare and infrequently encountered to detect changes in their abundance, even if they did respond significantly to top predator control. Another three native species (bellbird, tūī, kererū) can also be removed from the list because they are already responding significantly to region-wide possum control, which are likely to mask additional responses (if any) to top predator control. And finally, the three small native insectivores (whiteheads, tomtits, and robins) appear to be limited mainly by ship rats rather than by cats, possums, and mustelids, so may show no responses to top predator control unless, perhaps, if it is accompanied by rat control.

The three best candidates for monitoring are pāteke, dabchick and red-crowned kākāriki. All of these species have a threat status, are thought to be limited mainly by stoats, ferrets and cats, and are encountered sufficiently often to measure changes in abundance between sites and years. The next best candidates are mallards and game birds, though their population changes may be more difficult to interpret because they are harvested by hunters as well as by mammalian predators. Harriers also prey heavily on mallard ducklings in some years. Last on the list are the three small insectivores, but they are worthy of inclusion because of their potential use for documenting the outflow of threatened species from Cape Sanctuary, and their ability (or otherwise) to establish within *Cape-to-City*.

Mallard ducks, game birds, and dabchicks are already widespread in *Cape-to-City*. Their responses to top predator control can be determined by counting them in various places within *Cape-to-City*, and in a similar non-treatment area nearby (see below).

The remaining species (pāteke, whitehead, robin, tomtit, red-crowned kākāriki) are currently confined mainly to Cape Sanctuary but are beginning to spill out into neighbouring areas. They will be counted in Cape Sanctuary, *Cape-to-City*, and in a non-treatment area beyond *Cape-to-City*, using methods described below. In terms of experimental design, the geographical location of the non-treatment area is far from ideal, but there are no other options available (Map 2). Birds dispersing out of Cape Sanctuary first have to pass through *Cape-to-City* before reaching the non-treatment area, with inevitable attenuation along the way. Immigration rates into each area are therefore not going to be equal, perhaps making it impossible to evaluate whether top predator control increases rates of settlement and population establishment within *Cape-to-City*. The counts will show, however, whether species from Cape Sanctuary become more numerous in *Cape-to-City* over time, and whether any establishment occurs within the non-treatment area. Clearly, if some species do successfully establish and breed within *Cape-to-City*, subsequent population growth will result from both local recruitment and emigration from Cape Sanctuary, in unknown proportions.

In the second and third years of the programme, robins and tomtits from other parts of Hawke's Bay will be translocated to one patch of native forest (Mohi Bush) on the Maraetotara Plateau close to, but within, the southern boundary of *Cape-to-City*. If these transfers succeed, dispersers from Mohi Bush will eventually move into neighbouring bush patches and non-treatment forests beyond the Cape to City footprint, testing again whether top predator control facilitates the spread and establishment of small forest insectivores in agricultural habitats. In the third and fourth years of the programme, blue ducks (whio) will be translocated to the Maraetotara River, introducing another predation-sensitive species (see Whitehead et al. 2008) to *Cape-to-City*. This translocation will test whether *Cape-to-City's* predator control programme allows whio to successfully re-establish in a lowland stream. All translocated individuals will be radio-tagged so that their fates can be determined. Further details of the proposed whio monitoring programme are not included in this document.

5.1.2 Tomtits, robins, whiteheads and kākāriki in forest patches

A modified version of the 5-minute count technique (Dawson & Bull 1975) will be used to document the spread of small forest insectivores and kākāriki from Cape Sanctuary into the surrounding landscape. Five minute counts will be undertaken along fixed transect lines in patches of native and exotic forests in each of the three 'treatment' areas (Cape Sanctuary, *Cape-to-City* and non-treatment area, Map 2). Each transect line will have 5–20 counting stations at 100-m spacings, depending on patch size. Each transect line will be counted twice on each visit – odd-numbered counting stations on the way out, and even-numbered stations on the way back. The first set of counts on the outward journey will be conventional 5 minute counts at 200 m spacings, following the protocols of Dawson and Bull (1975). The counts on the return trip will also be 5 minute counts, but calls of robin, tomtit, whitehead, and kākāriki will be broadcast from time to time during each count to elicit responses from any nearby individuals that might have otherwise avoided detection. Broadcast calls are not a normal part of the 5-minute technique, but they are required here to increase detection rates of rare individuals.

Dawson and Bull (1975) provide a power analysis of the 5-minute count technique, based on the mean number of birds recorded per count. For rare species, with an average of 0.1 individuals per count, 125 counts are required in each of two samples (from different treatment areas or years) to detect a 78% difference between samples (i.e. differences smaller than 78% between the means of the two counts will not be statistically significant). Far more counts (1250) are required to detect a 25% difference. The equivalent figures for species with a mean of 1.0 individual per count are 125 counts to detect a 25% difference, and 1250 counts to detect an 8% difference.

The abundance figures given above are likely to span those encountered during this project. For example, the average number of tomtits per count in forest patches near Cape Sanctuary may increase tenfold from 0.1 to 1.0 over a 5-year period, but remain at zero, or close to it, in more distant forest patches in non-treatment sites.

The monitoring programme for tomtits, robins, whiteheads, and kākāriki has been designed to generate at least 125 counts each year from the three treatment areas (Cape Sanctuary, *Cape-to-City*, non-treatment area). Each sampling area will be counted four times a year (Table 1), twice during the forest bird breeding season (mainly to detect territorial insectivores) and twice at the end of the breeding season (when juveniles are dispersing out of natal areas). The locations of the sampling sites are shown in Map 2.

Table 1 Number of transects and counts for monitoring the spread and establishment of forest birds from Cape Sanctuary to Cape-to-City.

Cape Sanctuary	*Cape-to-City*	*Cape-to-City* Non-treatment
2 transects in exotic forests 2 transects in shrubland	6 transects in exotic forests 2 transects in native forests 1 transect in mixed habitat	3 transects in exotic forests 3 transects in native forest
Av. 10 sample sites per transect 4 counts per year = 4 x 10 x 4 = 160 counts per year	Av. 10 sample sites per transect 4 counts per year = 9 x 10 x 4 = 360 counts per year	Av. 10 sample sites per transect 4 counts per year = 6 x 10 x 4= 240 counts per year

5.1.3 Waterfowl, dabchicks and game birds

Counts of wetland birds are directed mainly at mallards, pāteke, and dabchicks, but will include all species visible in the counting sites, because most of them have to be examined anyway to determine if they are one of the target species. Pāteke are of special interest but are likely to be rare in most of the counting sites beyond Cape Sanctuary's boundaries. The waterfowl counting programme has been designed primarily with pāteke in mind (Table 2), guided by the power analysis of Dawson and Bull (1975). Sampling intensity is unnecessarily high for the common species, but it will enable small changes in their abundance (5–10%) to be detected from year to year or site to site.

Table 2 Number and type of survey sites for monitoring waterfowl and game bird abundance

Cape Sanctuary	*Cape-to-City*	*Cape-to-City* Non-treatment
10 wetlands	20 wetlands	20 wetlands
Approx. 20 km of farm roads	Approx. 120 km of country road	Approx. 120 km of country road

There are many ponds and wetlands throughout the three treatment areas, allowing a choice of sampling locations. Ponds and wetlands selected for the monitoring programme (Map 3) were chosen non-randomly, to give the greatest chance of detecting pāteke. Large ponds were selected ahead of small ponds, and large ponds with vegetated margins were selected ahead of large ponds with non-vegetated margins. The ponds will be counted four times a year (twice in spring and twice in autumn) by two people; one counting and the other walking the margins to flush ducks out of hiding.

Pheasants and Californian quail are locally abundant in all three treatment areas, supported in some places by landowners breeding them for release (pheasants only). Both species often feed along roads and perch on fence posts, especially early in the morning, and can be counted from a vehicle moving slowly along country roads (see Brockie et al. 2009). This is the technique that will be used in this programme, following the routes identified in Map 1. Approximately 20 km of farm track will be counted in Cape Sanctuary, and 120 km of country road in each of the *Cape-to-City* and non-treatment areas (Table 2). There will be four counts each year, involving two counts in spring and two in autumn. These sampling periods avoid the game bird hunting season, when both quail and pheasants are often more difficult to see.

Road kill, including live and dead harriers, will also be counted on the road transects to provide additional information on predator and pest abundance in and close to *Cape-to-City*.

5.2 Lizards

There are at least four characteristics of New Zealand lizards to consider when designing a lizard monitoring programme:

- Generally difficult to detect

- Detection is highly dependent on climatic conditions
- Patchy distribution
- Slow breeding

In most cases, high numbers of monitoring devices need to be deployed to detect lizards, and distributed across the entire survey area. Given the highly modified landscape in and around *Cape-to-City*, and the uncertainty of finding lizards, there is a risk that much of the data will be zeros. One way of improving sampling efficiency in this context is to combine random site selection (section 3.3) with a one-off widespread lizard survey, undertaken by distributing numerous single detection devices (we recommend track tunnels) in likely areas, and subsequently establishing the full repertoire of devices at sites where lizards were detected. Inclusion of a random selection of sites with zero detections is also necessary to satisfy randomization of sites, and for recording future colonization of vacant habitats.

Another efficient method is to target surveys where landholders and the public have seen lizards in the past. For example, spotted skinks and speckled skinks are known to occur along the coastal fringe of *Cape-to-City*.

The slow rate of increase of lizard populations means it is not always necessary to sample frequently throughout the year. Annual sampling may be sufficient to detect long-term change, but it needs to occur when lizards are most detectable – on mild sunny days, usually in early and late summer. Given the vagaries of day-to-day weather conditions, we suggest two lizard sampling sessions when it is not too hot or too cold, for example, one in November/December and one in March/April.

5.2.1 Artificial retreats

Artificial retreats are commonly used throughout New Zealand to monitor lizard abundance (Hoare et al. 2009; Thierry et al. 2009; Lettink et al. 2011). Retreats usually consist of three corrugated onduline stacked plates laid on the ground. Raukawa geckos and Northern grass skinks are the most common and widespread species in *Cape-to-City*. Artificial retreats are likely to detect them; however, at Poutiri they detected very few skinks, and no geckos. Some preliminary survey work is suggested to see whether the same occurs at *Cape-to-City*.

Artificial retreats need to be deployed for 1–3 months before monitoring begins to allow enough time for them to be colonised. Because they provide thermal refuge and shelter, they can potentially affect lizard breeding and survival in the long-term. Therefore, they are usually removed from the field in between monitoring periods to avoid these effects.

Artificial retreats should be deployed in open areas, such as rocky habitats (for geckos), rough grasslands, and along bush/forest margins. Underneath dark forest canopies should be avoided.

5.2.2 Track tunnels

The track tunnels used to monitor predator abundance (section 4.3) can also be used to monitor lizard abundance. Because individual lizard species cannot be reliably differentiated with foot prints, only 'skinks' and 'geckos' can be recorded. At Poutiri, five track tunnels were spaced 100 m apart along separate transects, and the proportion of lines intercepted by lizards was recorded, both in spring and summer. A power analysis of the summer data (i.e. when lizards were more detectable) showed that at least 50 transects are required to generate robust estimates of interception rates, indicated by a levelling out of the confidence intervals (Fig. 1). Therefore, up to 100 transects are recommended in total for the treatment and non-treatment areas (Table 3). Given the small home ranges of small common lizards, spacing between tunnels (and artificial retreats) could be reduced to a minimum of 20 m to achieve independence.

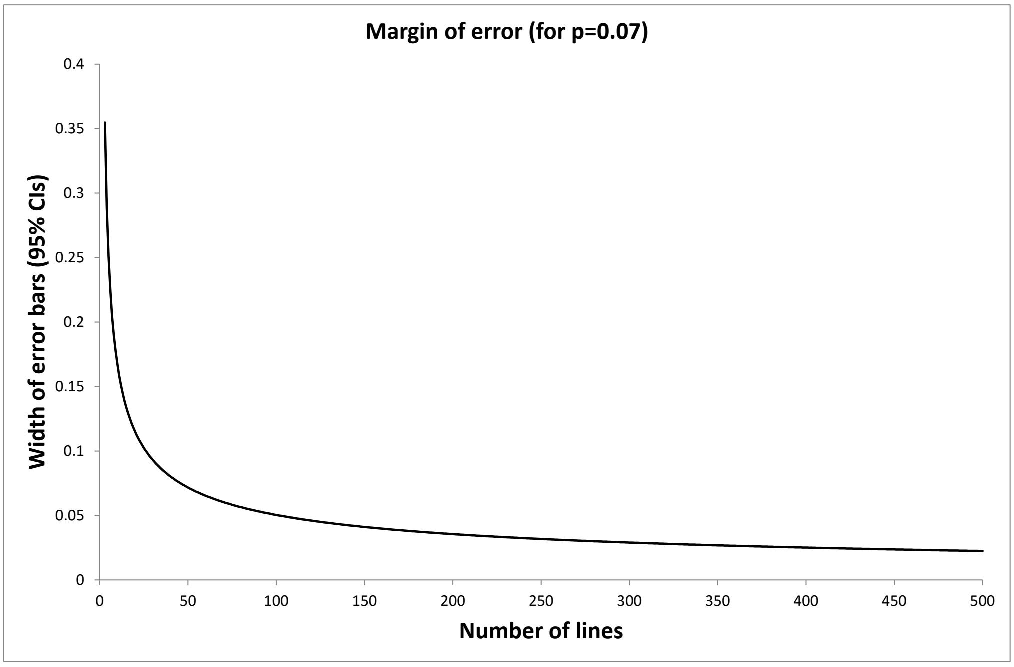

Figure 1 Width of 95% confidence intervals for proportion of transects intercepted by lizards, versus the number of transect lines. Calculated from summer data from Poutiri.

5.2.3 Tree wraps

Forest geckos are another species in the *Cape-to-City* area, but they are more difficult to find. Covering sections of tree trunks with closed cell matting can attract forest geckos, and has proven useful for surveys (Trent Bell, EcoGecko Consultants, pers. comm.). Weta and other invertebrates also inhabit tree wraps. We recommend their use in forest patches where rat control is proposed.

5.2.4 Other lizard detection methods

Green geckos can often be seen basking on bushes in the daytime, so it may be possible for people to search for them for fixed periods of time. However, searches need to be undertaken systematically (same observers, same time of day, same weather conditions) and by trained observers. Searches should focus on open shrub or forest edge habitat where geckos are more likely to bask.

Trained dogs are another option for detecting cryptic lizard species.

Targeted searches should be focused in areas where lizards have been seen in the past. Given the low encounter rates, it is preferable that sites are easy to access to minimise excessive travel for potentially little return.

Pitfall traps are a commonly-used method for capturing lizards. They usually consist of smooth-sided plastic beakers dug in at ground level, into which lizards drop and cannot escape. Because lizards must be released daily, it will not be practical to deploy pitfall traps across the treatment and non-treatment areas. Victoria University students monitor speckled skinks in Cape Sanctuary using pitfall traps, so some pitfall traps may be warranted in areas where speckled skinks are found (although artificial retreats may detect them adequately).

Another monitoring for detecting lizards is the minnow trap. These are small, one-way entry, cages that lie on the ground and capture live lizards. However, they also occasionally catch rodents and weasels, which eat any lizards that might also be present in the same trap. We therefore do not recommend their use for monitoring in *Cape-to-City*.

Lizards often use the refuge provided by boxes that house predator kill traps. Contractors should be encouraged to record the number of lizards seen on trapping devices.

Table 3 Number and type of survey sites for monitoring lizards. Surveys should be conducted in November/December and March/April

Cape-to-City	*Cape-to-City* Non-treatment
50 lines of **artificial retreats** in open areas (5 per line)	Up to 30 lines of **artificial retreats** in open areas (5 per line)
50 lines of **track tunnels** in open areas (5 per line, same lines as above)	Up to 30 lines of **track tunnels** in open areas (5 per line, same lines as above)
20 lines of **track tunnels** in forest patches proposed for rat control (5 per line)	20 lines of **track tunnels** in forest patches proposed for rat control (5 per line)
20 lines of **tree wraps** in forest patches proposed for rat control (5 per line, same lines as tunnels in forest patches)	20 lines of **tree wraps** in forest patches proposed for rat control (5 per line, same lines as tunnels in forest patches)

5.3 Invertebrates

Invertebrate communities are highly diverse and complex, and there are a myriad of ways of measuring them. Some strategic thinking is required about which components of the invertebrate fauna are indicative of predator impacts at *Cape-to-City*, otherwise invertebrate monitoring has the potential to absorb significant resources for little information on overall biodiversity outcomes of wide-scale predator control. Also, because many invertebrates are more likely to be vulnerable to rat predation, invertebrate sampling should be focussed on sites where rat control will take place (and in non-treatment sites with no rat control). Three simple methods for sampling invertebrate fauna on the ground, mid-canopy and canopy are outlined below.

As with lizards, we suggest two invertebrate sampling sessions in November/December and March/April.

5.3.1 Artificial retreats

Invertebrate data can be easily obtained from the artificial retreats set for lizards, either by recording the presence of broad invertebrate taxa (e.g. spiders, beetles, slaters, etc.), or counting the number of individuals. The latter is more time consuming, and the number of invertebrates in a sampling device at a given time is influenced by many factors other than predation. Nevertheless, invertebrate biomass is considered to be an indicative parameter of predator pressure on invertebrate communities, so counts may be necessary.

Another tool for monitoring ground invertebrates is wooden discs (Bowie & Frampton 2004). However, this requires deployment of an additional monitoring device, which may be beyond the budget of the project.

5.3.2 Track tunnels

The track tunnels used for monitoring lizards (section 5.2.2) can also be used to monitor ground weta (and perhaps other identifiable invertebrates).

5.3.3 Weta houses

Weta are considered to be good indicators of predation pressure, particularly by rodents (C. Watts, pers. comm.). Weta houses are a proven tool for monitoring their abundance (Trewick & Morgan-Richards 2000; Green 2005; Bleakley et al. 2006; Bowie et al. 2006).

Invertebrate data were collected at Poutiri in spring and summer from galleried weta houses. Two weta houses were located along the same transect lines used for the track tunnels, and the number of invertebrates counted in each. They showed small differences in mean counts between the predator treatment (mean no. per transect = 7.6) and non-treatment areas (mean = 5.6). A power analysis of the summer data (when invertebrates were more detectable) showed that the smaller the difference between treatments, the greater the number of transects required to detect those differences with sufficient statistical power (Fig. 2). For example, if a difference between treatments of only 2 invertebrates per line is considered enough to indicate a treatment effect, 50 lines in each treatment are required. But if a difference of just over 3 invertebrates per line is preferred, only 20 lines are required. We recommend 50 lines of 5 weta houses per line for the treatment area (Table 5).

Note that weta houses need to be deployed for a couple of months to allow them to be colonised.

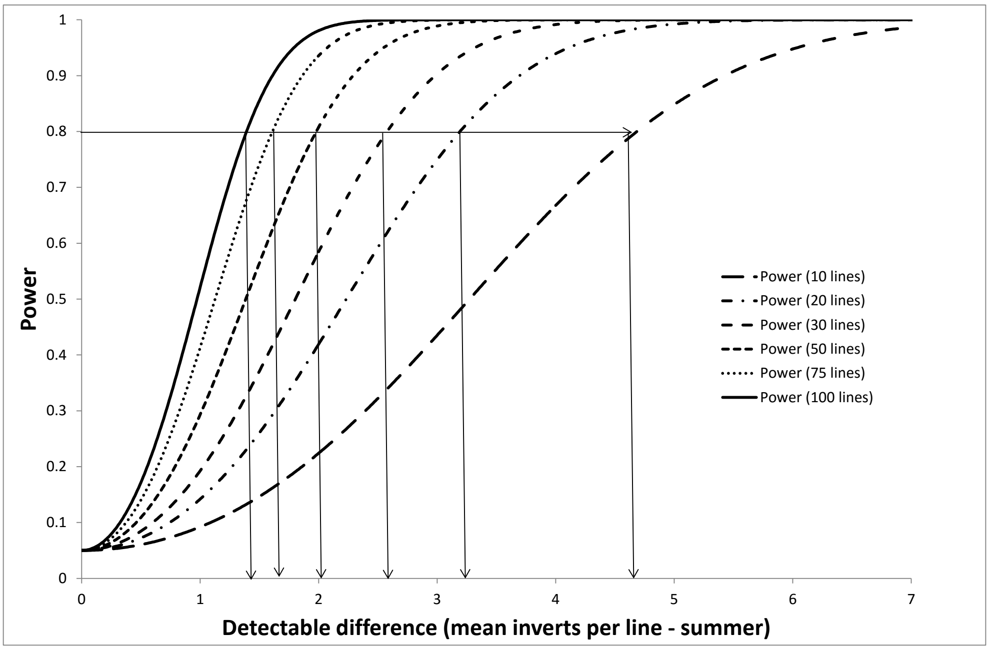

Figure 2 Relationship between the statistical power (conventionally set at 0.8) to detect a difference between treatments, the number of transect lines sampled, and the difference in invertebrate numbers between predator-treatment and non-treatment areas. If a difference between treatments of only 2 invertebrates per line, for example, is considered enough to indicate a treatment effect, 50 lines in each treatment are required. Calculated from summer data from Poutiri**.**

5.3.4 Canopy invertebrates

Canopy invertebrates, and their excreta (collectively termed 'frass'), can be collected in funnel-traps set underneath tree canopies, and counted at a later date (Morris 1949; Morris 1960; Mitzutani & Hijii 2001). The advantages of using frass are:

- Monitors invertebrates not accessible by the above methods
- Monitors abundance of tree seed and fruit that might be consumed by arboreal predators
- Population responses are more immediate (compared with the time taken for weta houses to be colonised)
- Funnel-traps are usually left out for several months and can integrate abundance over a season
- Simple and cheap method

Samples are frozen after collection, and air-dried before sorting. The disadvantage is that a significant amount of laboratory time is required to work through the samples. Sub-samples are usually taken, oven-dried and weighed (or counted, such as tree weta frass pellets). It can take 10–15 minutes for a trained person to check each sample.

The required number of samples has been calculated from frass data collected from the Tararua Ranges (Table 4). For example, 54 funnels are required to detect a doubling in biomass of stick insects. The number of funnels could probably be reduced if traps are placed under a single common tree species (e.g. kāmahi) because there is substantial variation between tree species. We recommend 50 lines of 2 funnels per line in the treatment area (Table 5).

This method has been used mainly in native forest, not in pine forest. Some testing of the method in pine forest is advisable as ship rats are likely to be controlled there.

Table 4 Estimated samples sizes required to detect changes in mean invertebrate frass and cockroach egg drop of 50 or 100%, for single-tray and three-tray sampling stations. Estimates are for frass extracted from trays placed against tree trunks (trunk trays). Peter Sweetapple (unpublished data).

Frass category	50% change in mean		100% change in mean	
	Single-tray samples	3-tray samples	Single-tray samples	3-tray samples
Mollusc (wt.)	88	60	31	22
Tree weta (no.)	54	26	19	9
Tree weta (wt.)	194	48	70	16
Stick Insect (wt.)	147	51	54	18
Cockroach eggs (no.)	17	15	6	6

Table 5 Number and type of survey sites for monitoring invertebrates. Surveys should be conducted in November/December and March/April

Cape-to-City	*Cape-to-City* Non-treatment
50 lines of **artificial retreats** (5 per line, same retreats as lizards)	Up to 30 lines of **artificial retreats** (5 per line, same retreats as lizards)
50 lines of **track tunnels** in open areas (5 per line, same tunnels as lizards) 20 lines of **track tunnels** in forest patches proposed for rat control (5 per line, same tunnels as lizards)	Up to 30 lines of **track tunnels** in open areas (5 per line, same tunnels as lizards) 20 lines of **track tunnels** in forest patches proposed for rat control (5 per line, same tunnels as lizards)
20 lines of **weta houses** in forest patches proposed for rat control (5 per line, same lines as tree wraps for lizards)	20 lines of **weta houses** in forest patches proposed for rat control (5 per line, same lines as tree wraps for lizards)
20 lines of **funnel traps** in forest patches proposed for rat control (2 per line, same lines as above)	20 lines of **funnel traps** in forest patches proposed for rat control (2 per line, same lines as above)

6 Using citizen science to measure responses to predator control

Citizen science is defined here as data collected by landowners and the wider community, rather than just scientists or professionals, using techniques that do not necessarily require training or expertise. It has been argued that citizen science has enormous potential to contribute to collaborative science projects throughout the world (Theobald et al. 2015). Some options are discussed below.

6.1 Opportunistic sightings of species

In its most basic form, citizen science can be used to gather information on the distribution of key species (e.g. Jackson et al. 2015) to document range expansion. Birds are a major focus of the *Cape-to-City* monitoring programme, so opportunistic sightings will add considerable value. In fact, it will be a vital part of documenting spill-over of bird species from Cape Sanctuary to *Cape-to-City*. Citizens and landowners living in or near *Cape-to-City* should be encouraged to report sightings of kākāriki and pāteke, thereby providing a second measure of their abundance. Over the next five years, kākāriki are likely to make increasing use of urban gardens, so citizen science counts of their abundance could be especially valuable.

There are a number of web-based data recording platforms for opportunistic sightings or for regular targeted field surveys (e.g. NatureWatchNZ; http://naturewatch.org.nz/). Birds have received much attention in New Zealand because of their high public profile, and because they are relatively easy to see and identify. A number of tools have been developed for capturing bird data. New Zealand eBird (http://ebird.org/content/newzealand/) is a web-based recording system specifically designed for birds, and has a double-checking system to mitigate identification errors. The Trustworthy Biodiversity Indicators project (https://www.landcareresearch.co.nz/science/plants-animals-fungi/animals/birds/biodiversity-measures) focuses on birds, using measures that people find useful and will trust.

An important way of maximising the quality of data gathered by citizens is to conduct regular education programmes on bird identification and recording systems. Phone apps are a useful resource for identification. If people register as observers, then 'push-prompts' can be sent at key periods of the year to encourage reports of sightings. Landcare Research recently developed an app for identifying Coprosma species (see http://www.landcareresearch.co.nz/resources/identification/plants/coprosma-key). Another good example of a phone app is MouseAlert (http://www.feralscan.org.au/mousealert/). MouseAlert provides farmers in Australia with a way of recording mouse activity, and for keeping a close eye on mouse populations in their local area. Data entered help predict mouse plagues, provide an early warning system, and help coordinate mouse control to reduce the damage they can cause.

A web presence for the Poutiri and *Cape-to-City* projects would be an efficient way of providing information on species identification (e.g. through a link to http://nzbirdsonline.org.nz/), events, and portals for reporting sightings.

It should be noted that the time and resources required to facilitate these citizen science initiatives, including curating data and managing the public's enthusiasm, should not be underestimated.

As public awareness and interest in biodiversity increases, bird sightings might increase without any real range expansion or increase in abundance. An equivalent citizen science programme is unlikely to run in a non-treatment area, so this potential artefact needs to be recognised when interpreting data.

6.2 Structured field surveys and community events

Targeted surveys are another form of citizen science. Once or twice per year, people could join forces to search for birds of interest to the *Cape-to-City* programme. Surveys could be run as community events, such as 'Bird ID' week (or weekend), or the number of ducks shot on opening day of the hunting season. The Alexandra Easter Bunny Hunt is an example of a community event that has provided 23 years of rabbit abundance data to measure the impacts of rabbit haemorrhagic disease (Rouco et al. 2014).

6.3 Questionnaires

Rather than relying on people's initiative to report sightings, the distribution of high profile and easily-recognised bird species, such as kākāriki and kākā, could be assessed through questionnaire surveys. For example, once per year, a postal questionnaire could be delivered to 100 or so urban and rural households, with significant gardens, scattered throughout *Cape-to-City*. Online surveys through social media are a preferable option.

6.4 Volunteer involvement in monitoring programs

Another form of citizen science is involvement of volunteers in more structured monitoring programs that are designed and supervised by trained people. For example, volunteers can help count the number of invertebrates (especially amateur entomologists), check track tunnels, or record the number of road-killed pest mammals. There are many opportunities for this form of citizen science, but again, the time and effort required to manage it should not be underestimated.

6.5 The 'science' of citizen science

The Biological Heritage Science Challenge is likely to include a component on citizen science. While the details of this work are yet to be developed, one of the questions is how citizen science measurements relate to more robust measurements gathered by trained people in a more rigorous fashion. *Cape-to-City* offers an opportunity to test this by coupling robust biodiversity measurements with citizen science data at a few sites. For example, the correlation between the citizen science measurements of pāteke abundance and the formal counts will be useful for testing whether the two programmes 'tell the same story'. Intensive surveys of uncommon lizard species could also be undertaken where citizens and landholders have observed them, and in likely habitats where no observations have been recorded. This would provide estimates of detection probabilities from citizens' observations.

7 Acknowledgements

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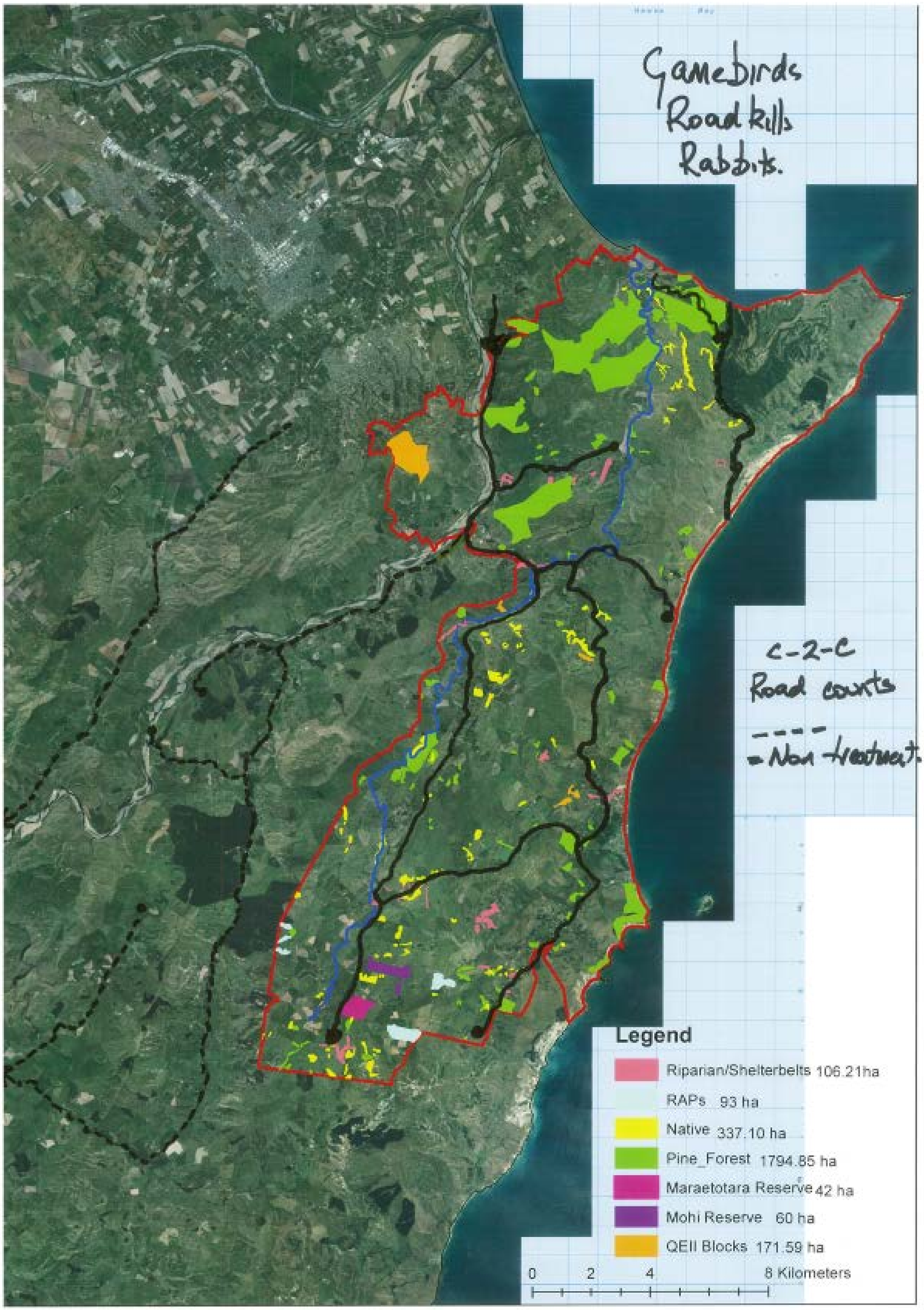
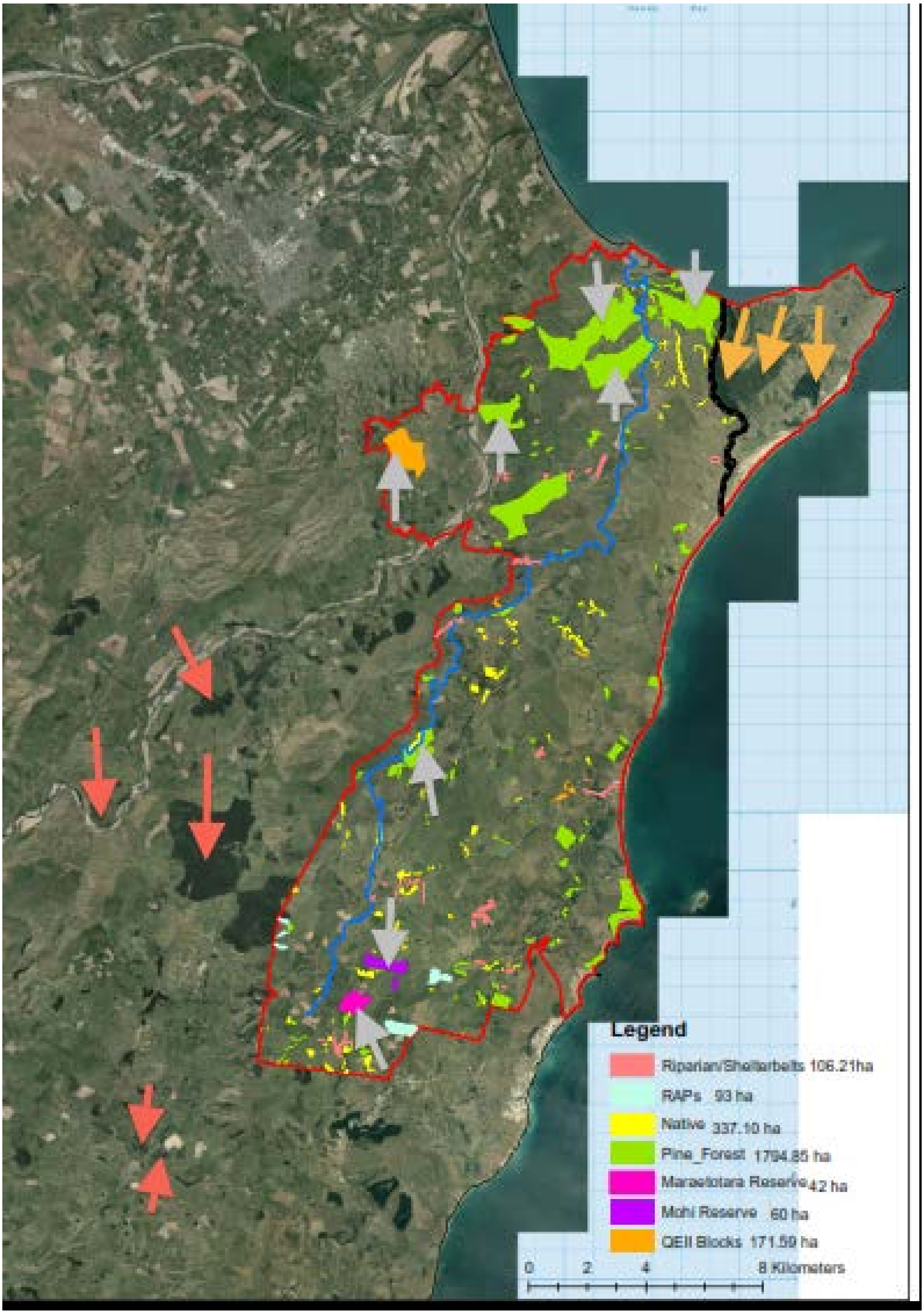
Map 1 Map of road transects for monitoring gamebirds and other species in the treatment (solid black lines inside red perimeter) and non-treatment areas (dashed black lines outside red perimeter).



Map 2 Forest patch locations for counts of tomtits, robins, whitehead and kākāriki. Orange arrows in Cape Sanctuary, grey arrows in treatment area (inside red perimeter), and pink arrows in non-treatment area (outside red perimeter).



Map 3 Locations of wetland counting sites in Cape Sanctuary, the treatment area inside the red perimeter, and the non-treatment area outside the red perimeter.