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Habitat availability for native New Zealand bird species within the Cape-to-City footprint: a preliminary assessment

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Summary

Project and client

Cape-to-City is a large-scale ecological restoration programme in a New Zealand pastoral landscape in the Hawke's Bay. The project targets predator species, specifically possums (*Trichosurus vulpecula*), cats (*Felis catus*) and mustelids − stoats (*Mustela ermine*), ferrets (*M. putorius*) and weasels (*M. nivalis*) − in a farmed area adjacent to the pest-fenced Cape Sanctuary. The vision of the Cape-to-City programme is that 'native species thrive where we live, work and play'. However, the restoration of native animals, including birds, will be limited by the shortage of suitable habitat as well as by the abundance of predatory mammals. Landcare Research was contracted by Hawke's Bay Regional Council to study habitat availability and connectedness in the Cape-to-City project area for native forest bird species.

Objectives

- To determine the amount of habitat for native forest bird species within the Cape-to-City footprint.
- To assess habitat quality and functional connectivity (species-specific connectivity) within the Cape-to-City footprint.
- To identify areas for increasing connectivity for native forest bird species within the Cape-to-City footprint.
- To characterise the habitat requirements, dispersal ability and predation vulnerability for bird species that are present within the Cape-to-City and Cape Sanctuary area, or that may be present in the future: these factors will influence the likelihood of these species successfully establishing.

Methods

- The New Zealand Land Cover Database version 4.1 (LCDB) was used to map and summarise the amount of habitat within the Cape-to-City footprint and Cape Sanctuary.
- Habitat quality and functional connectivity were assessed for three bird species representing a range of gap-crossing distances: North Island robin (hereafter robin, 110 m), tūī (20 km), and red-crowned kākāriki (hereafter kākāriki, 100 km). Functional connectivity was quantified using the Conefor software package.
- Bird habitat requirements, dispersal distances and predation vulnerability were tabulated, where known.

Results

- The Cape-to-City footprint and Cape Sanctuary together cover approximately 28,000 ha. Eighty-two percent of this area is in high- and low-production grassland.

Exotic forestry is the next most abundant land cover, comprising 7% of the area, and is most abundant in the northern portion of the footprint. Native forest covers less than 2% of the landscape, with the largest remnants found in the southern portion of the footprint.

- There is a relatively large amount of high-quality, but fragmented, habitat in the footprint for robins. However, robins have limited gap-crossing ability, and large distances between patches mean that robins are unable to use much of the potential habitat.
- Tūī and kākāriki are able to access habitat across the landscape but are likely to be limited by a lack of high-quality habitat.

Conclusions

- It will be very difficult to facilitate the spread of some forest-obligate species (such as robins) within the Cape-to-City footprint because they cannot disperse further than c. 110 m across non-forested habitat.
- Tūī and kākāriki can reach existing habitat patches but lack habitat, particularly high-quality habitat.
- Exotic forest plantations are a substantial portion of bird habitat in the footprint. If these forests were harvested at around the same time, this would greatly reduce total bird habitat and connectivity within the footprint.
- Given the extent of pasture within the footprint, native bird species that can use pasture as habitat should be considered in further research.
- All habitat quality assessments assumed predation had negligible effect on bird populations. This condition is unlikely to be met at present within the Cape-to-City footprint, and we have assumed a 'best-case' habitat scenario.

Recommendations

In light of the unsuitability of the pasture-dominated landscape for birds such as robins, and the importance of plantation forestry as habitat for some species, we make the following recommendations.

- Retain mature forestry plantations in the northern portion of the footprint, if possible, or at least stagger harvesting to retain some mature plantation forest over time.
- Encourage private landowners to increase seasonal food resources available to far-ranging species like tūī, bellbird and kākāriki through planting trees at all available sites across farms and around existing ponds (and households).
- Maximise the benefit of riparian plantings by selecting species that will provide food for native birds.
- Consider whether it is possible to facilitate the use of the Cape-to-City footprint by non-forest bird species, such as wetland birds, and birds that use pasture as habitat. Consideration of this possibility was outside the scope of this work.

1 Introduction

Forest bird populations in New Zealand are generally limited by predation from invasive species or by lack of habitat, and usually by some interaction between these two factors (Innes et al. 2010). The nature of this interaction for a given species in a given area will depend on the density of predators and the species' vulnerability to predation, and the quantity and quality of available habitat. Recent analysis suggests that in parts of New Zealand with substantially intact, large native forests, pest abundance has the greatest effect on native forest bird abundance, but that in deforested landscapes like Hawke's Bay, habitat area is the more important primary factor (Innes et al. 2010). Ruffell and Didham (2017) suggest that forest cover below 10% is strongly linked with lower native bird abundance, and Walker et al. (2017) found that forest bird species' richness is sensitive to forest cover reduction, even in heavily forested landscapes.

Bird abundance is also affected by fragmentation; that is, the division of continuous habitat areas into smaller, isolated remnants (Ewers & Didham 2006). In a fragmented landscape, birds that are capable of crossing only small areas of unsuitable habitat (e.g. pasture) may not be able to reach distant forest patches, reducing the amount of habitat available to them in the landscape. Species differ in their gap-crossing abilities and habitat preferences, which means a 'functional connectivity' approach is useful in considering habitat availability in a given landscape. Functional connectivity takes into account the amount of species-specific habitat and the species-specific effect of gaps between habitat areas (Tischendorf & Fahrig 2000).

The first steps towards an integrated landscape approach to species conservation require a stocktake of existing habitat and assessment of functional connectivity for species of interest. The analysis of functional connectivity in this report provides this assessment, but assumes that bird predators are controlled to a level at which they have no impact on birds. In the absence of effective predator control, increasing connectivity between source bird populations and other areas might create ecological 'traps' (Gates & Gysel 1978; Schlaepfer et al. 2002). Ecological traps are areas of low-quality habitat that animals prefer maladaptively. For example, birds with strong natal dispersal instincts may move away from predator-free areas into areas of high predator density (the 'traps'), in which they are likely to be killed.

2 Background

Cape-to-City is a large-scale restoration project in a New Zealand pastoral landscape (Figure 1). The project hopes to add to the restoration in the adjacent 2,500 ha Cape Sanctuary by targeting predators, specifically possums (*Trichosurus vulpecula*), cats (*Felis catus*) and mustelids − stoats (*Mustela ermine*), ferrets (*M. putorius*) and weasels (*M. nivalis*) − in the Cape-to-City footprint. Ship rats (*Rattus rattus*) are also being controlled in some forest fragments. Cape Sanctuary occupies a pest-fenced peninsula and contains c. 2,400 bait stations and 930 ground-based traps to kill pests that enter through or around the fence (McLennan 2013). Biodiversity is a key driver of the Cape-to-City management programme, alongside human health, and economic, social and cultural wellbeing.

While the vision of the Cape-to-City programme is that ‘native species thrive where we live, work and play’, the restoration of native animals (including birds) will be limited by the size and spatial arrangement of suitable habitat, as well as by predator abundance.

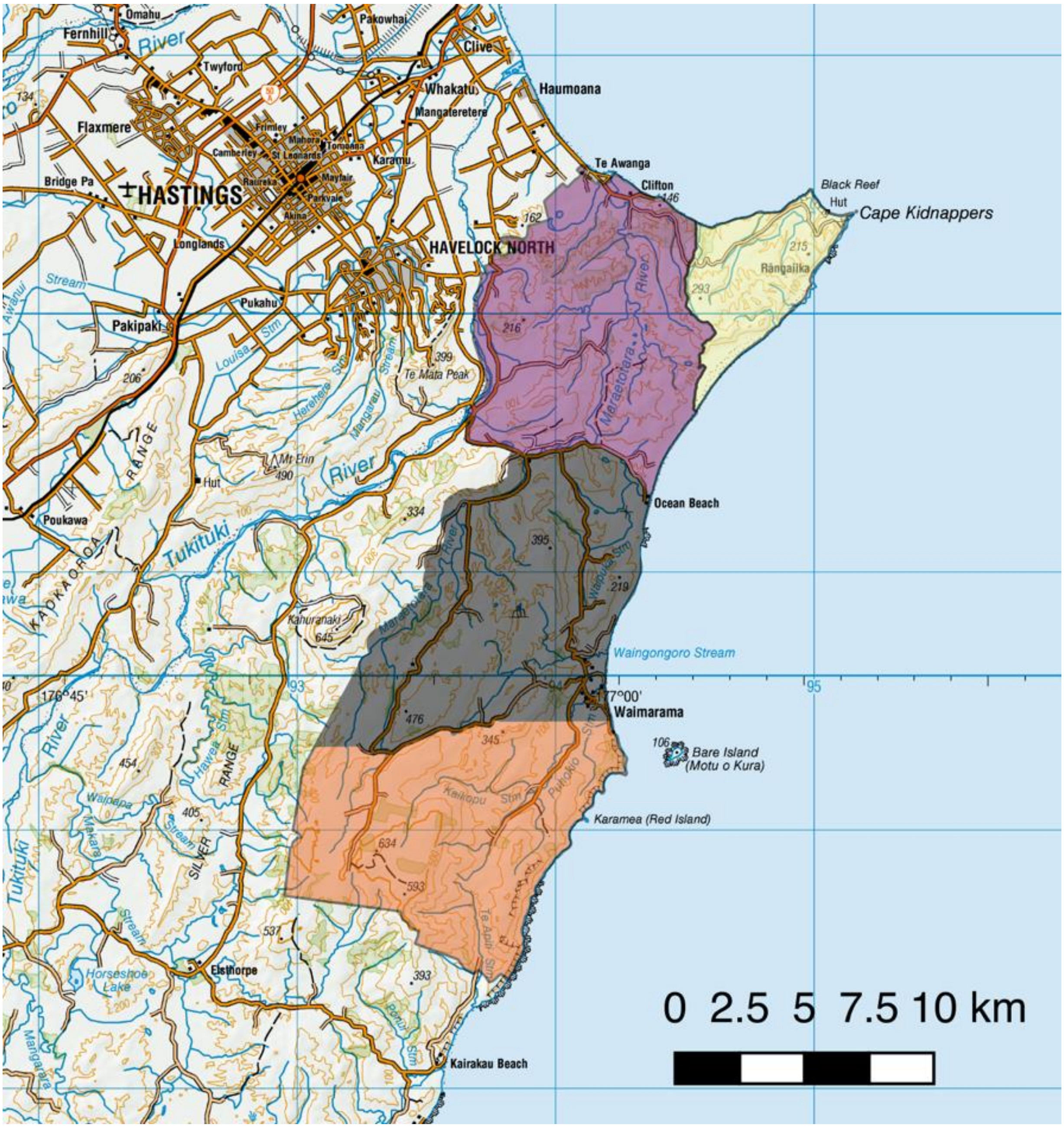

Figure 1 Cape-to-City and Cape Sanctuary footprint within the Hawke’s Bay region. The Cape-to-City footprint is divided into three areas (northern, central, and southern) as shown on other maps in this document. Cape Sanctuary occupies the eastern-most area shown in yellow.

This report summarises the amount of habitat available to native forest bird species and quantifies functional connectivity for three representative species, under the assumption that predators are controlled to levels that have negligible effects on bird populations. The final part of this report is a synthesis of existing information about which, and how much, vegetated habitat forest birds will use for feeding and breeding, and what predator control it may require.

3 Objectives

- To determine the amount of habitat for native forest bird species within the Cape-to-City footprint.
- To assess habitat quality and functional connectivity (species-specific connectivity) within the Cape-to-City footprint.
- To identify areas for increasing connectivity for native forest bird species within the Cape-to-City footprint.
- To characterise habitat requirements, dispersal ability and predation vulnerability for bird species that are present within the Cape-to-City and Cape Sanctuary area, or may be present in the future; these are factors that will influence the likelihood of these species successfully establishing.

4 Methods

Habitat area for the Cape-to-City footprint and Cape Sanctuary (when considered together, referred to hereafter as the 'cape area') was quantified using existing land cover mapping in the form of the New Zealand Land Cover Database 4.1 (LCDB; Landcare Research 2015). To assess functional connectivity, habitat quality was scored for each category of LCDB land cover for robins, tūī and kākāriki, and then specialised software Conefor was used to assess the connectivity of the cape area for each species. Conefor ranks each habitat patch in order of importance to landscape connectivity, for each species. Bird movement, habitat use and predation vulnerability data were compiled from literature and by contributed expert opinion.

4.1 Spatial data sources

Spatial files delineating the boundaries of the cape area were provided by Hawke's Bay Regional Council (HBRC). Minor editing was undertaken in ArcMap 10.2 to ensure the boundaries of the footprint and sanctuary were contiguous where they met. The footprint was split into three portions (northern, central, and southern) to indicate differences in habitat distribution through the footprint. The borders between the portions were digitised by eye in ArcMap 10.2 using both aerial imagery and topographic data and are for context only: they have no relationship to existing administrative boundaries. Habitat distribution was mapped. Areas of existing riparian plantings were provided as images by HBRC; these were digitised and overlaid on the LCDB data and classified as an extra 'riparian planting' habitat type. The total area of these plantings is small (33 ha).

4.2 Habitat quantity and quality

LCDB data for the cape area were extracted from the national data set. Statistics on habitat amount by LCDB category are provided in Appendix 1. Habitat quality was scored, using expert opinion, from 0 (habitat likely to be totally avoided by focal bird species) to 1 (best-quality habitat for species). Full habitat quality ratings for each LCDB category are provided in Appendix 2.

4.3 Bird movement

Thirteen species of native forest bird present in the Cape-to-City footprint were considered, as were four others (kākā, kākāriki, tīeke [North Island saddleback] and whitehead) that have been introduced to Cape Sanctuary and may disperse over the fence (Appendix 3). Brown and little spotted kiwi are already in Cape Sanctuary, but are most unlikely to exit the fenced area. However, they may be introduced separately to the Cape-to-City area and were therefore also included. The New Zealand falcon and long-tailed cuckoo are rare vagrants and were included because they may self-colonise in the future (McLennan 2017).

Information on (pasture) gap-crossing, natal dispersal and other seasonal movements of these 21 bird species is presented below and summarised in Appendix 3. Natal dispersal is 'the process through which immature individuals permanently depart their natal area in search of new sites' (Studds et al. 2008).

Movement estimates presented in Appendix 3 are mostly mean or representative figures from the available data; the intention in presenting them is to illustrate likely large differences between some taxa. Pasture-gap movement data are presented where they are available, and sea-crossing data if those are all that are available. 'Other seasonal movements' are sometimes territory diameter, and sometimes winter (non-breeding) movements if territories break down (e.g. tūī). They should generally be regarded as preliminary estimates, or perhaps as provocation for further research.

4.4 Functional connectivity

Three local bird species representative of short- (North Island robin) and far-ranging (tūī and kākāriki)[1] species were chosen to demonstrate a systematic framework under which species-specific functional connectivity can be assessed for the Cape-to-City project. All areas for which the habitat quality (see above) was zero were classified as *gaps*, commonly referred to as 'matrix', which birds had to cross to reach habitat *patches* (polygons with a non-zero habitat weighting). For patches, the quality-weighted habitat area was calculated as the product of a patch's area and its habitat quality (Minor & Urban 2007).

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[1] Scientific names of all birds are given in Appendix 3.

Conefor Sensinode 2.6 software (Conefor) was used to calculate three metrics: the likelihood of inter-patch connectivity, the metric of landscape-level connectivity, and patch importance for functional connectivity (Saura & Torné 2009). Methods of calculation for each metric are explained below.

The likelihood of inter-patch dispersal for a pair of patches *i* and *j* (p_{ij}) was calculated from the negative exponential distribution as a function of inter-patch Euclidian (or straight-line) distance (Urban & Keitt 2001):

$$p_{ij} = e^{-c \cdot d_{ij}}$$

where d_{ij} is the distance between patches *i* and *j*, and c is the constant set to make the function match the predicted maximum gap-crossing distance specified for each species. Euclidean distances between all patches were calculated in ArcMap.

The probability of connectivity index (PC) was used as the metric of landscape habitat connectivity (Saura & Pascual-Hortal 2007). The PC index is the probability that two individuals, placed randomly into a landscape, would be able to reach each other (given a set of *n* patches of habitat and the connections p_{ij} between the patches). The index is calculated as:

$$\mathrm{PC} = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} a_i a_j p_{ij}^*}{A_\mathrm{L}^2}$$

where *ai* and *aj* are the quality-weighted areas of patches i and j, and A_L is the total landscape area (including both habitat patches and matrix); p_{ij}^* is the maximum product probability[2] of all possible paths between patches i and j. Division by A_L^2 means PC is bounded between 0 and 1; thus values closer to 1 indicate greater functional connectivity (Saura & Rubio 2010).

Patches were ranked in terms of their importance for connectivity by calculating the change in the connectivity index (PC) resulting from the removal of each patch individually from the network:

$$\mathrm{dPC}_k = 100 \times \frac{PC - PC_{remove,k}}{PC}$$

where $\mathrm{dPC_k}$ is the importance of a patch to landscape connectivity, and PC is the connectivity index value in the original unmodified landscape, used here as a baseline value. $PC_{remove,k}$ is calculated by setting a_i (the patch attribute, here quality-weighted habitat

[2] The maximum product probability path may be direct movement between patches i and j, if close enough; otherwise the maximum probability path is the most likely path using 'stepping stone' patches.

area) to zero and setting p_{ij} to zero when $i = k$ or $j = k$. dPC_k is best considered as a relative index, as absolute values vary across landscapes (Saura & Rubio 2010).

4.5 Bird habitat use and predation vulnerability

Bird habitat usage can diverge when feeding and breeding behaviours are considered. Bird habitat usage was classified for each species, for each habitat type. Predation vulnerability was also classified for each species, for each habitat type.

LCDB categories were used as descriptors of bird habitat types because data on the LCDB classes are readily available and are the only source of information on habitat availability for the entire footprint. Thirteen classes of non-negligible cover were used, plus one further category (riparian plantings) that is not an LCDB cover class but is highly relevant in Hawke's Bay, given the riparian planting programme currently undertaken by HBRC (Pirie 2015).

These classes were further aggregated into seven ecologically relevant habitat types (native forest, exotic forest, exotic plantings, secondary nurse species [i.e. species under which natural forest regeneration is likely], riparian plantings, urban areas, and production grassland), which together cover more than 98% of the Cape-to-City and Cape Sanctuary land area. The LCDB classes and their equivalent aggregated classes are shown in Table 1.

Table 1 LCDB categories and aggregated categories that were used for analyses of bird habitat use. Information on bird habitat use, movements and predation vulnerability is presented in Appendix 3

LCDB	Aggregated
Broadleaved native hardwoods	Native forest
Indigenous forest	
Exotic forest	Exotic forest
Exotic forest harvested	
Deciduous hardwoods	Exotic plantings
Orchard, vineyard, crop	
Gorse and/or broom	Secondary nurse species
Mānuka and/or kānuka	
Matagouri or grey scrub	
Built-up area (settlement)	Urban areas
Urban parkland/open space	
High-producing grassland	Production grassland
Low-producing grassland	
NA	Riparian plantings

For each species, habitat types were classified as either 'preferred' (defined as the usual or main habitat used by the species in its natural range), 'occasional' (defined as used by some individuals at some stage of their year or life cycle), or 'avoided'. This was done for both feeding and breeding behaviours (Appendix 3). All classifications assume that no mammal predators are present, because our goal was to examine habitat factors independent of predation factors. The exception is dogs, which were assumed to remain because of their companion and work roles, but under control at all times, allowing both kiwi species to persist in urban and rural areas.

Predation vulnerability is classified separately as low, medium or high, based on existing knowledge of the extent to which each species has declined in response to predation and how much pest management is required for their persistence (Appendix 3). However, predation and habitat clearly interact strongly, and in many ways (Innes et al. 2010). For example, removing sufficient predators will reduce predation rates directly, but where the predator is an omnivore (such as ship rats and possums), removal will also increase habitat quality by reducing competition for food.

The classification also assumes that the area of habitat is not limiting, whereas in practice in the Cape-to-City footprint it often will be. Native forest was considered to be high-quality habitat, even though a very small patch may not be functionally useful for a bird species (Innes et al. 2010; Walker et al. 2017).

5 Results

5.1 Habitat area

The cape area (Cape-to-City footprint and Cape Sanctuary together) covers approximately 28,000 ha, 82% of which is in production grassland (Figure 2; see Appendix 1 for a detailed summary). Exotic forestry is the next most abundant land cover type, comprising 7% of the landscape, and is most abundant in the northern portion of the footprint. Native forest covers less than 2% of the landscape, with the largest remnants in the southern portion. There are several areas of 'nurse species' that might be expected to regenerate naturally to native forest outside of Cape Sanctuary. These areas − particularly if not removed, and if supplemented with initial plantings − could initiate a small amount of native regeneration to forest in the northern portion of the footprint.

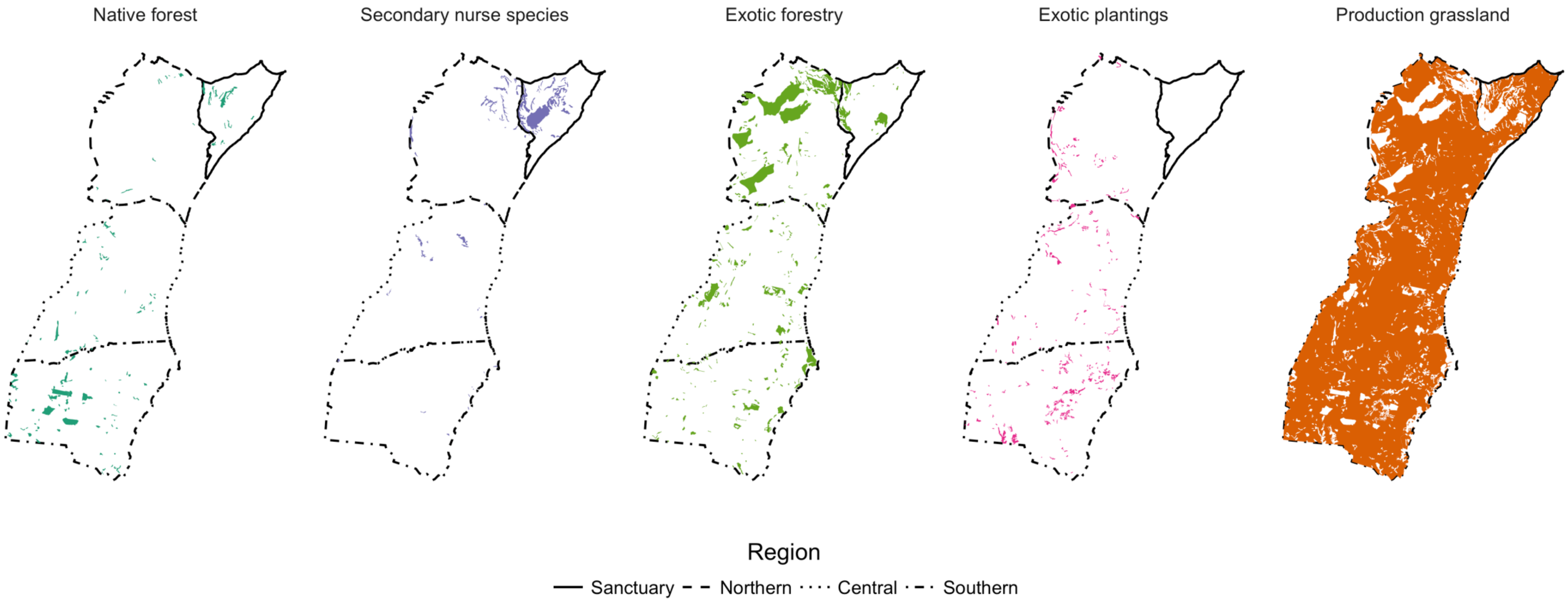

Figure 2 Habitat available in the cape area. 'Native forest' includes the LCDB categories broadleaved indigenous hardwoods, and indigenous forest. 'Secondary nurse species' includes gorse and/or broom, and mānuka and/or kānuka. 'Exotic forestry' includes forest – harvested, and exotic forest. 'Exotic plantings' includes orchard, vineyard or other perennial crop, and deciduous hardwoods. 'Production grassland' includes high-producing exotic grassland, low-producing grassland, and short-rotation cropland.

5.2 Bird movement

There is remarkably little reliable information on nearly all bird species' movements in New Zealand, simply because it is difficult, time consuming and expensive to obtain, and is likely to be highly variable between individuals and situations. In the species descriptions below, *n* refers to the size of the sample used to derive the estimated value.

Bellbird

Bellbirds are strong dispersers; for example, recolonising Tāwharanui Sanctuary north of Auckland over 20 km of ocean from Hauturu / Little Barrier Island within a year of mammal eradication at Tāwharanui (Brunton et al. 2008), and showing no genetic differentiation across Cook Strait (22 km; Baillie et al. 2014). Most dispersal movement is possibly made by juveniles (Baillie et al. 2014), so can reasonably be seen as natal dispersal. Although bellbirds are normally non-migratory, they may forage tens of kilometres from their breeding sites, especially in winter (Baillie et al. 2014).

Brown kiwi

North Island brown kiwi routinely inhabit and move across rough pasture, especially in Northland, where forest fragments are numerous. In one Northland radio-tracking study, 83% of 23 monitored kiwi used forest remnants scattered over farmland. The maximum distance walked by kiwi between forest remnants was 330 m, but movements up to 1.2 km were made using remnants as stepping stones (Potter 1990). Juveniles disperse up to 22 km, and territories are 5–80 ha (therefore 260–1,000 m diameter, if the home range is circular), depending on density (Miles et al. 1997; Basse & McLennan 2003; Robertson 2013).

Fantail

Movements of fantails are little studied. One banded individual crossed 150 m between islands in the Noises, Hauraki Gulf, and territories on Cuvier Island were at least 100 m across. Fantails are regarded as migratory in Australia but generally not in New Zealand (Higgins et al. 2006). Natal dispersal distances are unknown.

Grey warbler

At Kōwhai Bush, Kaikōura, mean territory size was 0.68 ha (*n* = 34; 100 m diameter if circular) and mean natal dispersal was 0.9 km (*n* = 17; Gill 1982). Ability to cross pasture gaps is unknown.

Harrier

Harriers are known to cross Cook Strait (22 km). Juveniles ‘may travel 100 km or more from natal territories’, and one banded adult travelled 740 km (Marchant & Higgins 1993). They can therefore can be regarded as highly dispersive at Cape-to-City.

Hihi

At Maungatautari and Ark in the Park, hihi crossed pasture gaps of 100 m (Kate Richardson, Massey University, pers. comm.), but at Bushy Park near Whanganui, 300 m was enough to stop them leaving; this implies the maximum pasture gap would be between 100 and 300m. Mean natal dispersal at Maungatautari was 1.75 km for males and 0.88 km for females (Richardson et al. 2017). Hihi ‘range all over’ 135 ha Mokoia Island (1,100 m diameter if circular; Higgins et al. 2001), but Maungatautari hihi nests were 200–400 m apart (Kate Richardson, Massey University, pers. comm.).

Kākā

Juveniles from Hauturu / Little Barrier Island travel 20–25 km (with one recorded at c. 400 km) to the North Island mainland and to Aotea / Great Barrier Island, all over water (Higgins 1999). Kākā leave Aotea in winter when food is limited and can travel over 100 km to Northland, Auckland and Coromandel (M. Rayner, Auckland War Memorial Museum, pers. comm.).

Kererū

Kererū ranged up to 102 km when followed via satellite tags near Invercargill, and some crossed Foveaux Strait (33 km) to Rakiura / Stewart Island (Powlesland et al. 2011). However, their natal dispersal distances are unknown.

Kingfisher

Sea- and pasture-crossing distances are unknown but may be large, given that the species is regarded as partly migratory in both Australia and New Zealand. Kingfishers around Wellington moved c. 2 km in their foraging range (Higgins 1999).

Little spotted kiwi

‘Adults probably occupy the same 2–3 ha territory throughout their lives’ (Marchant & Higgins 1990). Natal dispersal and gap-crossing distances are unknown.

Long-tailed cuckoo

This species breeds only in New Zealand but overwinters c. 8,000 km away on Pacific islands from Micronesia to French Polynesia, clearly a flight mostly over water. The fact that long-tailed cuckoos have not colonised sites such as Tiritiri Matangi Island, to which whiteheads have been successfully translocated, suggests that immature cuckoos 'disperse' to the near vicinity of where they were raised (Gill 2013). However, this has not been verified.

New Zealand falcon

New Zealand falcon habitat includes 'roughly grazed hill country' (Seaton & Hyde 2013). In exotic forest, mean natal dispersal was 9.6 km (*n* = 19) and mean home range size 6–9 km^2 (*n* = 13, equivalent to a diameter of 2.8–3.4 km if assumed to be circular; Seaton 2007). A single female, satellite-tracked over 3 years in central North Island exotic forest and farmland, had a home range c. 19 km long and more than 200 km^2, and occasionally moved more than 130 km before returning within 24 h (Holland & McCutcheon 2007).

North Island robin

North Island robins prefer to disperse in woody vegetation and are unlikely to cross gaps between forest cover of greater than 110 m (Richard & Armstrong 2010). Juvenile robins dispersed up to 20 km in the King Country (Richard & Armstrong 2010) and offspring of translocated robins dispersing from Wenderholm Regional Park established two populations 15 km away (Richardson et al. 2015). Robin territories were 1–5 ha at Kōwhai Bush, Kaikōura, but 0.2–0.6 ha in dense island populations (Higgins & Peter 2002). That is, territories are c. 200 m in diameter (if assumed to be circular) and 2 ha in area.

North Island tīeke

Tīeke/saddlebacks have not crossed the 90 m gap from Bushy Park reserve to adjacent forest (Peter Frost, Whanganui volunteer at Bushy Park, pers. comm.), but they did fly 250 m from Lady Alice Island to Middle Stack (Newman 1980). On Kapiti Island, one locally bred juvenile dispersed up to 3 km, but eight of nine settled within 1 km of the core area of their natal territories. Territory size varies with density, from 0.03 to 4 ha (Higgins et al. 2006).

Red-crowned kākāriki

Red-crowned kākāriki are capable of crossing open ocean in excess of 100 km (Greene 2013), although Luis Ortiz-Catedral (Massey University, Albany, Auckland, pers. comm.) suggests that over land they 'seem to like dropping into cover if [avian] predators are near'. A red-crowned kākāriki translocated to Motuihe Island from Hauturu returned (homed) to Hauturu 65 km away within 50 days (Ortiz-Catedral 2010), and others were reported in Torbay and Glenfield, Auckland, 20–25 km from Tiritiri Matangi Island (Spurr 2012).

Rifleman

At Kōwhai Bush, Kaikōura, five subadults that dispersed between study areas crossed at least 300 m of pasture containing small copses of native forest; maximum dispersal was 1.7

km, and adult territories reported at various locations were 0.5–2 ha (typical movement 150 m; Higgins et al. 2001).

Shining cuckoo

Shining cuckoo breed in New Zealand but overwinter in the Bismarck Archipelago (New Guinea) and Solomon Islands (Higgins 1999). Natal dispersal distance is unknown.

Silvereye

Silvereye colonised New Zealand late in the 19th century from Australia and so are clearly capable of crossing large habitat gaps, but there is no information available about their pasture-gap crossing. Foraging territories are 50–300 m diameter, and in one Australian study (Heron Island) mean natal dispersal distance was 160 m (Higgins et al. 2006).

Tomtit

A tomtit reached Rangitoto Island 3.5 km offshore, and another reached Tiritiri Matangi Island (3 km offshore; Anderson 2003). Natal dispersal distance is unknown, but the tomtit that reached Rangitoto Island was probably from the Hunua or Waitakere Ranges 30 km away, showing ability to disperse widely. Mean territory size in the Orongorongo Valley was 5.7 ha (n = 5; Brockie 1992) and elsewhere 1.2–4 ha (Higgins & Peter 2002).

Tūī

Tūī established by dispersal in Seatoun, Wellington, 8 km from a source population in the Karori/Zealandia wildlife sanctuary (Bell 2008) and at least 10 km from bush fragments surrounding Hamilton to Hamilton city itself (Fitzgerald et al. 2017), although natal dispersal distances estimated from banding young were up to 1.5 km in Auckland (Bergquist 1985). Tūī routinely move c. 20 km in the winter when not breeding, including across pasture (Fitzgerald et al. 2017).

Whitehead

Whiteheads may cross pasture gaps of up to 100 m (Kevin Parker, Massey University, Albany, Auckland, pers. comm.). On Hauturu / Little Barrier Island most young remained within 350 m of their natal site, with the maximum natal dispersal movement being 650 m; some home ranges were 7 ha (diameter 300 m; Higgins & Peter 2002). Winter flock movements may be much larger.

5.3 Functional connectivity

Functional connectivity within the cape area was assessed for three representative species: robin, tūī and kākāriki. For all three species most of the highest-value habitat was in the southern portion of the footprint (Figure 3). Robins had the largest areas of medium- to high-quality habitat due to their use of exotic forests, which are abundant in the northern portion of the footprint. Tūī had slightly more habitat than robins because, unlike the latter, they use exotic plantings and urban areas (Appendix 2). Kākāriki had the least habitat within the Cape-to-City footprint, but it was primarily of high quality (Figure 3).

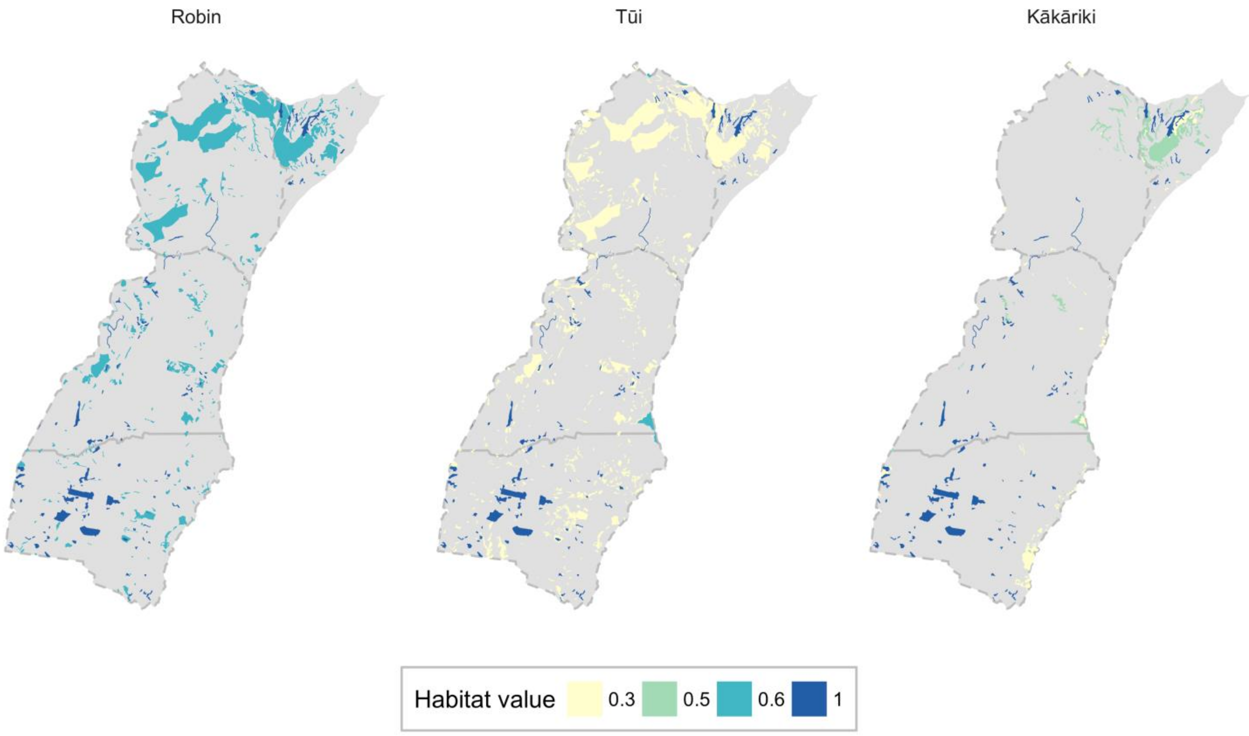

Figure 3 Habitat quality according to LCDB category weighting (see Appendix 2 for full weightings); grey indicates non-habitat (areas with a habitat quality of zero). Habitat quality of 1 indicates the most-preferred habitat.

Robins are limited by a gap-crossing distance of 110 m, which means the majority of the suitable habitat in the cape area will be inaccessible to a robin in any given habitat patch because they are unable to cross the pasture that surrounds it. Of the 10 most important patches for connectivity for robins, all were located in the northern portion of the cape area (Figure 4) and were primarily exotic forest.

Tūī can cross gaps of 20 km and kākāriki of 100 km, which means these species are less limited by gaps between habitat patches than robins. Outside of Cape Sanctuary most of the important areas for functional connectivity for kākāriki were in the southern portion of the footprint; in the northern portion the most important area was a stretch of riparian planting. Functional connectivity within the overall cape area was highest for tūī; even so, the dearth of native forest within the Cape-to-City footprint meant that most of the most important habitat patches for functional connectivity were exotic forest in the northern portion of the footprint (Figure 4).

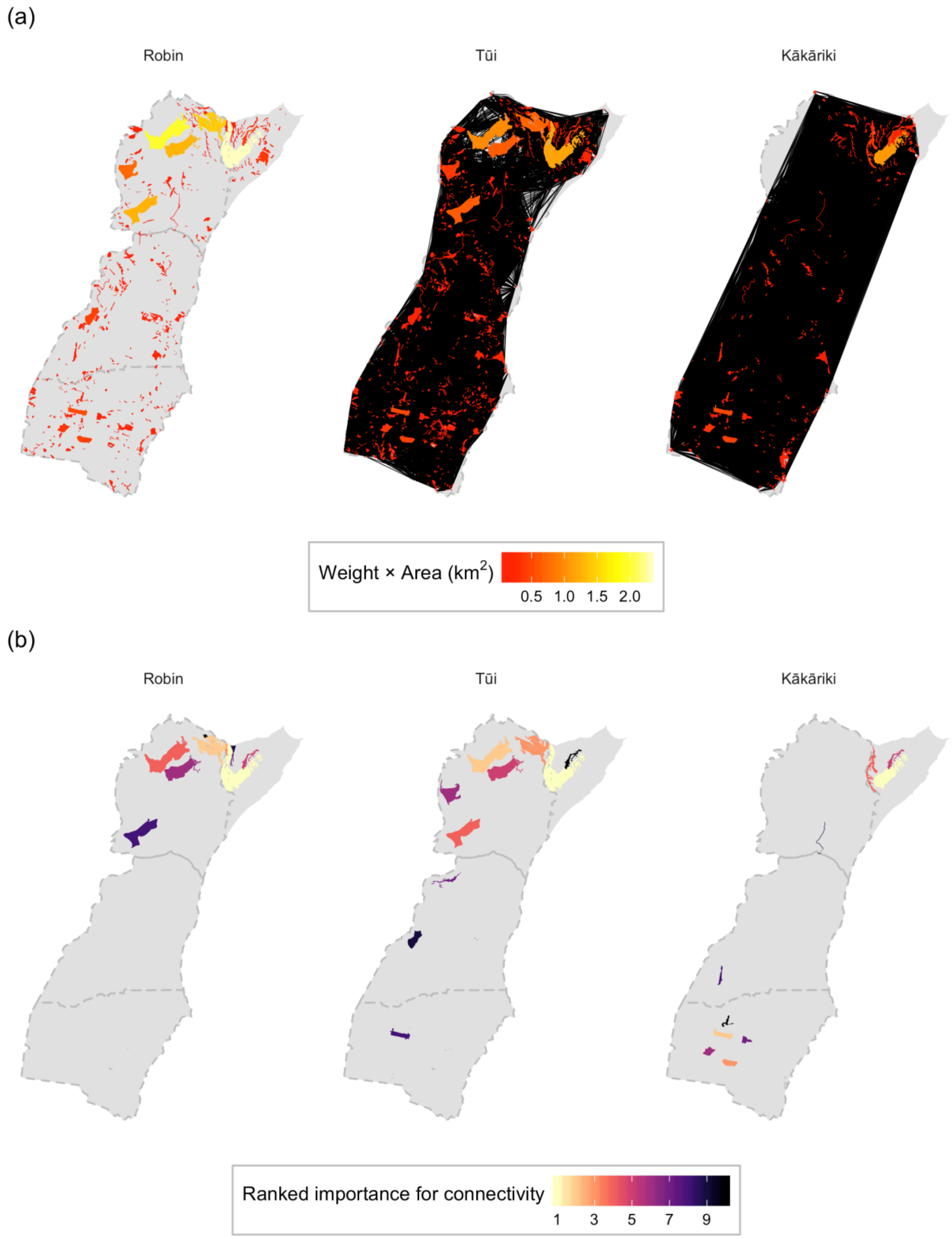

Figure 4 (a) Quality-weighted habitat area for each patch, for each species. Connected patches (where the likelihood of connectivity is greater than 50%) are shown as linked by a black line. In the case of tūī and kākāriki, the lines appear as a near-solid mass, such is their abundance. (b) The 10 most critical areas for functional connectivity are shown, for each species, coloured by their ranked importance (1 being most important).

6 Discussion and conclusions

6.1 Increasing bird habitat

It will be very difficult to facilitate the spread of forest-obligate species such as robins within the Cape-to-City footprint without transforming the landscape from predominantly pasture to predominantly forest. In terms of the objective of identifying areas for increased connectivity, far-ranging bird species will be able to reach almost all existing habitat patches, but for species like kākāriki, the amount of habitat is limited, and for tūī, high-quality habitat is limited.

The current 2% total of native forest cover in the cape area is likely to be inadequate for supporting gains in forest bird abundance that would otherwise be predicted from sustained predator control, because it is less than the 5–10% minimum estimated by Ruffell and Didham (2017). If current exotic forestry plantations were harvested completely, this would vastly reduce both total bird habitat and functional connectivity within the footprint for species that use exotic forest. The consequences of losing mature exotic forestry will be substantial for species such as robin and tūī. For these species, the large, mature exotic forestry plantations in the northern portion of the footprint are amongst the most critical areas for functional connectivity.

The identification of a riparian planted area as an important patch for functional connectivity for kākāriki indicates the potential worth of riparian plantings for this species, assuming riparian planted areas can reach the same habitat value as native forest areas (as assumed in the modelling).

Rather than embarking on the slow, difficult and expensive task of restoring native forest in pastoral sites, we suggest that management effort focus on:

- planting food trees at points throughout the wider landscape (including in riparian plantings) for mobile birds like tūī, bellbirds and kererū
- helping birds such as pipits (*Anthus novaeseelandiae*) that use rough pasture that is already in good supply
- wetland improvement or creation to support wetland birds
- retaining some current exotic forests as wildlife habitat rather than clearing them entirely for harvest (as discussed above).

6.2 Interactions with predation

All our habitat quality assessments assumed predation had negligible effect on bird populations. This condition is unlikely to be met at present within the Cape-to-City footprint and therefore is a 'best-case' habitat scenario. Most birds that are currently widespread in the Cape-to-City footprint have low predation vulnerability and prefer or occasionally use a broad range of habitats (Appendix 3). Conversely, birds with high predation vulnerability (Appendix 3) have narrower habitat tolerances.

Restoring the most charismatic bird species such as hihi, tīeke and kākāriki will therefore require both near-zero predator abundance and additional habitat restoration. Predator density threshold and bird habitat use data from the Cape Sanctuary can be used to inform the Cape-to-City project about what the management targets should be. Given that achieving zero predators in unfenced landscapes is currently unachievable, we suggest that the emphasis in the Cape-to-City project in the next decade be on the 10 forest bird species in Appendix 3 with medium vulnerability to predators, or on non-forest birds such as pipits, weka (*Gallirallus australis*) or pāteke (*Anas chlorotis*) that persist with low or no management elsewhere in New Zealand.

6.3 Bird movements

This report has highlighted that good data about bird movements of various kinds – especially pasture gap-crossing for forest birds and natal dispersal for all species – are rare, and are a clear priority for increased research effort as restoration projects become more ambitious in New Zealand. The strengths and limitations of available techniques of 'direct' (e.g. bird banding, radio transmitters) and 'intrinsic' (e.g. genetic markers, stable isotope ratios) bird markers to verify movement are presented by Coiffat et al. (2009) and Griesser et al. (2014).

The data presented in Appendix 3 are in many ways preliminary, but are, so far as is known, the first compilation of such data attempted for any New Zealand birds. The results emphasise the enormous differences between taxa in terms of how mobile they are, especially in fragmented landscapes. There are several small, insectivorous, obligate forest birds, including the rifleman, robin, tīeke and whitehead, that are known to be unable to cross pasture gaps larger than 250 m. This poor ability may be advantageous if it prevents translocated or dispersing individuals from leaving small habitat refuges and entering habitat 'traps' outside pest-controlled areas, or disadvantageous if it prevents populations expanding into adjacent excellent habitat. On the other hand, some mobile frugivores – especially bellbirds, tūī and kererū – can range tens of kilometres across pasture and so will visit single or clustered food trees if these can be planted in private and public gardens, amenity parks, in riparian or roadside reserves, and on farms.

7 Recommendations

In light of the unsuitability of the pasture-dominated landscape for birds such as robins, and the importance of plantation forestry as habitat for some species, we make the following recommendations.

- Retain mature forestry plantations in the northern portion of the footprint, if possible, or at least stagger harvesting to retain some mature plantation forest over time.
- Encourage private landowners to increase seasonal food resources available to far-ranging species like tūī, bellbird and kākāriki, through planting trees across farms, or around existing ponds (and households).

- Maximise the benefit of riparian plantings by selecting species that will provide food for native birds.
- Consider whether it is possible to facilitate the use of the Cape-to-City footprint by non-forest bird species, such as wetland birds and birds that use pasture as habitat. Consideration of this possibility was outside the scope of this work.

8 Acknowledgements

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Appendix 1 – Habitat cover within Cape Sanctuary and the Cape-to-City footprint: detailed summary

Table A1 Habitat cover (ha) within the cape area (Cape-to-City footprint and Cape Sanctuary)

LCDB classification	Total area	Mean area	N polygons	% cover
High producing exotic grassland	23,173.3	772.4	30	83.0
Exotic forest	2,057.0	7.6	272	7.4
Mānuka and/or kānuka	528.8	8.8	60	1.9
Deciduous hardwoods	502.7	2.4	213	1.8
Sand or gravel	381.7	7.1	54	1.4
Indigenous forest	353.3	5.1	70	1.3
Low producing grassland	222.6	6.6	34	0.8
Broadleaved indigenous hardwoods	176.2	3.8	47	0.6
Forest − harvested	107.4	10.7	10	0.4
Short-rotation cropland	71.1	14.2	5	0.3
Matagouri or grey scrub	63.4	1.9	33	0.2
Lake or pond	47.5	0.8	61	0.2
Gorse and/or broom	45.4	3.8	12	0.2
Mixed exotic shrubland	45.4	1.7	26	0.2
River	42.3	10.6	4	0.2
Built-up area (settlement)	36.8	6.1	6	0.1
Gravel or rock	24.4	3.5	7	0.1
Urban parkland/open space	17.4	4.4	4	0.1
Orchard, vineyard or other perennial crop	12.9	2.6	5	0.0
Herbaceous freshwater vegetation	11.4	3.8	3	0.0
Landslide	6.4	1.6	4	0.0
Fernland	5.3	1.8	3	0.0
Surface mine or dump	1.0	1.0	1	0.0
Total within cape area	**27,933.5**		**964**	**100.0**

Appendix 2 – Habitat quality rating by habitat type for robin, tūī and kākāriki

Table A2 Habitat quality rating (ranging from 0 to 1) for tūī, robin and kākāriki for each LCDB category present in the Cape-to-City footprint

LCDB classification	Tūī	Robin	Kākāriki
Exotic forest	0.3	0.6	0
Forest – harvested	0	0	0
Deciduous hardwoods	0.3	0	0
Orchard, vineyard or other perennial crop	0.3	0	0
Broadleaved indigenous hardwoods	1	1	1
Indigenous forest	1	1	1
Gorse and/or broom	0	0	0
Mānuka and/or kānuka	0.3	0.6	0.5
Matagouri or grey scrub	0	0	0
Built-up area (settlement)	0.6	0	0.5
Urban parkland/open space	0.6	0	0.3
Fernland	0	0	0
Gravel or rock	0	0	0
Herbaceous freshwater vegetation	0	0	0
High producing exotic grassland	0	0	0
Lake or pond	0	0	0
Landslide	0	0	0
Low producing grassland	0	0	0.3
Mixed exotic shrubland	0	0	0.3
River	0	0	0
Sand or gravel	0	0	0
Short-rotation cropland	0	0	0
Surface mine or dump	0	0	0
Riparian planting	1	1	1

Appendix 3 – Native forest bird movements, habitat use and predation vulnerability

Table A3 Movement distances for native bird species currently present, or having a realistic possibility of being present in the future, in the cape area. Dispersal distances are mostly means or representative figures from available data, and generally do not include outlying records, as explained in the text (section 4.5). Scientific names follow Gill et al. 2010

Species	Scientific name	Pasture* or sea# gap-crossing (km)	Natal dispersal (km)	Other seasonal movements (km)
Bellbird/korimako	*Anthornis melanura*	22#	22	20
Brown kiwi	*Apteryx australis*	0.33*	20	0.26–1
Fantail/pīwakawaka	*Rhipidura fuliginosa*	0.15#	Unknown	0.1
Grey warbler/riroriro	*Gerygone igata*	Unknown	0.9	0.1
Harrier/kahu	*Circus approximans*	22#	100+	100s
Hihi	*Notiomystis cincta*	0.1–0.3*	0.9-1.7	0.5
Kākā	*Nestor meridionalis*	25#	25	100+
Kererū	*Hemiphaga novaeseelandiae*	33#	Unknown	100
Kingfisher/kotare	*Todiramphus sanctus*	Unknown	Unknown	2
Little spotted kiwi	*Apteryx owenii*	Unknown	Unknown	0.1
Long-tailed cuckoo/koekoeā	*Eudynamys taitensis*	8,000+#	Unknown	Migratory 8,000+
New Zealand falcon/karearea	*Falco novaeseelandiae*	20*	10	2.8–19
North Island robin/toutouwai	*Petroica longipes*	0.11*	15	0.2
North Island tīeke	*Philesturnus rufusater*	0.25#	0.8	50–200
Red-crowned kākāriki	*Cyanoramphus novaezelandiae*	100#	2.5	20
Rifleman/tītipounamu	*Acanthisitta chloris*	0.3*	1.7	0.15
Shining cuckoo/pipiwharauroa	*Chrysococcyx lucidus*	5,000#	Unknown	migratory 5,000+
Silvereye/tauhou	*Zosterops lateralis*	100+#	0.16	50–300
Tomtit/miromiro	*Petroica macrocephala*	3#	Unknown	0.12–0.16
Tūī	*Prosthemadera novaeseelandiae*	20*	5	20
Whitehead/pōpokatea	*Mohoua albicilla*	0.1*	0.35	0.3

Table A2 Usage of simplified (see Table 1) LCDB land cover types by native bird species currently present, or having a realistic possibility of being present in the future, in the cape area. P = preferred, O = occasional use, X = not used. Usage is split into use for breeding or feeding. Usage classification assumes all predators are controlled (see Methods), and that fragment area is not limiting

Behaviour type	Species	Exotic forest	Exotic plantings	Native forest	Production grassland	Riparian plantings	Secondary nurse species	Urban areas
Breeding	Bellbird	O	O	P	X	O	O	O
	Brown kiwi	O	O	P	X	O	O	O
	Fantail	P	P	P	X	O	P	P
	Grey warbler	P	O	P	X	O	O	O
	Harrier	O	X	X	O	P	X	X
	Hihi	X	X	P	X	X	O	O
	Kākā	X	X	P	X	X	X	X
	Kererū	X	X	P	X	X	X	O
	Kingfisher	O	X	P	X	P	X	O
	Little spotted kiwi	O	O	P	X	O	O	O
	Long-tailed cuckoo	O	O	P	X	O	O	O
	New Zealand falcon	P	X	P	O	X	X	X
	North Island robin	O	O	P	X	O	O	O
	North Island tīeke	O	O	P	X	X	O	O
	Red crowned kākāriki	O	O	P	X	X	O	O
	Rifleman	O	O	P	X	O	O	O
	Shining cuckoo	P	O	P	X	O	O	O
	Silvereye	P	P	P	X	P	P	P
	Tomtit	O	O	P	X	O	O	O
	Tūī	O	O	P	X	O	O	O
	Whitehead	P	O	P	X	O	O	O
Feeding	Bellbird	O	O	P	X	O	O	O
	Brown kiwi	O	O	P	O	O	O	O
	Fantail	P	P	P	X	O	P	P
	Grey Warbler	P	O	P	X	O	O	O
	Harrier	O	O	O	P	O	O	O
	Hihi	X	X	P	X	X	O	O
	Kākā	O	O	P	X	X	X	O
	Kererū	O	O	P	X	O	O	O
	Kingfisher	O	O	P	X	P	X	O
	Little spotted kiwi	O	O	P	O	O	O	O
	Long-tailed cuckoo	O	O	P	X	O	O	O
	New Zealand falcon	P	O	P	O	O	O	O
	North Island robin	O	O	P	X	O	O	O
	North Island tīeke	O	O	P	X	O	O	O
	Red crowned kākāriki	O	O	P	O	O	O	O
	Rifleman	O	O	P	X	O	O	O
	Shining cuckoo	P	O	P	X	O	O	O
	Silvereye	P	P	P	X	P	P	P
	Tomtit	O	O	P	X	O	O	O
	Tūī	O	O	P	X	O	O	O
	Whitehead	P	O	P	X	O	O	O

Table A3 Vulnerability to pest mammal predation of native bird species currently present, or having a realistic possibility of being present in the future, in the Cape-to-City footprint or Cape Sanctuary. Note that unlike in other tables in this appendix, species are arranged by predation vulnerability and then alphabetically

Species	Predation vulnerability
Fantail	Low
Grey warbler	Low
Harrier	Low
Kingfisher	Low
Shining cuckoo	Low
Silvereye	Low
Bellbird	Medium
Falcon	Medium
Kāka	Medium
Kererū	Medium
Long-tailed cuckoo	Medium
Rifleman	Medium
Robin	Medium
Tomtit	Medium
Tūī	Medium
Whitehead	Medium
Brown kiwi	High
Hihi	High
Little spotted kiwi	High
Red-crowned kākāriki	High
North Island tīeke	High