Foraging behaviours of translocated takahē (*Porphyrio hochstetteri*) at two contrasting sites, New Zealand

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Abstract

The South Island takahē (*Porphyrio hochstetteri*) is an endangered ground-dwelling species, endemic to New Zealand. To prevent the species' extinction, individuals were translocated to protected sites, such as off-shore pest-free islands and pest-fenced, mainland sites. The takahē may be one of the most researched bird species in New Zealand, but there are very few studies on its behavioural habits and ecology at these protected offshore island and mainland sites.

This study was an investigation of translocated takahē foraging behaviour at two very different sites, Motutapu Island (Hauraki Gulf, Auckland) and Maungatautari mainland site (Waikato region), with two translocated takahē populations (18 vs 6 takahē respectively). In total, 24 takahē were observed at the time of this study. The aims of this research were to determine: (1) how takahē foraging behaviour differed between pasture and other habitats on Motutapu Island and at Maungatautari, (2) how other habitat elements (incl. vegetation cover, water, roads, tracks) affected foraging behaviour, and (3) if habitat restoration may assist takahē establishment. This study was conducted in reference to future successional habitat changes on Motutapu Island, as it is subject to active re-vegetation of native trees and shrubs. Similarly, Maungatautari is not actively maintaining the pastoral grassland sites between forest edge and the pest-proof fence. Therefore, without management, natural forest successions of these sites are likely to decrease food availability for takahē in the future.

Plant species eaten by takahē were identified during field observations. Foraging behaviour was categorised into three main behaviours: (1) cutting for grass-blades, (2) tillering for grass meristems (leaf base, leaf blade discarded) and (3) stripping (grass seeds). A multinomial regression analysis, with confidence intervals of 95% level confidence, determined the odds of a takahē behaviour occurring according to various habitat variables. Foraging behaviours were found to differ according to the percentages of vegetation cover. On Motutapu Island, the main findings were that takahē favoured tillering grass meristems at sites where a high percentage of shrubland was available rather than at sites with high tree cover (vegetation >6 m) or with a high percentage of open grassland. In contrast, stripping seeds was favoured at sites with high tree cover and/or at restoration planting sites. Qualitative behavioural data from Maungatautari showed that takahē foraged primarily on pastoral grassland species, obtained primarily between the fence and the forest.

Nesting and breeding observations were also made during incubation and chick-rearing. Only one chick reached juvenile-adult stage at Motutapu Island, compared to two chicks at Maungatautari. I identified nest material and nest cover plant species used by takahē (native and exotics- sedges/flax/shrubs/native long grass) during the breeding season and present a plant list based on qualitative fieldwork. Extensive pastoral grasslands on Motutapu Island are now being restored into forested areas, but wetland and native grassland restoration should be another priority for takahē habitat management. Similarly, the Maungatautari Ecological Island Trust (MEIT) may have to control the natural succession of the forest at the edge of the pest-proof fence. Overall, adding native species in pastoral grassland takahē territories at Motutapu Island and Maungautari will be necessary for the future well-being of these translocated takahē. This study has shown that analysing takahē foraging behaviours can help conservation management to improve habitat restoration and subsequent breeding success.

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Literature Review

Insular Ecosystems and Bird Fauna- New Zealand offshore islands conservation, a global leading case and its application to ornithological field science

1.1 Introduction

Conservation and restoration sciences have developed many methods to protect endangered species, especially in insular systems where there is currently a high rate of species extinction (Loehle & Eschenbach 2012). Conservation management of native and endemic biodiversity of island ecosystems is the focus of this review. The aim is to highlight the problems and challenges faced from research studies that have been carried out in New Zealand and Pacific islands and to examine practical ways to improve our knowledge of protecting and conserving native and endemic birds.

First, insular biotas are unique because of their isolation and have well-defined boundaries (Gillespie 2007). The fauna and flora within these systems have evolved over time, possessing particular community and species characteristics. One of the principal insular community characteristics is disharmony (underrepresented or missing taxon/ taxa) (Gillespie 2007; Briggs 2009). This phenomenon occurs because of differential colonization ability of taxa. Further, colonization frequency becomes rare with higher degree of isolation (MacArthur & Wilson 1963). Islands, such as New Zealand (NZ), have highly disharmonic biotas, which can lead to adaptive radiation, that is, the diversification of a group of organisms into forms filling empty ecological niches. Thus, levels of endemism can be very high (Gillespie 2007).

The community ecological characteristics of an ecosystem are also dependent on the types of island. Islands are differentiated into two types, oceanic and continental (Gillespie 2007). Continental islands result when a large landmass is either fragmented by sea level rise or land breaks off and drifts from the mainland. Oceanic islands on the other hand, can either be created from volcanoes rising above sea level, or where lithospheric plates converge (Daugherty et al. 1993; Walter 2004; Gillespie et al. 2008; Briggs 2009). The principal biological difference between these two types of islands is that continental islands, when separated from landmass, already have a set of species (i.e. vicariance), whereas oceanic islands are formed without life (Gillespie 2007). However, even though continental islands might have had an initial set of species, the biotas cannot necessarily be considered as “relict” species (Feild et al. 2002; Gillespie et al. 2012). This is because some continental islands have been separated from their original landmass millions of years ago and undergone complex geological processes, including submersion events (e.g. New Zealand, New Caledonia). Species evolve then through time and natural selection (Grandcolas et al. 2008; Wallis & Trewick 2009).

When considering the concept of long-term dispersal, “relictualism” cannot always be applied to the evolutionary histories of fauna on different islands (Gillespie et al. 2012). For example, even though the New Zealand landmass has been separated from Gondwana for 60-85 million year ago, according to molecular genetics, few endemic species seem to have originated from ‘recent’ (geological time) colonization events (long-distance dispersal) from Australia rather than Gondwana, as it was previously assumed. Thus the present set of species is not necessarily the result of vicariance, but rather long-distance dispersal (Daugherty et al. 1993; Feild et al. 2002; Briggs 2009; Gillespie et al. 2012).Even though the biotas of continental and oceanic islands may have been different in origins, it has been observed that many general characteristics are still very similar (Drake et al. 2002). One characteristic is that island species often lose their dispersal abilities. The loss or reduction of these abilities can result in the acceleration of species diversification (i.e. adaptive radiation) (Drake et al. 2002). This leads to another characteristic of island biotas, which is the development of unusual traits (Briggs 2009). A common example for island avian species is the loss of flight, due to the absence of mammal predators and competitors. In addition, they may have very specialized diets resulting in anatomical differences between species. A well-known example is Darwin’s research on the Galapagos finches' species where the size of the bill was observed to be correlated to seed size (Darwin 1936; Briggs 2009). Finally, another observation of island biotas is that there are some particular occurrences of either gigantism (e.g. NZ North Island giant moa *Dinornis novaezealandiae*) or dwarfism (e.g. Cretan dwarf mammoth *Mammuthus creticus*) in the species. Thus, island species are biologically unique compared to main continental species (e.g. Europe) (Drake et al. 2002; Briggs 2009).

An island is useful for the scientific community to study as it is small in size and has ecosystems with simpler trophic relationships due to its well-defined geographic boundary, which is the surrounding ocean water (Darwin 1936; Drake et al. 2002). Additionally, islands provide an ideal setting for conservation practice. Conservation methods such as pest eradication or translocation to a safe habitat are often more feasible on islands than on continents, where direct predation or competition from exotic species cannot be completely suppressed (Drake et al. 2002; Vitousek 2002; Courchamp et al. 2003). Island bird conservation is an important field of research, and its progress is of great interest to the general public (Drake et al. 2002; Meine et al. 2006; Brooks et al. 2008). It is quite important in terms of ecotourism, considering the large community of worldwide bird-watchers. Bird species also have a long-history of great cultural significance. In Māori and other Pacific island cultures, avian species were either used for their feathers or meat; inspired many legends and even were part of ancient religious beliefs (Gouni et al. 2007; Towns et al. 2012).

1.1.1 Island birds

As birds have the ability of flight to assist dispersal, all islands have high biodiversity of birds (BirdLife International 2008; Gillespie et al. 2008). Continental species have been using islands as resting places in their migratory path. Seabirds, especially, have a very large geographical range for feeding, and have nests, burrows and roost sites across many islands (e.g. petrel species) (BirdLife International 2008; Miskelly et al. 2009). Land birds are either endemic to a group of islands or to a single island (including islets) (Gouni et al. 2007) (Figure 1.1). Some island birds have evolved into ecological equivalents of species that were naturally absent from the native ecosystem. For example, most oceanic islands originally had no mammals, meaning there were no herbivorous ungulates (hoofed mammals, such as goats, cows, etc.) (Darwin 1936). These empty niches were then replaced by large herbivorous birds such as the North Island giant moa) and the takahē (*Porphyrio hochstetteri*) in New Zealand, or the Hawaiian goose (*Branta sandvicensis*) in the Hawaiian archipelago (Gouni et al. 2007; Gillespie et al. 2012).

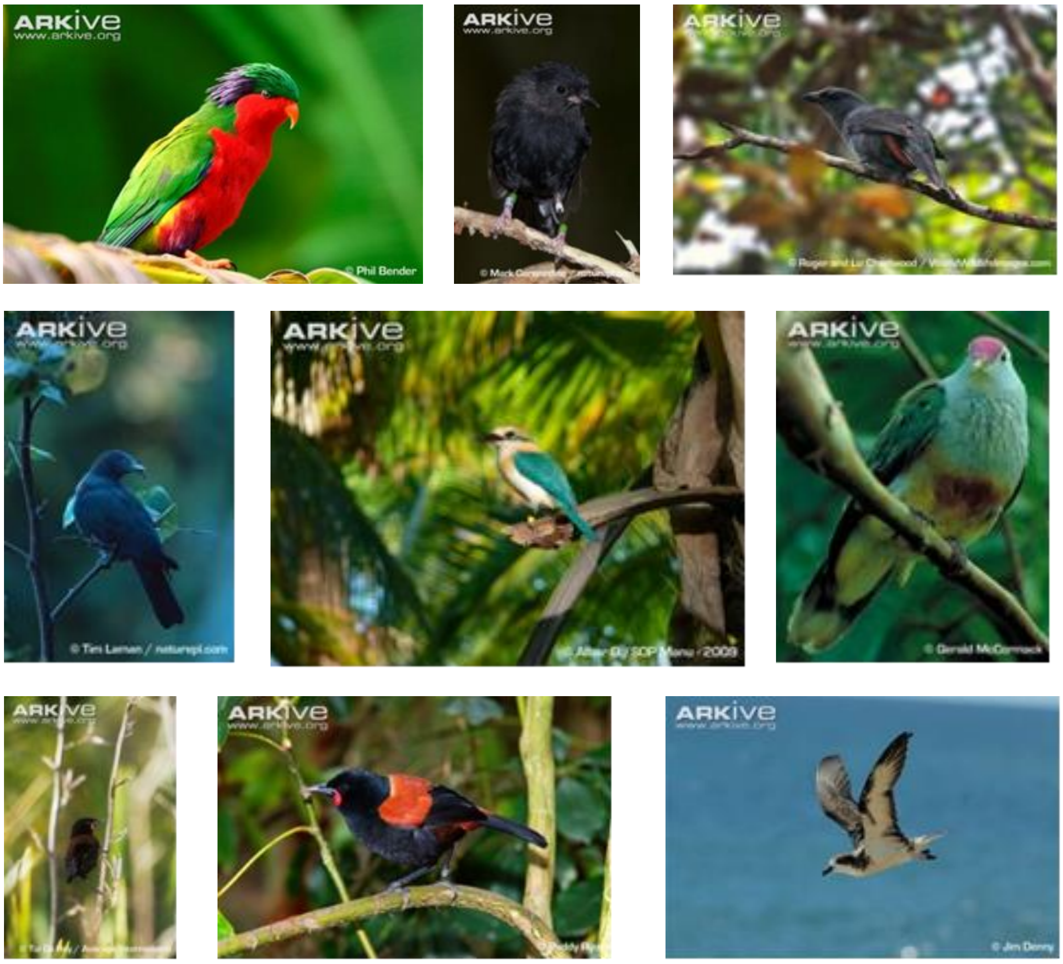

Figure 1.1: Examples of single island endemic birds- from left to right: Rimatara Island lorikeet (*Vini kuhlii*) (©Phil Bender), Chatham Island black robin (*Petroica traversi*) (©Mark Carwardine) and New Caledonian cuckoo shrike (*Coracina analis*) (©Roger Charlwood). Archipelago endemics- from left to right: Marquesan imperial pigeon (*Ducula galeata*) (©Tim Laman), Tuamotu kingfisher (*Todiramphus gambieri*) (©Guillaume Albar), Cook Islands fruit dove (*Ptilinopus rarotongensis*), New Zealand saddleback spp. (*Philesturnus spp.*) (©Tui De Roy & Paddy Ryan) and Hawaiian petrel (breeding endemic *Pterodroma sandwichensi*) (©Jim Denny)

1.1.2 New Zealand: continental and oceanic features

New Zealand consists of the North, South and Stewart Islands, a few hundred smaller islands (e.g. Northern group: Great Barrier Island, Southern: Resolution Island), and several groups of offshore islands (e.g. Chatham Islands, Kermadec Islands) (Wallis & Trewick 2009). It is located in the Pacific, at latitudes 29–52°S, including all small islands. The mainland (North and South islands) is mostly mountainous, being separated from the closest large landmass Australia by the Tasman Sea. Seventy-five percent of the landmass is greater than 200 meters above sea level, with 19 peaks above 3000 meters (in Fiordland, South Island) (Wallis & Trewick 2009).

New Zealand is derived from Zealandia, which was part of the Gondwana supercontinent. Zealandia separated from the rest of Gondwana 82 million years ago (Ma); the rest of Gondwana became Australia, Antarctica and South America (Wallis & Trewick 2009). The subsequent opening of the Tasman Sea completely separated Zealandia, in addition to the later opening of the New Caledonian basin, separating New Caledonia from the northern Lord Howe Rise (Grandcolas et al. 2008).

As a result of this long isolation, the fauna of New Zealand exhibits oceanic features. New Zealand has been called the ‘Land of Birds’ (Fitter & Merton 2011) due to the large number of unique bird species, many of which have gone extinct such as the moa (Dinornithiformes), laughing owl (*Sceloglaux albifacies*) and Haast eagle (*Aquila moorei*). The oceanic feature of gigantism is often observed among NZ fauna. Large birds such as moa species, radiated in the absence of other large herbivores, as well as large insects such as wēta (Orthoptera), in the absence of rodents (Fitter & Merton 2011). Some groups show extensive endemic radiations (e.g. moa, rails, skinks, moths, etc.), while others have little diversity (e.g. freshwater fish, amphibians, etc.)(Fitter & Merton 2011).

Before human arrival, New Zealand was covered by native bush and wetlands, with diverse lowland podocarp, evergreen and montane forests. With the arrival of humans, the ecosystems were largely affected by extensive habitat loss (due to Māori clearing forests by fire and Europeans further converting land to farmland and urbanization) and the introduction of many exotic species (Daugherty et al. 1993; Wallis & Trewick 2009). A large proportion of New Zealand bird species (41%) have become extinct following human settlement and predation/competition from exotic species (Towns et al. 2012). Fortunately, some offshore island ecosystems have remained intact without the negative influences of invasive species. Some offshore islands may have had only one species of exotic/introduced/pest rodent, so there has been little damage. For this reason, a common conservation strategy in New Zealand is to use offshore islands for the conservation of the most endangered species of birds (Bellingham et al. 2010). This strategy will be reviewed in this paper, as it has been practised in many other Pacific conservation projects.

First, I will review the general knowledge of conservation of bird fauna, especially the reasons for the present high rates of extinction. Important advances in ornithological conservation will then be discussed, especially within the context of islands. As New Zealand is one of the leading countries in terms of offshore island conservation, its conservation efforts will be discussed throughout this review. Finally, as the takahē (*Porphyrio hochstetteri*) is one of the only species that has been subjected to a translocation from a very different initial habitat to offshore islands, its conservation management will also be reviewed.

1.2 Ornithological science

1.2.1 Global bird extinction

The Earth has around 10 000 bird species (BirdLife International 2008), meaning that they are an important part of the world's biodiversity. Birds are found nearly everywhere and occupy a large range of habitats. Many species are highly threatened, with one in eight bird species worldwide in danger of becoming extinct (BirdLife International 2008). It is believed that since 1500 AD, 153 bird species around the world have gone extinct (BirdLife International 2008). Most of these were island species (Figure 1.2), with the highest number of extinctions of 18 island species between 1850 and 1900 (BirdLife International 2008).

Figure 1.2: Some examples of bird species most threatened in the world, from left to right- Spix's macaw (*Cyanopsitta spixii*) (©Thomas Arndt), Hawaiian crow (*Corvus hawaiiensis*) (©Jack Jeffrey), Tahiti monarch (*Pomarea nigra*) (©Tun Pin Ong) and kākāpō (*Strigops habroptilus*) (©Rod Morris). From left to right: the first two species are extinct in the wild. The Tahiti monarch has a total population less than 50 individuals in the wild, while the kākāpō has a total population less than 200 individuals.

According to BirdLife International (2008), which coordinates the International Union for the Conservation of Nature (IUCN) Red List for bird species, 1226 species are endangered by extinction, with 190 species being critically endangered. It is important to know that the threatened status is not evenly distributed across families. For example 82% of all species of albatrosse (*Diomedeidae*) are threatened. Worldwide, 16 bird species would have been extinct if not for conservation efforts, and 49 critically endangered species are benefitting from these actions. The rate of severe declines have been declining for 24 species and some 25 species have even improved in status (BirdLife International 2008). Overall, large bodied-birds (e.g. kākāpō *Strigops habroptilus*, takahē *Porphyrio hochstetteri*) and, or species with low reproductive success (e.g. the Tahitian flycatcher *Pomarea nigra* lays only one egg per clutch) are the ones most likely to be subject to extinction (Figure 1.3) (Blanvillain et al. 2003; BirdLife International 2008; Loehle & Eschenbach 2012).

1.2.2 Global ornithological contribution to conservation science

Birds are one of the most studied group of organisms in the world (Brooks et al. 2008). First of all, in terms of atlases of species distribution, there are a higher number of atlases for birds than for any other organisms (Brooks et al. 2008). There are 127 bird atlases, compared to only 69 for plants, 26 for reptiles, 21 for butterflies, 18 for amphibians, 17 for mammals and 6 for dragonflies. Second, population indices are another indicator, where 778 (59%) of the 1313 datasets incorporated in the 2006 Living Planet Index are avian-related (Brooks et al. 2008). Third, ornithological conservation has enabled the identification of sites of global conservation significance, especially due to the Important Bird Areas (IBA) program. There are now more than 10 000 IBAs that have been identified around the world, across 200 countries and territories (BirdLife International 2008; Brooks et al. 2008). This work has stimulated the appearance of similar programs, such as the Prime Butterfly Areas and the Important Plant Areas (Brooks et al. 2008). Finally, birds were the first class of organisms to be evaluated for threat status against repeated criteria in Collar and Andrew (1988), which led to the making of the IUCN Red List that is now used for all existing species (Collar & Andrew 1988; BirdLife International 2008; Brooks et al. 2008).

1.2.3 Global ornithological shortcomings

According to Brooks et al. (2008), non-threatened species seem to be more studied than threatened species. This may be due to the fact that threatened species population numbers are very low, so encounter rates are unpredictable (i.e. rare sights) or that these species are only present in either politically unstable or remote areas (Brooks et al. 2008; Loehle & Eschenbach 2012). This means that many threatened bird species remain understudied (Brooks et al. 2008). It was also shown that most studies concentrate on the bird population number (e.g. breeding outputs), while there are very few studies that document the socio-economic aspects of bird conservation, conservation practise and the results of conservation action (Brooks et al. 2008). And finally, Brooks et al. (2008) have pointed out that, although the highest regional proportions of threatened bird species are in Central America, the Caribbean and the Pacific, there have been actually very few studies conducted there. Most ornithological research studies have been conducted by scientists based at universities rather than in non-governmental organizations (NGOs) or other independent scientific organisation, and often in countries (e.g. New Zealand or Europe) where more funding is available for conservation projects (Brooks et al. 2008). This is why certain regulations or practises in conservation have not been adapted to Pacific countries, where the NGOs or private scientific group research communities do not own land, in contrast to the New Zealand's Department of Conservation (DOC) (Keppel et al. 2012).

1.3 Threats

Birds world-wide are threatened by a variety of reasons, but the most severe threats are agriculture, logging and invasive species. Respectively, these particular threats affect 1,065 (87%), 668 (55%) and 625 (51%) globally threatened species. These threats cause stress to the populations, especially in terms of habitat destruction and degradation, thus affecting 1146 (93%) of threatened species. On islands, increase in human populations decreases available habitat, which is already small in size. This means that habitat loss has a higher impact on islands than on continents (BirdLife International 2008; Brooks et al. 2008; Loehle & Eschenbach 2012). Additionally, some islands were colonized at least 800 years ago by humans, so some habitat requirements that native species may have had before the invasion of exotic species might not be well understood, so the real impact of these exotic species may not be well-known as well (Miller & Hobbs 2007; Loehle & Eschenbach 2012).

World-wide, invasive species have been considered as one of the most important causes of bird biodiversity loss. Introduced animal species have a large direct impact on bird population numbers, but invasive plant species can also modify habitats and ecosystems rapidly (Courchamp et al. 2003). This is particularly true in island ecosystems, where species are especially vulnerable as they have evolved in the absence of strong competition, herbivory, parasitism or predation (Moors et al. 1992; Courchamp et al. 2003; Oppel et al. 2011).

The introduction of exotic species usually results in failure to successfully colonize and develop self-perpetuating populations due to problems of adapting to the new habitat. In the Hawaiian Islands, out of the 150 bird species that were introduced, only 30 species have become established. This is the same case in New Zealand, where 145 bird species were also introduced, and only 36 bird species have been established (Courchamp et al. 2003). This phenomenon can be referred to as the 10% rule, where 10% of introductions that succeed are significantly ecologically disruptive (Courchamp et al. 2003). As the number of introduction attempts increases, the higher the chance that the introduced species are able to establish. More importantly, some introduced species have ecological equivalents which are lacking in the natural ecosystems. So these may have disproportionate impacts on that system (Courchamp et al. 2003). In New Zealand 32 of the 55 mammal species that have been introduced have established, which is much more than the standard 10% success rate. It has been estimated that 80% of all islands have been invaded by rats (*Rattus* spp.) and at least 65 major island groups have been invaded by domestic cats (*Felis catus*) (BirdLife International 2008). As most conservation projects are focused on controlling one species at a time, there is often not enough funding or time to deal with them separately.

Additional factors influencing bird species vulnerability to predation pressure are the characteristics of the species (Courchamp et al. 2003). Avian species vulnerability can be influenced by egg size, shell thickness, timing of breeding season, number of young per season, length of the fledging period, ability to re-nest after losing young, and length of time the nest is left unattended (Moors et al. 1992).

1.3.1 Rat*s*

Rodents (rats and mouse) have the highest ability of dispersal, and have colonized almost all islands by a combination of human transport (boats and ships), rafting or swimming. Rats in particular have the most negative and documented effects on birds (Moors et al. 1992; Bellingham et al. 2010). The adverse effects on birds differ depending on the species of rat (Moors et al. 1992). Birds nesting on or near ground or in burrows are often targeted by the Norway rat (*R. norvegicus*), whereas tree-nesting birds are at higher risk from the black or ship rat (*R. rattus*) because of its climbing ability (Moors et al. 1992). On islands, the black rat has caused a higher rate of losses of forest birds than any other rat species (Moors et al. 1992; Bellingham et al. 2010). Similarly, the Norway rat *R. norvegicus* has caused the higher loss of seabird species. Important factors that determine bird vulnerability to rodents are size and behavioural tendencies of the birds themselves (Moors et al. 1992).

Larger birds or birds which nest in sites difficult to access (e.g. treetops) are less vulnerable to predation (Moors et al. 1992). In addition, if bird species are already naturally aggressive (e.g. pukeko *Porphyrio melanotus*), they are more likely to defend their nests from predation (Moors et al. 1992). Rats do not necessarily impact only by direct predation, they also affect species via direct competition for food as they have a general diet including plants and insects (Moors et al. 1992; Bellingham et al. 2010) and may also compete for shelter or nest-sites (Moors et al. 1992).

1.3.2 Feral cat (*Felis catus*)

Feral cats (*Felis catus*) are also major predators that prey on all island bird species from ground-dwelling to forest birds (BirdLife International 2008; Medina et al. 2011; BirdLife International 2013). Domesticated cats also prey on avian species, but their impact is not as easily determined. As a generalist predator, a global review on effects of feral cats on island vertebrates has estimated that feral cats caused 14% of island vertebrate extinctions and are the principal threat for 8% of island species (Medina et al. 2011). Although feral cats have negative effects on many bird species (16% of critically endangered taxa), they can also negatively affect other vertebrate species, especially reptiles (Medina et al. 2011). In addition, most studies were in the Pacific islands. Even if this review was supposed to be a worldwide estimation of the effects of feral cats on island native and endemic species, there is an underestimation of the total effects of cats on all islands as there are not many studies conducted in Asia, Indonesia and Micronesia (Medina et al. 2011).

1.3.3 Ungulates

While rodents and feral cats have the most adverse effects on most bird species worldwide (BirdLife International 2008; Medina et al. 2011; BirdLife International 2013) ungulate species (pigs, goats, deer, etc.) can also have a disproportionate effect on island ecosystems, especially forested systems. Not only does their presence contribute to a major habitat loss, they can also be the cause of direct competition for food resources (i.e. for avian herbivorous species). Their presence might also disperse invasive plant species (D'Antonio & Meyerson 2002), further contributing to plant community shifts, and elimination of plant species that some bird species might depend for feeding or nesting (Crawley 1983; Courchamp et al. 2003; Oppel et al. 2011). This is the case in New Zealand, as well as the Hawaiian Islands, where lowland tropical dry forests are replaced by pasture grass for farmland and native forest remnants are grazed upon by ungulates (Weller et al. 2011; Ammondt et al. 2013). As these species are not direct predators, reducing their numbers does not seem to be a priority compared to the eradication of rodents and feral cats (Campbell & Donlan 2005). For this reason, there has not been much research on the direct effects of ungulates on bird populations, but rather more about how their presence correlates with habitat loss of island systems. This is also the case for invasive plant species and invasive insect species (Bellingham et al. 2010; Towns et al. 2012).

1.3.4 Introduced birds

The negative effects of exotic birds are the least understood of all other introductions (Bellingham et al. 2010; Towns et al. 2012; Baker et al. 2014). This might be because invasive birds may not seem as disruptive as mammals. However, it has been demonstrated that invasive birds can compete for food and nest sites, and can also be direct predators (Tindall et al. 2007). This is especially true in the case of the invasive common myna *Acridotheres tristis* (Dhami & Nagle 2010; Heptonstall 2010) or the red-vented bulbul *Pycnonotus cafer* (Blanvillain et al. 2003). It has been reported that these species can cause serious loss in the numbers of critically endangered species, such as the Tahiti or the Rarotonga *Pomarea dimidiata* flycatcher species (Blanvillain et al. 2003). In New Zealand, predation from common myna was also reported, and an eradication program on one of the offshore islands was followed by an increase of the bird biodiversity (Tindall et al. 2007). However, Baker et al. (2014), in a review of worldwide threats of introduced birds to native birds, found only 10 cases where introduced birds have caused serious loss to endangered bird species populations.

1.3.5 New Zealand invasive species: possum and mustelids

In New Zealand additional major bird predators are stoats (*Mustela erminea*) and possums (*Trichosurus* spp.*)* (Invasive Species Specialist Group (ISSG) 2013). According to BirdLife International (2008), these species are categorized as the least invasive species to affect all island birds. This may be due to the fact that their dispersal was not accidental, but these species were introduced on purpose and only in a few islands (BirdLife International 2008; Invasive Species Specialist Group (ISSG) 2013). In fact, the stoat was introduced from Europe into New Zealand and a few European islands for rabbit control, while possums were introduced from Australia to New Zealand for fur. Possums mainly affect plant species (e.g. Myrtaceae, mistletoe *Alepis flavida* (Loranthaceae)), but they do supplement their feeding by eating bird chicks or eggs (Brown et al. 1993). For example, in the case of the endangered North Island kōkako (*Callaeas wilsoni*), the possum will sometimes kill the nesting adult while preying on eggs and chicks (Innes et al. 1999).

In the case of stoats, the size of the birds does not seem to be a problem for their feeding habits compared to rats and they are a major predator of the takahē (*Porphyrio hochstetteri*), which is a very large rail species (Hegg et al. 2012; Veale et al. 2012). It is also essential to note that there are other mustelid species present in New Zealand, but the stoat seems to be the most adverse one (BirdLife International 2008; Hegg et al. 2012; Invasive Species Specialist Group (ISSG) 2013). Despite the fact that their introduction was not accidental, stoats have primarily invaded offshore islands via swimming (Veale et al. 2012), but accidental introduction from boats cannot be entirely ruled out (Bellingham et al. 2010; Towns et al. 2012; Veale et al. 2012).

1.4 New Zealand ornithological conservation

1.4.1 Pest eradication, translocation success and its application in other Pacific countries

Using pest-free offshore islands within proximity of the New Zealand mainland as conservation and restoration sites has been very successful, by providing safe "havens" for New Zealand vulnerable species. Conservation management in New Zealand using offshore islands developed within the field of ornithology and at first started with the development of more effective pest eradication methods (Bellingham et al. 2010).

In New Zealand, eradication of rodents on islands over the last 20 years has proven beneficial for 26 terrestrial bird species, 14 seabird species and 32 out of 73 taxa translocated terrestrial bird species (Bellingham et al. 2010; Towns et al. 2012). However, restoring habitats via planting native species has been also important for these projects. The development of effective translocation guidelines was critical, especially for bird species low in numbers (e.g. black robin *Petroica traversi* or kākāpō) (Bellingham et al. 2010). Many New Zealand avian species have increased very rapidly once they were translocated (Figure 1.3) including the saddleback (North and South Island *Philesturnus rufusater,P. carunculatus*hihi (*Notiomystis cincta*), chatham black robin (Bellingham et al. 2010; Towns et al. 2012).

Further, behavioural studies have also contributed to the successful management of translocated species (Bellingham et al. 2010). Famous examples are the first-ever fostering experiment of black robin eggs with Chatham Island tits (Petroica macrocephala chathamensis) to increase egg productivity (Butler & Merton 1992), or the discovery of lek breeding behaviour of the kākāpō (Merton et al. 1984). For example, even with pest eradication, attracting adult seabirds back to old roost sites on islands was quite difficult at first (Miskelly et al. 2009). Behavioural studies have been important for the development of transferring and raising young chicks on the islands where their population is needed (rather than adults, which would have rapidly left) (Miskelly et al. 2009; Bellingham et al. 2010). This is a technique normally used for the establishment of new populations of seabirds (Miskelly et al. 2009) such as the burrow-nesting seabird the common diving petrel *Pelecanoides urinatrix* (Figure 1.3) (Miskelly et al. 2009).

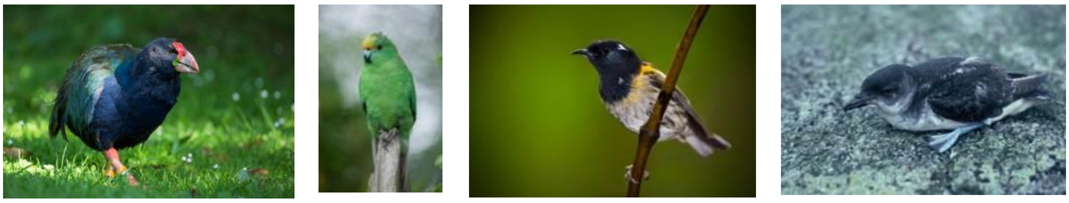

Figure 1.3: Some examples of New Zealand species that were translocated to pest-free sites. From left to right: takahē (*Porphyrio hochstetteri*) (©Sabine Bernert), orange-fronted parakeet (*Cyanoramphus malherbi)* (©Sabine Bernert), hihi (*Notiomystis cincta*) (©Tony Whitehead) and common diving petrel (*Pelecanoides urinatrix*) (©Alan Tennyson).

The increase of endangered bird populations following human intervention also took place at other pacific countries, with the help of pest management and translocation strategies that were developed in New Zealand. An example where New Zealand participated in the conservation of other Pacific countries' conservation is in the Cook Islands, with the Rarotonga flycatcher species project. This project is on-going with different organizations collaborating together, including the South Pacific Environmental Program (SPREP), DOC and Takitumu Conservation (Robertson et al. 2009). This collaborative long-term management (since 1995) has enabled the flycatcher population to increase from 35 initial individuals to a 100-200 population on Rarotonga, with the pest management of rats. With the increase of this initial population, it then enabled the translocation of some individuals to a pest-free island, Atiu, which has now increased to around 100 individuals (Robertson et al. 2006; Robertson et al. 2009).

Another example is the Rimatara Lorikeet *Vini kuhlii* translocation project which was also a success in Atiu Island (Cook Islands) (Albar et al. 2009). This species is actually a critically endangered species from French Polynesia (native to Rimatara Island) and establishing a second population was critical for its conservation. However, as there are no other islands that are rat-free (i.e. black rat *Rattus rattus*) at Austral archipelago (French Polynesia), this species was introduced outside of their natural range. In collaboration with the Cook Islands, French Polynesian ('MANU') ornithological organisation and the local government of Rarotonga, the species was translocated at Atiu Island, has now established and increased from 24 translocated individuals to a population of 90 individuals in 2012 (Heptonstall 2010; BirdLife International 2013). These examples show that the collaboration of different countries for the conservation of highly endangered species can be an effective strategy (Albar et al. 2009; Heptonstall 2010).

1.4.2 ‘Mainland’ (North and South Islands, NZ) pest-free fenced sites

Finally, it can be presumed that conservation on New Zealand offshore islands has inspired the ‘mainland islands’ concept, on North and South Islands of New Zealand (Burns et al. 2012; Innes et al. 2012). Even though ecological restoration and conservation in New Zealand mainland began early as national parks (> 100 years ago) for reserve establishment, it is only in the past 10-15 years that there were serious efforts to improve mainland native fauna and flora by either fencing large areas of native forests and wetlands or constant pest control (Atkinson 2001; Saunders & Norton 2001). Total pest eradication is not feasible on the New Zealand mainland, not only because the area is much larger, but also because of anthropogenic activities, such as farming or urbanisation (Burns et al. 2012). It is unlikely that the mainland can ever be restored entirely to its previous native ecosystem (Clarkson et al. 2007; Burns et al. 2012). Some compromise is being made in urban restoration field sciences, where re-planting gullies might enable common native fauna (e.g. tui, *Prosthemadera novaeseelandiae*) to re-colonize private gardens in urban areas (Clarkson et al. 2007). However, endangered native fauna and flora are not able to re-colonize the mainland on their own, so fencing to prevent access by pest with predator-proof fences will enable the local communities to have better access to some of New Zealand iconic species (Burns et al. 2012).

Most of these mainland sites are not funded by the New Zealand government, but are supported by local communities and privately held trusts (Burns et al. 2012). As with offshore islands, these sites also serve as a safe ‘haven’ for endangered ground-dwelling species such as kiwi (*Apteryx* spp.), kōkako or takahē. Mainland sites have been criticized for their lack of connectivity, but a similar criticism can be made of offshore islands. Another criticism of mainland sites, which can also be made toward offshore islands, is that fenced areas are not entirely pest-proof, so cannot prevent introduced insects, birds, or small mammals such as mice, even mammal re-invasion (Scofield et al. 2011). Finally, another serious concern is that some of these sites are located in mountainous regions, thus targeting only a restricted array of forest and/or grassland systems (Smuts-Kennedy & Parker 2013). This might also affect decision-making for translocation, especially for endangered species that actually occur mostly in NZ lowland forests or wetlands systems (Scofield et al. 2011; Burns et al. 2012). In this case, these sites might not provide a suitable habitat for these species (McLean & Armstrong 1995).

1.4.3 Translocation failure

There are several drawbacks in using offshore or ecological islands for endangered bird species. First of all, in the case of mainland sites, the risk of re-invasion is quite high, due to the closeness of adjacent islands or the mainland. This is especially true when considering the swimming capabilities of stoats and ship rats (Veale et al. 2012). As prevention costs much less than eradication campaigns (Bellingham et al. 2010), there are numerous methods that have been developed to stop re-invasion. Examples of preventive methods are strict biosecurity rules for people and boats, and using trained domesticated dogs to detect invaders. Even genetics can be used to establish the source population to pinpoint where the invasion started geographically (Bellingham et al. 2010; Towns et al. 2012).

Although translocation has frequently been successful, especially in New Zealand, there were cases where translocation has resulted in failure (Bellingham et al. 2010). For example, in the case of bush wren *Xenicus longipes*, all sub-species became extinct. An attempted rescue of 6 individuals from Big South Cape Island, off Stewart Island in 1964 eventually failed as they all died (last accepted sighting: 1972) (Harper 2009; Bellingham et al. 2010). Other than problems with the translocation protocol, generally failure also occurred because of the lack of data on the species' response to translocation (McLean & Armstrong 1995; Bellingham et al. 2010; Towns et al. 2012). It could be argued that the translocation of highly endangered species is a preferable solution rather than not to prevent the species extinction because of the lack of data. However, insufficient information for successful translocation could result in the death of important individuals for the population, and therefore posing a greater risk of extinction (e.g. NZ bush wren) (McLean & Armstrong 1995; BirdLife International 2013).

Another problem, which should be noted, is that successful translocation has sometimes been affected by disease outbreak in the translocated individuals (Bellingham et al. 2010). For example, the translocated hihi at Mokoia Island suffered high mortality from nest mites and aspergillosis outbreaks (Armstrong et al. 2007). Eventually, this resulted in the complete removal of the translocated population on Mokoia Island (Armstrong et al. 2007).

1.4.4 Small founding population or founder events/ genetic bottlenecks

An important problem with translocating endangered bird species into island ecosystems is the small size of the founding population, which is likely to represent only a subsample of the genetic variation of the source population (Jamieson et al. 2006; Jamieson 2009).The main goal of translocation is to have a self-sustainable population, but if these populations are genetically depauperate, they are likely to result in inbred populations and would not be able to develop new adaptations to possible changes of habitat (Conant 1988). This major problem has been brought to the spotlight by recent genetic studies. A report from DOC has summarized a 5-year research programme about the loss of genetic diversity and inbreeding in NZ endangered species (Jamieson 2009). An extreme example that was cited in Jamieson (2009) was the black robin, as its conservation is one of the world’s major successes. The original population was reduced to 5 birds (a single pair) in 1980. The population number has now increased to around 230 individuals through human intervention (Dimond & Armstrong 2007). But because of the very small population, the genetic diversity in the current population is low (Dimond & Armstrong 2007; Jamieson 2009; BirdLife International 2013). Clearly, without the past intensive conservation efforts, this particular species would have probably become extinct (Armstrong & Ewen 2002).

1.4.5 Habitat requirements

Another important concept for the conservation of offshore islands is that the island ecosystem must return to its ‘pristine’ state (i.e. original fauna/flora before human arrival) (Brown & Sax 2004; Jackson & Hobbs 2009). However, this might be counterproductive, especially in terms of the self-sustainability of the bird population. Another important consideration is that translocated populations might not be able to be brought back to the mainland (Amstrong & Davidson 2006; Moore et al. 2008). It is possible to translocate critically endangered species back to the mainland into fenced sites if there are no exotic mammals (Burns et al. 2012). However, these individuals are not subject to any predation, meaning that these may never evolve against the predation or competition from exotic species, and so might also lose their anti-predator behaviours (Moore et al. 2008). It seems that there will always be a need for human intervention, constantly controlling the exotic species to prevent the extinction of endangered species (Armstrong & Ewen 2002; Amstrong & Davidson 2006; Moore et al. 2008).

Habitat requirements are also the most problematic issue for translocation because there is either not enough knowledge of the previous state of the islands, or that the species themselves have been studied only in degraded environments (McLean & Armstrong 1995; Johnson 2007; Miller & Hobbs 2007). Having noted the difficulties of translocation and the lack of information about habitat requirements, the conservation of the takahē is a case study where individuals were translocated from alpine tussock grasslands of the South Island to offshore islands with very different habitats (Jamieson & Ryan 2001).

1.5 Takahē conservation on offshore islands and pest-proof fenced mainland sites

The South Island takahē (*Porphyrio hochstetteri*) is an endangered ground-dwelling species, endemic to New Zealand. Thought to be extinct, a small population of takahē was rediscovered in 1948 by Dr Geoffrey Orbell, in the Murchinson Mountains, Fiordland (Lee & Jamieson 2001). In the 1970s, the Fiordland population decreased to around 100 individuals due to predation by introduced stoats and competition for food with the exotic red deer (*Cervus elaphus*) (Mills & Mark 1977; Mills et al. 1984; Beauchamp & Worthy 1988; Wickes et al. 2009). To increase the population size, past actions included collecting the eggs, captive-rearing the young and then releasing in the wild when they were older (Mills et al. 1991; Wickes et al. 2009; Hegg et al. 2012). To prevent the species' extinction, individuals were translocated to other sites since 1984, such as offshore pest-free islands, protected mainland sites and other captive-breeding sites (i.e. zoos) (Jamieson & Ryan 2001; Lee & Jamieson 2001; Wickes et al. 2009; BirdLife International 2013).

Their translocation was unusual as individuals were translocated from an alpine tussock habitat to offshore islands with mostly lowland pasture and native broad-leaved forest patches (Figure 1.4) (Jamieson & Ryan 2001). Mainland sites were more diverse in terms of habitats, either being coastal forested lowlands with pastoral grassland (e.g. Tawharanui, Cape Sanctuary) or montane forested area, again with pasture grassland (e.g. Maungatautari) (Jamieson & Ryan 2001; Burns et al. 2012; BirdLife International 2013; Smuts-Kennedy & Parker 2013). This transfer to another type of habitat was allowed because previous fossil research revealed that takahē existed throughout New Zealand, inhabiting lowland broad-leaved forest margins and wetland habitats (Beauchamp & Worthy 1988; McLean & Armstrong 1995; Jamieson & Ryan 2001). At the time, it was assumed that takahē would not have any issues adapting to the new habitats as the climate was not as harsh as in Fiordland (Figure 1.4), and there were no predators apart from Australasian harriers (*Circus approximans*) .

Figure 1.4: From left to right- Takahē valley (Murchison, Fiordland) (©Rod Morris) and a Fiordland takahē individual in an alpine tussock-land (©Chris Rance).

After the first translocations to offshore islands, most individuals survived and established themselves into self-sustainable populations (Clout & Craig 1995). It was observed that takahē spent most of their time foraging in pasture grassland (Beauchamp & Worthy 1988; Clout & Craig 1995; Jamieson & Ryan 2001). On Mana Island, the only site where restoration of a wetland had taken place previously, the takahē seemed to alternate between the wetland edges and the pasture grass habitats, rather than spend all their time in the wetland areas (Ryan & Jamieson 1998).

Further monitoring revealed that translocated takahē had longer life spans than Fiordland takahē and the different populations across these islands were self-sustainable (Bunin & Jamieson 1995; Clout & Craig 1995; Bunin et al. 1997; Jamieson & Ryan 2001). Despite this, the island population numbers have not been increasing rapidly, even though there were no predation pressures (Bunin & Jamieson 1995; Bunin et al. 1997). Infertility and egg and/or young chick death was found to be abnormally high and the principal cause of this slow increase in offshore island takahē populations (Bunin et al. 1997); multiple studies have found that inbreeding was the main cause of this high infertility and egg and/or chick deaths(Jamieson et al. 2006; Grueber & Jamieson 2008; Grueber et al. 2008; Jamieson 2009; Grueber & Jamieson 2011; Grueber et al. 2012).

Another observation is that the home range size of island takahē is much smaller than in the Fiordland (Ryan & Jamieson 1998). Their average home range size in

Fiordland is around 30 to 35 ha and ranges between 2.8 and 80 ha. On Tiritiri Matangi Island (220 ha), the home-range size was highly variable between the three family groups, ranging from 10.1 to 33.8 hectares (Ryan & Jamieson 1998; Baber & Craig 2003a; Baber & Craig 2003b). Large home-range size on offshore islands was correlated with low habitat quality, with individuals travelling a greater distance for food resources, even though they might be subject to greater predation risk from the Australasian harrier (Baber & Craig 2003a).

Takahē do not seem to travel great distances when there is insufficient plant cover, which may explain the small size of some of the territories (Ryan & Jamieson 1998; Baber & Craig 2003a; Baber & Craig 2003b). On Mana Island (217 ha), observations during the breeding season have shown that the pairs had a small home-range (2.8 ha, + or/and -1.9 ha), especially during incubation (0.5 ha) (Ryan & Jamieson 1998). Small home-range size may have been due to the fact that pairs or family groups of takahē do not roam as much when the chick is small (Lee & Jamieson 2001). It may have been because Mana Island has more grassland and less tree cover than Tiritiri Matangi (Ryan & Jamieson 1998; Baber & Craig 2003a; Miskelly 2010).

Takahē diet on offshore islands seem to be less diverse than at the Fiordland alpine tussock habitat, and is considered as an additional explanation for the slow increase at all offshore island and mainland population numbers (Bunin & Jamieson 1995; Bunin et al. 1997; James et al. 2004; Jamieson 2004). Indeed, Fiordland takahē are specialists, as they till (eat grass meristems) leaf bases of various native tussock grass species (*Chionochloa* spp., Poaceae) (Williams et al. 1976), and sometimes consume *Celmisia petrei* (Asteraceae) for starch (Mills & Mark 1977; Mills et al. 1991). If available, grass-heads are stripped of seeds, by the beak slideing over grass-heads and then consumed when accumulated (Mills & Mark 1977; Baber & Craig 2003b). In winter, when deep snow hinders takahē movement to the lower altitude scrubland, Fiordland takahē consume alternative carbohydrate sources such as starchy rhizomes of the fern species *Hypolepsis millefolium* (Dennstaedtiaceae) (Mills et al. 1980).

In contrast, on islands and mainland sites, takahē mostly feed on the introduced pasture grass species (mostly cutting grass blades), and again, grass-heads are stripped of seeds. Takahē seem to also supplement their feeding with insects, and rarely, ducklings and lizards (Ryan & Jamieson 1998; Jamieson & Ryan 2001; Baber & Craig 2003a; Baber & Craig 2003b). Even though this species has historically prospered in a variety of habitats, the genetic fitness of takahē might be environmentally dependent, and so may have adapted over time to an alpine tussock habitat rather than any other lowland habitats (Bunin et al. 1997; Jamieson & Ryan 1999; Jamieson 2009; Grueber et al. 2010; Hegg et al. 2013).

It is not known if the differences in these habitats have affected their functional behaviours and habitat use (Jamieson & Ryan 2001; Johnson 2007). There are no other wild populations to compare to and especially no ‘natural’ diet to compare with, other than the Fiordland population (DeGabriel et al. 2014). The main issue with having a very different habitat from the initial habitat is that it is unclear if the translocated takahē might ever be able to prosper within these new environments. To improve their diet from only pasture grass, it is not possible to introduce Fiordland snow tussock species to offshore islands not only because introductions of these species out of their natural range might present a risk for the local species (i.e. invasion), but also the climate itself may not be suitable.

Takahē habitat and foraging requirements are not well known or researched on offshore islands. It seems that the takahē might be a generalist feeder, in contrast to the Fiordland takahē specialist-foraging habits. However, it was observed by Baber & Craig (2003b) that translocated takahē on Tiritiri Matangi Island seem to favour clover leaves for food (*Trifolium* spp., Fabaceae). Because their qualitative data was for a single island and for a specific takahē population, we are not albe to conclude as to whether the takahē might consume clover more than any other plant species.

Nutrient deficiency can have a serious impact on breeding success, but its effect is not always evident (Crawley 1983). Jamieson (2004) has measured nutrient levels of offshore island takahē eggs, and no evidence has shown that takahē were nutrient-deficient. It is important to note that high nutrient content might not be the only foraging goal of takahē as other plant properties might be needed for takahē breeding success (DeGabriel et al. 2014). James et al. (2004) found that introduced pastoral grasses, such as cocksfoot, seemed to be the best food source for takahē, compared to other plant species (*Chionochloa* spp., Poaceae), as they contain higher levels of soluble sugars. However, while island takahē may maintain their condition and weight by extracting high levels of soluble sugars, it does not necessarily mean that takahē health and breeding success would improve by only foraging for pastoral grass (James et al. 2004).

It may be interesting to analyse how plant species (sedges or other), besides pasture grass species, could contribute to takahē nutrient requirements. The main objection that takahē may suffer from nutrient deficiency is the breeding success of pukeko. Pukeko has very similar foraging behavioural habits, but it does not seem to be suffering from nutrient deficiency (Suttie & Fennessy 1992; Trewick 1997; Garcia-R & Trewick 2014). The high breeding success exhibited by the pukeko may also be because it is much more carnivorous in its foraging habits than the takahē (Bunin & Jamieson 1996).

Finally, there has been only one paper published on takahē behaviour on offshore islands, conducted at Tiritiri Matangi Island, which correlated foraging behavioural habits with habitat use (Baber & Craig 2003b). According to this research study, an ideal habitat is composed of sufficient grassland areas for foraging, patches with mixtures of grass and shrubs and some broad-leaved forest patches for connectivity between foraging sites. It may be true that shrubland and grassland are the ideal habitats for takahē on offshore islands, as well as wetlands, which may also offer an alternative vegetation cover (Baber & Craig 2003a; Baber & Craig 2003b). Wetlands could also provide various food resources in terms of vegetation, rather than only pasture grass, such as native sedges and grass species (Ryan & Jamieson 1998; Jamieson & Ryan 2001; Baber & Craig 2003a; Baber & Craig 2003b).

In conclusion, even though inbreeding depression due to the combination of genetic bottleneck and founder events can still be proposed as the principal reason of low fertility in translocated takahē. There remain many knowledge gaps in the roles of habitat, vegetation and nutrition requirements on functional foraging behavioural habits of translocated takahē. Further studies will continue to inform conservation practices and habitat restoration. In the case of the takahē, there is a lack of data, especially for offshore islands and mainland pest-free fenced sites, on whether they are generalist or not in their behavioural habits, and whether any plant species is preferred more than another for either foraging or nesting. Obtaining this knowledge could be critical for future takahē management in their offshore islands and fenced mainland habitats

1.6 Literature review summary

In summary, island birds are an important component not only for insular ecosystems, but are part of world-wide biodiversity ‘hotspots’. However, some of these species are the most threatened in the world, and have not been sufficiently studied. New Zealand has been a leading country in terms of the conservation of their offshore islands, and has served as an example for other countries. Eradication and planting campaigns have led to the protection of existing populations from exotic species predation and provided new ecosystems for translocation purposes. Behavioural studies have also contributed knowledge about translocated populations, either by enhancing breeding capabilities, or retaining or attracting other species to the protected sites. Although there are many studies about invasive mammals and the effects of grazing ungulates on bird habitat, there are hardly any findings about the effects of invasive plants, birds and insects on the endangered insular avian biodiversity and its habitat. Increasing the knowledge about the unknown effects of invasive species (other than exotic mammals) and habitat requirements, especially in relation to the endangered species’ ecology and population genetics should be priorities in the field of avian research.

In this review, several drawbacks about using translocation as a conservation strategy have been identified. It is difficult to predict if the island habitat will meet all the endangered species’ requirements in terms of feeding and breeding. This is illustrated particularly well with takahē conservation management of the initial population, as individuals were translocated from a very different initial habitat, in terms of vegetation and climate. It should be noted that there is a lack of data especially for offshore islands takahē population, regarding whether they are generalist or specialists in their food preferences. Obtaining this knowledge could be critical for future management of habitats on offshore islands, as well as fenced, mainland pest-free sites.

Chapter 2

Field research

Foraging behaviours of translocated takahē (*Porphyrio hochstetteri*) at two contrasting sites, New Zealand

This chapter is written in manuscript form for publication under the regulations of thesis with publication. The contributions of the authors are as follows:

Ms. Adara Tehani Withers – conducted the field work on Motutapu Island (Auckland) and Maungatautari ecological site (Waikato), analysed the data and wrote the thesis manuscript.

Dr. Chrissen Gemmill – was the Chief supervisor for this research project. She facilitated the research with supervision, funding acquisition (TAPA award), editing and revising the manuscript.

Mr. John Innes – was the secondary supervisor for this research project. He made contact with Maungatautari (MEIT) to include their takahē population in the research. He also facilitated the research with supervision and contributed by editing and revising the manuscript.

Dr. Steven Miller – was the tertiary supervisor for this research project. He led the statistical analyses of the dataset through R statistical software and contributed to the interpretation of the statistical results.

2.1 Introduction

The South Island takahē (*Porphyrio hochstetteri*, Rallidae) (Meyer 1883) is a flightless, ground-dwelling endemic bird species of New Zealand. With a total population of approximately 250 takahē, they are now listed as Endangered according to the IUCN Red List (Kilduff et al. 2011; BirdLife International 2013). The takahē was thought to be extinct in the early 1900s, although there were occasional sightings by local hunters (Lee & Jamieson 2001), and later re-discoveredin 1948 by Dr Geoffrey Orbell in Fiordland, South Island (Lee & Jamieson 2001). The takahē was one of the first species to be protected by the New Zealand Wildlife Service, making its conservation one of the longest running bird restoration programmes in the world (Lee & Jamieson 2001).

The Department of Conservation (DOC) and the Takahē Recovery Trust actively manage their numbers through pest-management, captive breeding and translocation of individuals to pest-free offshore islands and mainland fenced sites (Wickes et al. 2009).Currently, translocated takahē populations are managed in five offshore islands and three mainland pest-fenced sites (Wickes et al. 2009; Kilduff et al. 2011). While these translocated and island-bred (or mainland site-bred) takahē appear to live longer than the Fiordland population, their breeding success is much lower. The high egg infertility may be due to inbreeding depression (Jamieson & Ryan 2001; Jamieson 2004; Jamieson et al. 2006) which is a disadvantage of this conservation strategy. To improve their reproductive success and population sustainability, further research is required at these protected sites, as they can provide useful insights for conservation management and habitat specific restoration.

My field-based behavioural study of translocated takahē was carried out to assess their foraging behaviours at two North Island sites, a pest-free offshore island, Motutapu Island (Hauraki Gulf, Auckland region) and a predator-fenced mainland site at Maungatautari (Waikato region). Motutapu Island is managed by the Department of Conservation (DOC). Shortly after the successful eradication of pests from Motutapu and nearby Rangitoto Island in 2011 (Griffiths et al. 2014), a total of 21 takahē were translocated to Motutapu Island. Since then, only one female has died (Ella, died August 2014) and one male has not been located (i.e. no transmitter signal) since its translocation in 2012. One juvenile hatched and survived during the 2014/2015 breeding season. In contrast, Maungatautari is a mainland island sanctuary. It is overseen by the private Maungatautari Ecological Island Trust (MEIT), and is one of the very few predator proof fenced mainland sites where takahē have been translocated. Two takahē were first introduced in 2006, with additional introductions in 2011 (three birds) and 2013 (three other birds again) (Smuts-Kennedy & Parker 2013). Two of the translocated takahē were found dead in 2014, so the current (July 2015) Maungatautari population is comprised of six translocated adult takahē and two juveniles from the 2014/2015 breeding season.

Takahē purportedly pair for life suggesting that they have a strictly monogamous mating system, although mate switching may occur after several years of breeding failures (Jamieson & Ryan 1999; Jamieson & Ryan 2001; Lettink et al. 2002; Jamieson et al. 2003). Pairs occupy seasonal territories (5 to 60 ha) around key feeding-habitats and nesting sites, and these are defended from neighbouring pairs or groups. Following breeding, family groups (parents & juveniles) roam widely and are less predictable in their locations (Ryan & Jamieson 1998; Jamieson & Ryan 2001; Jamieson & Wilson 2003b).

Takahē feed up to 19 hours per day over the year, and habitat use is closely related to availability of preferred species (Mills & Mark 1977; Mills et al. 1991). Takahē are mostly herbivorous, however there is a brief period, when chicks are newly hatched, when they may feed on insects (Lee & Jamieson 2001). Fiordland takahē mostly feed on succulent leaf-bases of tall *Chionochloa* (Poaceae) tussock species (Mills & Mark 1977; Mills et al. 1991; Lee & Jamieson 2001). Using their beaks, the birds extract a single tiller, which usually breaks off at the stem and leaf junction (Lee & Jamieson 2001). Holding the tiller with their foot, the takahē removes the outer mature leaves and eat the basal leaf meristem section of the immature leaves (2-4 cm) (Mills & Mark 1977; Lee & Jamieson 2001; Kilduff et al. 2011). The remaining leaf is discarded in piles. This behavioural action was recorded by Baber and Craig (2003b) as ‘tillering’.

When available, grass seeds are eaten in a characteristic action called ‘stripping’ (Baber & Craig, 2003b). This involves sliding the beak up the flowering culm and ingesting the seeds as they accumulate (Lee & Jamieson 2001; Baber & Craig 2003b). Pastoral grass species leaf blades are eaten too if available, and referred to as ‘cutting’. Changes of diet are seasonal, and patterns of interspecific and intraspecific selection are based on the bird’s nutrient requirements (Mills et al. 1984; Mills et al. 1991). These requirements generally depend on nitrogen and phosphorus levels, although *Celmisia* (Asteraceae) for example is eaten for high calcium levels and the fern rhizomes (*Hypolepis millefolium*, Dennstaedtiaceae) for starch (Mills & Mark 1977; Mills et al. 1980; James et al. 2004; Jamieson 2004).

The food and feeding ecology of takahē in Fiordland differ markedly from that of takahē inhabiting offshore islands (Ryan & Jamieson 1998; Jamieson & Ryan 2001). As these locations have distinctly different habitats, alpine-tussock versus lowland broad-leaved forests and grassland habitats, it is expected that the behaviours would also differ. Differences in habitats also have an effect on the breeding season (Bunin & Jamieson 1995; Ryan & Jamieson 1998; Jamieson & Ryan 2001). As such, island takahē seem to have adapted to island vegetation, foraging primarily for introduced and/or native grasses, especially cocksfoot (*Dactylis glomerata*, Poaceae) and clover (*Trifolium* spp., Fabaceae) (Baber & Craig 2003b). Island takahē individuals were also observed to prey occasionally on native fauna including earthworms, cicadas, small lizards, and possibly brown teal ducklings (Bunin & Jamieson 1995; Bunin et al. 1997; Baber & Craig 2003b). This means that the success of takahē on offshore islands depends on their behavioural flexibility, which is their ability to adapt to novel environments (Bunin et al. 1997; Ryan & Jamieson 1998; Jamieson & Ryan 2001; Baber & Craig 2003b).

Takahē may be one of the most researched bird species in New Zealand, but there are very few field-based studies on its behavioural feeding ecology on offshore islands. Home range and habitat studies have been conducted on Mana Island, Kapiti Island and Tiritiri Matangi Island, providing indirect insights on feeding ecology and habitat use (Ryan & Jamieson 1998; Jamieson & Ryan 2001; Baber & Craig 2003a; Jamieson & Wilson 2003b). Baber and Craig (2003b) have conducted the only research to date specifically on takahē feeding ecology related to habitat use on islands, but the research was limited to three takahē family groups on Tiritiri Matangi Island.

2.2 OBJECTIVES

The aims of this research were to determine: (1) how takahē foraging behaviour differed between pasture and other habitats on Motutapu Island and at Maungatautari, (2) how other habitat elements (including vegetation cover, water, roads, tracks) affected foraging behaviour, and (3) if habitat restoration may be needed to improve takahē establishment.

2.3 MATERIALS & METHODS

2.3.1 Takahē populations at study sites

In total, 24 birds were observed over the austral summer of 2014 and eight months of the year 2015 (from July 2014 until February 2015). These birds formed nine pairs or/and family groups (Table 2.1). Birds that subsequently joined a pair were part of the family group, and were also observed, as these individuals contribute to the breeding success by helping the pair raise their chick (Table 2.1). Only birds that were in pairs or family groups were observed during this research study. Radio transmitters were fitted to the all the birds by Department of Conservation (DOC) staff upon release and are removed when the individuals reach four to five years of age.

Table 2.1: Names of birds, present pairing and family groups, territory, and number of nests and chicks in the breeding season of 2014/2015. Refer to maps (Appendices 1&2) for territories and Appendix 7 for age, sex, origins and transmitters frequency of individual birds.

Pairs or Family groups	Locations (Area)	Nests	Chicks
Motutapu Island			
Raumati,Westy & Ariki	Nursery & Islington Bay	2	1
Bradshaw, Charlie & Emelius	Islington Bay	2	0
He Maipa & Autahi	West Point & Pig Bay	1	0
Bligh & Tautari	MOEC (Motutapu Education Camp) & Pig Bay	1	0
Beacon, Chalky, Bowen & Te Rangi	Mullet Bay	2	1 (died)
Hemi & Ella (original pair), then Pearl (8/14), then Tarawera (11/14)	Home Bay (Ella, then Pearl) & Central Gully (Tarawera)	2	0
Maungatautari main mountain fenced site			
Te Wero & Marlee	Cooper & Garland (264-341)	1	1
Ngutu Whero & Nancy	Brown & Ramsey (204-264)	1	1
Maungatautari Tautari wetland fenced site			
Hauhunga & Matariki	Tautari Wetland	2	0

2.3.2 Motutapu Island

Motutapu Island is a low-lying island of approximately 1509 hectares with rolling topography (Davidson 2013; Griffiths et al. 2014). One of the oldest islands of the Harauki gulf, Motutapu is linked by a causeway and an extensive area of sand flats to Rangitoto Island, which is the youngest volcanic island of Auckland. The coastline is mainly composed of steep rocky cliffs, rocky shore platforms, and swampy, steeply backed beaches (Griffiths et al. 2014). The primary habitat available on Motutapu Island is pastoral farmland, with some areas of regenerative native forests (i.e. mostly mānuka *Leptospermum* spp., kānuka *Kunzea* spp., Myrtaceae), forest remnants (coastal pohutukawa fringes *Metrosideros excelsa*, Myrtaceae and exotic pine forests, etc.) and wetlands (mostly raupo *Typha orientalis*, Typhaceae) (Griffiths et al. 2014; Department of Conservation n.d.) (Appendix 1). Motutapu and Rangitoto islands are now managed together by DOC as an open sanctuary and are accessible to the public.

Apart from livestock (cattle and sheep) and trained farm dogs, no non-native mammals are present or allowed on the islands (Griffiths et al. 2014).

Motutapu Island takahē population monitoring

All adult birds were translocated to Motutapu Island (no island-bred chicks until breeding season 2014/2015). Nevertheless, family groups were formed after translocations. The data collection via radio-telemetry was done on foot.Three pairs and three family groups (two groups of three and one group of four) were observed on Motutapu Island (Table 2.1). Normally, a family group of takahē forms when a pair of takahē has a juvenile that stays the successive year with them to help raise the chick, however some family groups in this case were composed of unrelated adults.

Field observation data were collected during the summer of December 2013 until February 2014 during two fieldtrips of two weeks each (4 weeks in total) and from July 2014 until February 2015 each month, during two week long fieldtrips. I visited pairs and family groups 3–4 times per week (18–24 visits per month, depending on the weather forecast). In total, I visited the birds at least 145 times during the time of this study. Missing dates in the dataset (Appendix 3) reflect days when no birds were sighted (they were roaming long-distance or at the centre of a wetland/gully due to stress from my presence) (Figure 2.1).

2.3.3 Maungatautari

Maungatautari is an extinct volcano covered with indigenous forest, and is the largest remaining area of original forest in the Waikato basin (Smuts-Kennedy & Parker 2013). The mount rises up to 797 m a.s.l. in the central Waikato. It is bound to the east and north by the Waikato River and Lake Karapiro, respectively (Smuts-Kennedy & Parker 2013). The mountain and the forested slopes are the dominant landform in the area. The topography ranges from strongly rolling slopes at the mountain-base to steep and very steep up the peak and gullies.

The total area of native mature and regenerative forest is 3363 hectares, with 75% of this area managed as a scenic nature reserve by Waipa District Council (Smuts-Kennedy & Parker 2013). The council has a Memorandum of Understanding with the Maungatautari Ecological Island Trust (MEIT) for management functions. The remaining land is owned by adjoining farmers, iwi and Waipa District Council (Appendix 2). A 47 km predator proof fence around the entire mountain (total area: 3400 ha) was completed in 2006 (including small sub-enclosures totalling up to 18 ha)(Maungatautari Ecological Trust n.d.). The mountain went through a massive pest eradication program with brodifacoum baits. Mice are the only non-native mammal left in the reserve that could not be exterminated and active management of these were stopped in 2011 due to the high cost (Scofield et al. 2011; Innes et al. 2012; Smuts-Kennedy & Parker 2013).

Maungatautari takahē population monitoring

Maungatautari data were collected from September 2014 until February 2015. The pairs or groups were each visited at least twice per month (6 visits per month) from 9.00 am to 3.00 pm. I accompanied the MEIT staff during their weekly monitoring. It took sometimes an hour or two to travel to and in-between the sites by quad bikes. The Tautari Wetland pair was monitored the rest of the time, as they did not have telemetry sets. I visited the Maungatautari birds at least 35 times during the time of this study (Appendix 4). Sometimes the forested areas made finding takahē individuals difficult, even for the radio-telemetry to have a signal. The takahē were not followed into the forest as the terrain was sometimes too difficult and we did not want to stress the birds or force them into hiding away from their nesting and foraging sites.

Figure 2.1 below are some of the pictures I have taken of takahē territories across Motutapu Island and Maungatautari main mountain fenced site.

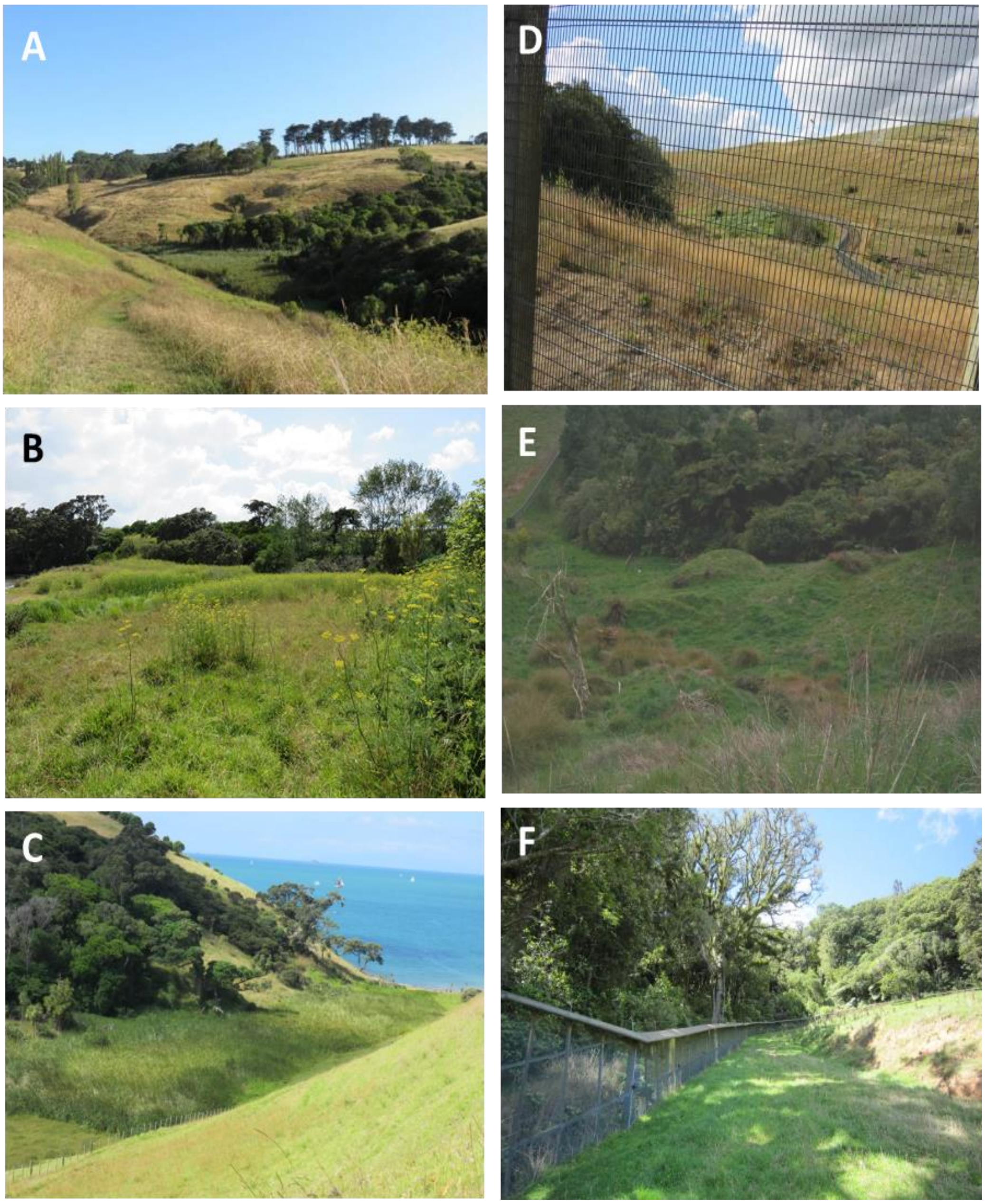

Figure 2.1: Examples of takahē territories on Motutapu Island: A. Raumati (F), Westy (M) & Ariki (M) at Islington Bay area, B. He Maipa (M) & Autahi (F) at West Point area, C. Beacon (M), Chalky (F), Bowen (F) & Te Rangi (M) at Mullet Bay area. Examples of takahē territories at Maungatautari main mountain fenced site: D. Fenced grassland of Ngutu Whero (M) & Nancy (F) territory at Ramsey farmland area, E. grassland territory of Te Whero (M) & Marlee (F) at Cooper farmland area and F. Narrow grassland area between fence and forest at Garland farmland, also used by Te Whero & Marlee (Photo F credit: Jane Reeves).

2.3.4 Data Collection

The Motutapu and Maungatautari pairs or groups' territories and habitat were identified via radio-telemetry (i.e. triangulation) and behavioural monitoring by direct observation (Baber & Craig, 2003). The target species were subjected to minimum impact as they were observed from distances not smaller than 15 metres, as used previously by Baber & Craig (2003). Behavioural data were recorded by following target birds and noting their behaviours at 1-minute intervals (see below), and habitats used were classified in rectangular variable area plots placed round their locations.

Plots in which habitats were assessed averaged 9 m (min.–max. 5–25 m) x 7 m (min. –max. 3–20 m). I placed plots visually around where takahē were located feeding so that plots contained the small takahē movementsfor each foraging observation period. A new plot was estimated if the group or pair moved from the previous plot. I did not assess habitat plots when takahē made larger movements between foraging sites (e.g. Bligh and Tautari movement from MOEC to Pig Bay).

I classified habitats within plots as the percentage cover of trees (canopy height > 6m), shrubs and grass. I noted the percentage of canopy that was natural cf planted vegetation (Appendix 1). Planted areas included the native plant nursery at Islington Bay area (some nursery planting/some restoration planting) and the planted area of pohutukawa trees (*Metrosideros excelsa*, Myrtaceae) at Mullet Bay and Home Bay. I also recorded canopy height (m), the distance in metres from takahē to roads or tracks (m), distance to house and to water source (stream, pond, plant nursery taps; m). Habitat data were taken for all observation periods, including those <30 minutes, unlike the behavioural data as described below.

The behavioural data collection method was based on the only other research study of foraging behaviour on takahē by Baber & Craig (2003b). Within each sampling period, foraging behaviour was recorded using 1 minute instantaneous sampling (Altmann 1974). This means that every minute, each individual was observed. The behaviour that was most displayed by the family group or the pair within this minute was recorded (Altmann 1974; Baber & Craig 2003b). When an individual or individuals were momentarily separated or obscured from view, observations were recorded for the visible bird or birds (Baber & Craig 2003b). Each sampling period lasted from 30–120 minutes. Consecutive samples on the same takahē group were conducted at least 1 day apart. Observations were spread evenly and randomly during the day from 7.00 am to 5.30 pm.

All behaviours – foraging and non-foraging – were recorded. Foraging behaviours were categorised into (1) cutting (grass blades or clover leaves), (2) tillering (basal meristems of grass) and (3) stripping (grass seed-heads) (Figure 2.5, see below). Instances of non-foraging behaviours were less frequent than foraging behaviour, but were categorized as moving (roaming), still, preening, allo-preening (feather cleaning) and other/unknown.

Figure 2.2: Takahē behaviours. A. Tillering (foraging for 'tiller' or eating grass meristem and disregarding grass blades), B. Still (non-foraging behaviour), C., Stripping (strip grass seeds from grass heads), D. Cutting (grass blades, here short pasture grass). Photos A. to C. are Hemi and Tarawera at Central Gully. D. Bligh and Tautari cutting at Motutatpu Education Camp MOEC (Photo credit: Louise Kyzclork, DOC volunteer).

I collected plant tillers and by field observations, identified plant species used by takahē via the NZ grass key website (Ford et al. 2007), the NZ Plant Conservation Network website (New Zealand Plant Conservation Network (n.d.)) and an illustrated book guide to common grasses, sedges and rushes of NZ (Champion et al. 2012).

2.3.5 Habitat available versus habitat takahē used

Areas (hectares) available to takahē on Motutapu Island were estimated via Arc-GIS (aerial photograph) (Table 2.2). Maungatautari areas were available in Smuts-Kennedy and Parker (2013). I also calculated the habitat use by takahē (Table 2.3).

Table 2.2: Surface areas on Motutapu Island and Maungatautari

Surface areas	**Hectares (ha)**
Motutapu Island	
Total Motutapu Island area	**1509**
Total non-pasture plant cover (wetlands, shrubs and forests)	247
Total pastoral areas	1262
Maungatautari	
Total Maungatautari area	**3400**
Total forest and shrubland	3363
Total pastoral grassland	37

Table 2.3: Percent habitat available versus average percent used by takahē per site

	Habitat available as percent of total area	**Habitat used by takahē as a percent of total takahē habitat use**
Motutapu Island		
Non-pasture areas (wetlands, shrublands and forests)	16.7	43.4
Pastoral areas	83.6	56.6
Maungatautari		
Forest and shrubland	98.9	52.5
Pastoral grassland	1.1	47.1

In terms of foraging behavioural observations, only the Motutapu Island dataset was analysed statistically, as the Maungatautari dataset had insufficient quantitative data.

2.3.6 Motutapu Island quantitative statistical analyses

There were two separate recorded datasets for Motutapu Island takahē, one for 2013-14 and one for 2014/15 (Figure 2.3). During the summer of 2013/2014, from 29 January to 2 February 2014, 10 sets of behavioural observations were made. There were 487 minutes (~8.12 hours) of behavioural activities recorded over this time, 292 (60.0%) of which were of foraging behaviours. Of the 292 minutes of foraging behaviours, 139 (47.6%) were of cutting grass blades or clover leaves, 128 (43.8%) were of tillering grass meristems and 25 (8.6%) were of stripping seeds (Appendix 5).

During the year of 2014/2015, from 17 July 2014 to 26 January 2015, 29 sets of observations were made. There were 1664 minutes (~27.33 hours) of behavioural activities recorded over this time, 1144 minutes (68.8%) of which were of foraging behaviours. Out of the 1144 minutes, 641 (56.0%) were of cutting, 433 (37.8%) were of tillering, and only 70 (6.1%) were of stripping. As seen in Figure 2.3, there were not many differences of recorded behaviour between the datasets, so they were combined together for the multinomial regression analysis (Appendix 5). No invertebrate foraging behaviours were observed during the time of the study.

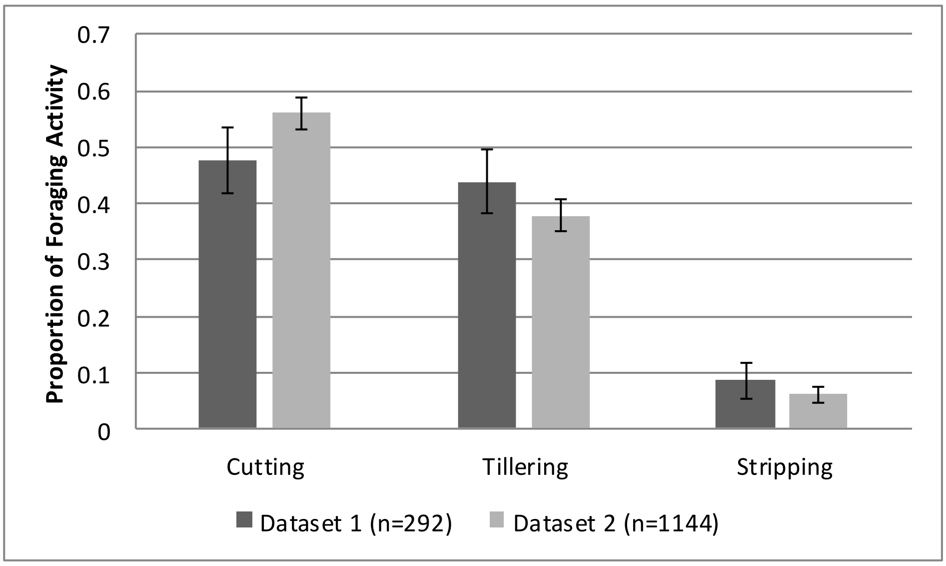

Figure 2.3: The proportions of major takahē foraging behaviours on Motutapu Island, split between two datasets (2013/14 and 2014/15). Error bars are 95% confidence intervals.

Almost all visits to the different groups and pairs of Motutapu takahē resulted in habitat data collection (Appendix 3). However, collecting the minimum 30 minutes of behavioural data per visit was not always possible and the typical sampling period lasted 5 –15 minutes rather than the standard 30 minutes. This time period of 5–15 minutes was sufficient to assess the plot size (length x width) and habitat elements, such as distance to roads or percentage cover used by family groups and pairs. The numbers of foraging and non-foraging actions observed were matched to each visit made to the family groups and pairs during the time of the study (Appendix 3 and 5).

The multinom() function in the nnet package (Venables & Ripley 2002) for the R statistical software (R Core Team 2013) was used to perform multinomial logistic regression with the foraging behaviours as response variables, and habitat variables as predictor variables. Results inferred from this analysis are not necessarily applicable to the entire takahē population. The aim was to assess if there were any consistent habitat variables motivating foraging behaviours in takahē on Motutapu Island.

The data presented some difficulties, as the multinom() function ignored the entire dataset where there were no nearby roads or houses. This is because this information was not available for takahē observed in areas where there were no houses or roads within sight. The data were technically right-censored, as we know the distance is at least as faraway as the eye can see in the distance, but we do not know how much further. That is why the records from areas where there were no roads or houses were treated separately.

The effects of the predictor variables are taken as the expected multiplicative factors of the odds of one response relative to a baseline response for a unit increase of the predictor variable. The ***odds*** of a particular behaviour occurring is the probability of this behaviour occurring divided by the probability of any other behaviour occurring. The results are presented with 95% confidence intervals. These intervals only concern the significant effects at the 5% level of significance, i.e. where the effect was concluded to be due to more than just random variation in the data. The effect of any variable associated with such intervals would have a p-value less than 0.05. Thus, the confidence intervals convey not only the significance of the estimated effects, but also a sense of the size of those effects.

2.4 Motutapu Island statistical results: takahē foraging behaviour relative to habitat components

2.4.1 Tillering versus cutting

Tillering was more time consuming than cutting. This is because the entire grass stem is cut off at the base or sometimes the entire grass plant is entirely rooted out. The takahē then holds the grass, removes the basal blades (or the roots) and feeds only on the leaf-base (2-4 cm of meristem) before discarding the rest into piles (Lee & Jamieson 2001). This was observed especially for long pastoral grass or other large native and introduced species (i.e. toetoe *Austroderia* spp., pampas grass *Cortaderia selloana*), which is generally foraged by takahē via tillering rather than cutting grass blades.

Table 2.4 presents the significant effects of habitat elements on tillering behaviour relative to cutting behaviour. As the percentage of tree cover increased (canopy height> 6 metres), the odds of tillering decrease. Increasing the percentage of shrub cover increases the odds of tillering. With every extra metre of canopy height that is added to this shrub layer, the odds of tillering increase as well. It seems that extra height to the average canopy of shrubs and trees favours tillering behaviour, until the percentage of tree cover (> 6m) becomes high, where cutting is favoured instead. Non-vegetation habitat elements, such as housing, roads and water, showed some significant effects on takahē foraging behaviour. For each metre further from the houses, assuming there are houses nearby, the odds of tillering decrease. For each metre further from roads, the odds of tillering increase. Finally, for each metre further from water, the odds of tillering decrease. This overall means that tillering tends to occur to houses and water, but not close to roads.

Table 2.4: Odds of tillering relative to the odds of cutting

Variable	Point estimates	95% Confidence Lower Bound	95% Confidence Upper Bound
Percentage Tree Cover	0.939	0.884	0.997
Percentage Shrub Cover	1.075	1.037	1.114
Canopy Height	2.106	1.696	2.615
Distance from the takahē to houses	0.912	0.862	0.964
Distance from the takahē to roads	1.046	1.015	1.078
Distance from the takahē to water	0.900	0.765	0.931

However, there were some instances where I observed many displays of tillering on maintained grass, in open spaces close to houses and roads (Appendix 3). This may be due to shrub and tree cover areas close to the houses and roads at some of the sites (e.g. Central gully, road crosses over surrounding wetland and pine forest) (Appendix 1). Takahē individuals that were observed tillering next to houses were not deterred by open grassland, as they may be over-familiar with humans, such as Bligh (M) and Tautari (F) (Motutapu Education Camp MOEC) or the birds at Home Bay (tourist camp-site) where MOEC and DOC staff regularly work.

2.4.2 Stripping versus cutting

Although the odds of stripping increase under specific weather and seasonal conditions (Austral Summer), it does not necessarily mean that the odds were very high to start with. Stripping was the least observed behaviour (Figure 2.3). Further, stripping is not as time consuming as tillering, as a takahē is only sliding its beak along the grass stem to remove the seeds. However, it is much more conspicuous than cutting or tillering. I observed that the head was easy to detect while stripping, even in long grass and/or from long distances (25-30 metres), rather than when individuals were displaying tillering or cutting behaviours.

According to table 2.5, increasing the percentage of tree cover (vegetation >6 m. high) increases the odds of stripping. This suggests that stripping behaviour is favoured at sites with high tree cover, compared to cutting. Increasing the percentage of planted plant cover (for native plant restoration purposes) increases the odds of stripping. This means that takahē favour stripping at plant restoration sites, rather than cutting.

Non-vegetation habitat elements also have significant effects on stripping. For each extra metre further from the houses, the odds of stripping increase. Stripping tends to occur further from houses, compared to cutting. For each extra metre from the road, the odds of stripping increase, suggesting that stripping also tends to occur further from the road.

Table 2.5: Odds of stripping relative to the odds of cutting

Variable	Point estimates	95% Confidence Lower Bound	95% Confidence Upper Bound
Percent tree cover	1.585	1.119	2.245
Percent artificial planting	1.132	1.033	1.240
Distance from the takahē to houses	1.337	1.172	1.525
Distance from the takahē to roads	1.213	1.052	1.399

2.4.3 Stripping versus tillering

It is interesting to note the significant effects of stripping versus tillering are similar to the significant effects that we identified for stripping versus cutting (Table 2.6). According to table 2.6, increasing the percentage of tree cover increases the odds of stripping. This means that stripping tends to occur at sites with high tree cover (> 6 metres). Increasing the percentage of planted plants increases the odds of stripping. This suggests that stripping tends to occur at sites with high tree cover and restoration planting sites.

Again, for each extra metre further from houses, the odds of stripping increase. Stripping tends to occur further from houses compared to tillering. Finally, for each extra metre from the road, the odds of stripping also increase. It seems that stripping tends to occur further from the road.

Table 2.6: Odds of stripping relative to the odds of tillering

Variable	Point estimates	95% Confidence Lower Bound	95% Confidence Upper Bound
Percent tree cover	1.697	1.197	2.407
Percent artificial planting	1.120	1.023	1.228
Distance from the takahē to houses	1.470	1.277	1.692
Distance from the takahē to roads	1.158	1.007	1.331

The results discussed above are summarized into Table 2.7.

Table 2.7: Probability of occurrence of takahē foraging behaviours according to habitat: (1) most favourable behaviour according to the habitat variable, (2) second most favourable behaviour- significant, (3) least favourable behaviour- still significantly different. Blank cells are not significant.

Habitat variables	**Tillering**	**Stripping**	**Cutting**
Percent tree cover (>6m)	3	1	2
Percent shrub cover	1		2
Canopy height (from 0 to – m)	1		2
Percent planted		1	
Increasing distance from takahē to houses	3	1	2
Increasing distance from takahē to roads	2	1	3
Increasing distance from takahē to water	2		1

2.4.4 Maungatautari qualitative data and observations

During the year of 2014/2015, from 16 September 2014 to 10 February 2015, 10 sets of observations were made at Maungatautari. There were 112 minutes (~ 1.8 hours) of behavioural activities recorded over this time, 75 minutes (70%) of which were of foraging behaviours and 37 minutes (30%) of non-foraging behaviour. Out of the 75 minutes of foraging behaviours, 22 (29.3%) were of cutting grass-blades or clover leaves, 29 (38.7%) were of tillering for grass meristems, and 24 (32%) were of stripping seeds.

Qualitative data indicates that Maungatautari takahē seem to be tillering, cutting and stripping in the pastoral areas between the edge of the forested areas and the pest-proof fence (Appendix 6). Takahē at the Tautari wetland were observed to cut grass blades and strip seeds in the open space between the pond and the regenerative forest (i.e. mostly mānuka *Leptospermum* spp., kānuka *Kunzea* spp., Myrtaceae).

Forested areas were thought to be used as shortcuts to access the scattered grassland (Jane Reeves, MEIT, pers. comm. and pers. obs.). This was hypothesized as takahē left the large grassland areas they were using as nesting and chick-rearing to travel long-distance (approximately 15 km sometimes) after their chick was at juvenile stage. At some of these sites, takahē could not have been accessed as rapidly without crossing the mountain (refer to Appendix 4). No broad-leaved shrubs or ferns were eaten by takahē during direct observation. No invertebrates foraging behaviours were observed either.

2.4.5 Plant species list used by takahē as food

Several grass species were identified during foraging behavioural observations (i.e. while they were feeding, collected sometimes tillers and grass for later identification) on Motutapu Island and Maungatautari (Table 2.8) and are listed. As the data are qualitative, it is not confirmed if these plants were eaten by takahē simply because of their presence, or if they have a particular preference for them. All species were from the Poaceae plant family (mostly pastoral grass species), apart from clover species (Fabaceae).

Takahē behavioural habits overlapped for some grass species, meaning that one species may have been tillered for grass meristem, stripped of seeds and grass blades cut (Table 2.8). Sometimes, plant morphology constrained behavioural habits. For example, pampas grass *Cortaderia* spp. (Poaceae) leaves were not cut as they may have been too big or too hard to eat. These large plants were instead tillered for their meristems. Clovers were too small to be tillered, thus only leaves were eaten. I observed that, generally, pastoral grass that was maintained short via mowing were mostly foraged for grass-blades. However, there were some instances where even if the pastoral grass species was mowed, the birds would tiller for the meristems. I did not observe takahē eating any broad-leaved shrub leaves or ferns during direct observations.

Table 2.8: Plants eaten by takahē on Motutapu Island and observed behaviours

Plant species	**Tillering**	**Stripping**	**Cutting**
Motutapu Island			
Poa spp.	+	+	+
Paspalum spp.	+	-	+
Agrostis spp.	+	+	+
Arrhenatherum spp.	+	+	+
Bromus spp.	+	-	-
Festuca spp.	+	+	-
Lachnagrostis billardierei	+	-	-
Dactylis glomerata (cocksfoot)	+	+	+
Pennisetum clandestinum (kikuyu)	+	-	+
Austroderia splendens (toetoe)	+	-	-
Trifolium spp. (clover)	-	-	+
Cortaderia selloana (pampas grass)	+	-	-
Maungatautari			
Poa spp.	+	+	+
Agrostis capillaris (browntop)	+	+	+
Holcus lanatus (yorkshire fog)	+	-	-
Trifolium spp. (clover)	-	-	+

2.5 Discussion

In this particular research study, 24 free-range translocated takahē birds were observed at two different sites with distinct habitats, Motutapu Island and Maungatautari a predator free mainland ecological island. It was only on Motutapu Island that sufficient foraging behavioural observations were recorded for statistical analyses, but not for Maungatautari since the takahē population was too small and the data collected was too sparse. However, the qualitative results obtained on Maungatautari are discussed as they give some insights of their foraging behaviour in their particular habitat.

As Motutapu Island is mostly composed of pastoral grassland, with highly scattered vegetation cover (Tables 2.2 and 2.3) (Appendix 1), the translocated takahē population may be restricted to tall vegetation areas, thus fewer food resources may be accessible to them (Baber & Craig 2003a; Baber & Craig 2003b). This might then hinder their feeding and nesting habits, thereby affecting nutrient requirements and breeding success. Kilduff et al. (2011) and other research studies stated that the takahē will not use wide open spaces if there is no cover nearby to hide from aerial predators (Australasian harrier, *Circus approximans*) (Ryan & Jamieson 1998; Jamieson & Ryan 1999; Jamieson & Ryan 2001; Baber & Craig 2003a). However, this was not always the case for some family groups and pairs, as they sometimes were observed to be foraging 25 metres away from any cover (i.e. Bligh and Tautari, MOEC).

Compared to Maungatautari, Motutapu Island has more grassland areas available for food resources. Although Maungatautari is larger in size, the main mountainous fenced site being 3400 hectares (Motutapu Island: 1509 ha), most of it is forested (3363 ha forested, 37 ha grassland) (Tables 2.2 and 2.3) (Smuts-Kennedy & Parker 2013). Maungatautari has more dense forested cover, for nesting and dispersal, compared to Motutapu Island. However, Maungatautari has much smaller patches of grassland, thereby reducing takahē nutrient requirements (Appendix 2).

According to direct observations collected during this field research study, it was found established that on Motutapu Island, takahē spent 60% of the total observed time foraging during the summer of 2013/2014. Of the time spent foraging, 47.6% was spent eating grass blades or clover leaves, 43.8% was spent eating grass meristems, and 8.6% was spent eating seeds. During the year of 2014/2015, Motutapu takahē foraged 68.8% of their time. Of the time spent foraging, 56% was of eating grass and clover leaves, 37.8% was of eating meristems, and 6.1% was of stripping (Figure 2.3). Percentages of eating grass blades and meristems were very high compared to stripping seeds, which mostly occurred only during flowering time during Austral summers. Eating grass blades or meristems did not differ much during summer of 2013/2014, although during the year of 2014/2015, the percentages of time spent eating grass blades versus eating grass meristems differed by almost 15%.

At Maungatautari, for 70% of the observed time, takahē were foraging. Of the time spent foraging, 29.3% was spent eating grass-blades or clover leaves, 38.7% was spent eating grass meristems, and 32% was spent eating seeds. It is interesting to note that many more instances of tillering behaviours were recorded at Maungatautari compared to Motutapu Island.

2.5.1 The effects of vegetation type cover on takahē foraging behaviour and insights on behavioural manipulation according to vegetation restoration.

In terms of behavioural habits (tillering vs stripping vs cutting), it was found that differences in percentage of vegetation type cover affected takahē foraging behaviours (Table 2.7). Cutting behaviour (grass blades) was the most observed behaviour (Figure 2.3) compared to tillering and stripping on Motutapu Island. Instances of cutting behaviours were mostly observed in open grassland (mainly pastoral grassland), sometimes at the edges of tall, vegetated areas (at wetlands and gullies), and especially favoured next to roads/tracks (Tables 2.4 and 2.5). This further confirms percentages calculated of habitat use, as the pastoral grassland was the vegetation type most used by takahē. On Motutapu Island, while 83.63% was available on Motutapu Island, the birds used areas with 56.6% of this type of vegetation. On Maungatautauri, even if not analysed statistically, pastoral grassland use was found to be much more disproportionate. Only 1.1% of pastoral grassland was available at Maungatautari, but the percentage used of this cover type by takahē was 47.1% (Table 2.3).

Tillering was a time-consuming behaviour compared to the other two behaviours, and it was found to be the most favoured behaviour at sites with high shrub cover. In addition, with every metre of height added to this shrub cover, the probability of tillering behaviour occurring also increased (Table 2.4). However, at sites with high forested cover of more than 6 metres in height, growth of undercover shrubs and grass may have been inhibited by light and water. Tillering was then the least favoured behaviour at highly forested sites. On Motutapu Island, while 16.37% of habitat available was tall vegetation, takahē used 43.4% of this vegetation type. It seems that Motutapu Island takahē, even with very scattered (Appendix 1) vegetation remnants and restoration plantings, still used the areas with tall vegetation as foraging sites most often. Even though it was not possible to calculate if takahē used more shrubland/forest than the pastoral grassland at Maungatautari via statistical analysis, we estimated percentage plant cover type and direct observations, which suggests that takahē mostly used the forest edges. So although the forest covered 98.9% of the fenced area, the birds used this only 52.5% of the time (Table 2.3).

It is unclear why tillering behaviour still occurs at offshore islands, especially at Motutapu Island, as it seems that pasture grass (or other species) blades (leaves) should provide enough nutrients and soluble sugars (Table 2.8). It may be an innate behaviour that has evolved with this species (Mills et al. 1984). *Chionochloa* species eaten by Fiordland takahē do have high levels of nutrients and soluble sugars in the lower cut of the meristem (Williams et al. 1976). Pastoral grasses on the other hand have even higher levels of soluble sugars, compared to *Chionochloa* species (James et al. 2004). Thus, in the case of offshore islands and fenced mainland sites, pastoral grass species differences in nutrients and/or soluble sugars levels in meristem (versus grass blades) may be driving takahē to tillering some plant species more so than others (Williams et al. 1976; James et al. 2004). Another reason for island takahē to continue this tillering behaviour may be due to grass meristem may have higher water content, fewer secondary compounds and are softer and easier to digest (Evert 2006). This means that if tillering for grass meristems is more advantageous for takahē to meet their nutrient requirements compared to eating grass blades, it would then be necessary to increase the mixture of grass/shrub areas. This should be done via restoration planting, rather than increasing forested areas or leaving wide-open pastoral grassland unmanaged.

Compared to tillering, stripping was not as time-consuming (Tables 2.6 and 2.7), as the only motion is to slide beak along the grass-heads and feed as it accumulates. However, stripping is the more conspicuous foraging behaviour as it is easier to spot takahē's head and neck among grassland as they sometimes have to stretch out their head to get to the grass-heads (pers. obs.). Stripping was found to be most favoured behaviour at sites with high tree cover and restoration planting areas (Table 2.7). Some of these sites where observations took place were sites with predominately coastal pōhutukawa as tree cover species, which have a very sparse canopy and not much shrubland growing underneath. This sparse canopy would not hinder grass cover, but as there are no shrubs to hide in, it may be why takahē may be stripping seeds rather than tillering grass meristems at these sites.

As for restoration planting, behavioural differences were especially observed for birds that had restoration planting as part of their territory (i.e. Raumati family group, Islington Bay) compared to the sites where birds had access to only natural forest remnants. It may be an unexpected advantage for stakeholders (i.e. Takahē recovery group, Motutapu Island trust, etc.) that stripping tends to occur at restoration planting sites. Grass seeds may have very high nutritional value compared to other plant parts (tiller/leaf), but this was not determined especially for takahē nutrient requirements. The only studies on takahē plant food nutritional requirements (Williams et al. 1976; James et al. 2004) mostly measured the plant tiller and blades, but seeds by themselves were not considered as potential drivers of foraging behaviour. Within restoration planting sites, it might be interesting to compare if it the type of tree or canopy height that affected takahē behaviour.

The results found in this study support the findings of Baber and Craig (2003b) in that takahē may use more shrubland (with a mixture of extensive grassland) to forage for vegetation, rather than forested or open grassland areas. Baber and Craig (2003b) particularly highlighted the problem of natural forest succession at Tiritiri Matangi Island, where less grassland may be available to support an adequate number of takahē individuals (Baber & Craig 2003b). Forest regeneration, at the expense of grassland and shrubland, may also be an issue that would affect takahē habitats on Motutapu Island and Maungatautari.

2.5.2 Non-vegetation habitat elements (roads, houses and water) effect on takahē foraging behaviours, in relation to takahē over-familiarity with humans

Non-vegetation habitat elements, such as the presence of roads, houses, water sources (ponds, streams, etc.), seem to have significant effects on foraging behaviours (Table 2.7). The main findings were that cutting was the most favoured behaviour closer to roads rather than tillering or stripping (Tables 2.5 and 2.6). Although disturbances occur more often around roads, takahē still used these areas for foraging. The presence of water sources were also sites where tillering tends to occur more often than cutting.

An interesting finding is that around houses, tillering was found to be the most favoured behaviour, rather than cutting or stripping (Tables 2.4 and 2.5). This was observed for only some pairs that were over-familiar with humans, and wide open spaces of short pasture grass did not deter them from displaying tillering foraging behaviour (especially at MOEC and Home Bay). This is because foraging behaviour seems to be affected by the presence of humans (Savillo & Villaluz 2013). Indeed, I had observed that collecting data for the takahē pairs and family groups at MOEC, Home Bay and Islington Bay, where people are frequently found, was less difficult compared to recording data of the takahē individuals located at Mullet Bay and West point. This was especially the case for Tautari (Female) at MOEC, who would stop foraging and approach me at a distance of less than 5 metres.

A few examples of behavioural habits that may affect the status of endangerment of certain bird species, that are applicable to takahē are: (1) inappropriate habitat selection (selected habitat with poor food quality, or no vegetation cover, etc.), and (2) inhibited dispersal, where for example individuals cannot disperse across wide open grassland areas to more favourable habitats (Reed 1999). These examples are definitely the case for some takahē individuals on the islands. These ‘negative’ behavioural habits, as possible factors of takahē decline, have not been assessed thoroughly.

Takahē that are over-familiar with people on Motutapu Island may not be the only ones that may have behavioural habits affecting their survival. One example would be Bradshaw (M), with Charlie and Emelius (F) around the Islington Bay area (Appendix 1) have a territory with a very narrow fringe of vegetation growing on cliffs, right next to pasture grassland used by cattle, hence, this territory especially may not be the best area for foraging. The presence of water sources (i.e. streams) may be the best explanation for the selection of this specific area. Thus, increasing water availability at sites that have plenty of vegetation cover (or where it is planned to increase vegetation cover via restoration) may be the best way to improve takahē habitats. As discussed above, tillering grass meristems was also the most favoured behaviour around water. It would also be beneficial then to add water sources if eating meristems do fulfil more takahē nutrient requirements than eating grass blades or seeds.

2.5.3 Qualitative observations - invertebrate foraging and some insights on Maungatautari takahē for further conservation management

Baber and Craig (2003b) suggested that on Tiritiri Matangi Island, forested areas were mainly used for foraging invertebrates (insects, worms, etc.). However, foraging for invertebrates was not often observed on Motutapu Island, which may be because there are greater grassland areas available for takahē, so they do not need to obtain additional nutrients from eating invertebrates. Or it may simply be that there is less forest than grassland, thus insufficient invertebrates were available for food. It would be interesting to carry out an invertebrate survey on Motutapu Island to know if it is an abundant food source or not. In addition, according to Baber and Craig (2003b), invertebrates foraging mostly occurred during the young age stages of the chicks. The low number of chicks hatched this season on Motutapu Island (1 chick) and Maungatautari (2 chicks) compared to the number of adults (24 adults) may also have an effect on why invertebrates foraging was not observed, as young chicks mainly need to eat invertebrates for growth. And there is a definite lack of data here as young chicks were hidden by the pairs of family groups during the time of the study.

In contrast with Motutapu Island, takahē individuals at Maungatautari main mountain fenced site were very difficult to observe. Takahē foraging behaviour was not always observed more than 5 to 10 minutes, and individuals at the main mountain especially were stressed by the observer or MEIT staff. Some instances of behaviours were observed while they were feeding on the supplementary food provided by the MEIT staff during monitoring (hopper-feeding device recognizable by takahē). This is one of the reasons why the data were so sparse, in addition to logistic reasons and the difficult terrain. Another plausible reason for difficulties in direct observation is that Maungatautari takahē hardly interacted with humans, apart with the MEIT staff. The birds were highly stressed by my presence and the fact that the observations were conducted during the breeding season (September 2014 until February 2015).

Most direct observations of Maungatautari takahē individuals were made between the edge of the pest-proof fence, in pastoral grassland, and the edge of the native forest and shrubland (Appendices 4 and 6). Maungatautari takahē may forage more for invertebrates as they seem to be using the forest as shortcuts to several scattered grassland areas around the edges of the fence. However, not many direct observations were made in the forested areas of Maungatautari. Thus, it is only a suggestion that they may be foraging more for invertebrates at Maungatautari than in Motutapu Island. It would be very interesting to know exactly what takahē do in the forests, maybe with live-feed cameras along the plausible pathways that they are using for movements (Kays et al. 2010).

2.5.4 Plant list, recommendations for future research and the importance of understanding functional foraging behaviour for conservation science

There are several reasons why wild animal functional behaviours should be studied extensively, especially in terms of conservation management of an endangered species (Sutherland 1998). First, animal functional behaviour, especially foraging habits can inform habitat requirements at sites where translocation would take place. Collecting diet and foraging habit datasets can provide information for future vegetation restoration of different ecosystems (i.e.

wetland, forest, etc.). Analysing faecal matter in the future via morphology or DNA might be also essential to identify foraged plants.

Some pastoral grass species were identified during the foraging behavioural study (Table 2.8). A recommendation that has stemmed from this plant list is that, as the birds mainly use pastoral grasses for food, it would then be deemed important to know exactly how these specific species are distributed across Motutapu Island and Maungatautari. Consequently, by knowing the distribution of grass species eaten by takahē, their habitat selection may be better understood in the future. Further, according to Baber and Craig (2003b), it was found that native grass was the habitat most used by takahē at Tiritiri Matangi. This was not particularly the case here, but that may simply be because introduced species were prominent at these sites. If restoring native grass at these sites is possible, further research on foraging may have to be done to assess plausible changes in behaviour.

Vegetation restoration may also need to take into account the animal species dispersal method in fragmented populations (Sutherland 1998). Motutapu Island and Maungatautari takahē populations are still very small, so it is unclear how exactly they choose suitable habitats, with or without proper vegetation corridors to access the different foraging sites. In most cases, individuals just stayed in the area they were translocated to (i.e. West Point pair), or they roamed widely before finding a suitable territory (Mullet Bay, MOEC, Islington Bay family groups). This study showed that the takahē had to use a wide range of different habitats (or roam long distances in the case of Maungatautari), to obtain food.

This study also demonstrates the concept of trade-offs, such as predation risk (i.e. aerial predation from Australasian harrier) versus food supply (Sutherland 1998). I observed three instances when takahē hid in the bush because of Australasian harrier at MOEC and Home Bay. If food is available in open grassland, foraging behaviours at these sites may be predominant rather than avoiding aerial predation. Another clear trade-off demonstrated here is human disturbance versus food supply. Even with the risk of being disturbed by humans, takahē may still choose these areas for foraging (i.e. MOEC, Home Bay campsites, Motutapu Island). Differences in behaviours were found to be significant depending on the presence of houses or roads (Table 2.7).

Lastly, there is the concept of retaining "cultural skills", such as foraging methods, food recognition, etc. (Sutherland 1998). Takahē chicks learn from their parents how to forage (tillering vs. cutting), and what species to feed on. Translocating takahē was not an issue for offshore islands as they learn rapidly how to use and feed on introduced pastoral grass (Table 2.8). However, it was observed by the Takahē recovery group (Phil Marsh, pers. comm.) that re-introducing island takahē to the South Island was not possible. A few island takahē were transferred to the South Island, but before they could be released into the wild, these individuals had to be 'winter-trained' at Burwood captive takahē facility (Kilduff et al. 2011).

This may mean that by transferring birds to such a different habitat, we may loose certain aspects of takahē behaviour ('cultural skills'), thus maybe causing the species to evolve into a new one (Sutherland 1998). Natural selection and adaptations to these new environments may affect genetic variation over time (Conant 1988; Sutherland 1998). Thus, the best recommendation at present is to use localized plant species adapted to these offshore islands and mainland sites, and maybe re-introduce a variety of native species specific to the region with high nutrients (Motutapu Island: Auckland region versus Maungatautari: Waikato region).

2.6 Summary of the research study

Habitat available and habitat use was estimated according to surface areas, and observational data on Motutapu and Maungatautari. Statistical analysis was only conducted for Motutapu Island dataset as Maungatautari dataset was insufficient, and more qualitative than quantitative. On Motutapu Island, cutting was the most probable behaviour in open grassland, and/or at the edges of forested, shrubland or wetlands. Tillering from grass meristems was more probable at sites with shrubland cover, rather than forest or open grassland. This may be because, as a vegetation type, shrub lands offers a mixture of food resources and vegetation cover, which seems to encourage the time-consuming foraging behaviours that is tillering. Tree cover over six metres inhibits grass and shrub cover, thus cutting and stripping were found to be the most probable foraging behaviour.

Proximity to houses, roads and water also affected takahē behaviour at Motutapu Island. While roads were sites where cutting grass blades behaviour was most likely to occur, areas next to houses and water were where takahē were most likely to be tillering. Tillering close to houses may be because the birds were over-familiar with human presence. Over-familiarity may have a significant effect on overall results, as in some instances, tillering next to houses in wide open grassland was observed at Motutapu Island (MOEC and Home Bay campsites). At Maungatautari, takahē were often found foraging at pastoral grassland, between the forest edge and the fence. Finally, a plant list of takahē food was made according to the foraging behavioural study. Many introduced species (e.g. *Dactylis glomerata*, *Trifolium* spp., etc.) seem to have been foraged on by takahē at Motutapu Island and Maungatautari. It may be beneficial in the future to encourage further native plant restoration planting, especially for native grass, sedges, etc. Foraging behaviour may significantly differ from sites that have more native species rather than introduced species.

More takahē behavioural studies should be conducted to fully understand the functional behaviour that is foraging, how it drives takahē biology and ecology, and to identify takahē habitat requirements. Many behavioural traits in this research study were not consistent across among the individuals of Motutapu and Maungatautari. Behaviour also differed greatly among different Motutapu Island sites. All cognitive abilities were not necessarily identified for wild takahē. Although there are seasonal movements across different areas, in terms of behaviour, we are not sure how they select these areas in the first place. It is unclear if it is instinct, learning and/or memory that enables the movements between sites, and how exactly their habitat use is related to foraging behaviour.

Not much is known about how individual behavioural habits might drive differences in foraging behaviours and habitat use across takahē from different offshore islands and mainland sites. We also need to assess how much over-familiarity takahē would show with humans and how this affects their behaviour, as well as if they differ greatly across specific sites. Domestication may easily happen when takahē often interacts with human and may affect instinctual behavioural habits against predation.

Overall, this research was conducted to further understand takahē foraging behavioural habits, and how it might drive their habitat use at two protected distinct sites. This type of study should be deemed important as the takahē is an invaluable asset of the New Zealand fauna, as it is one of the largest ground-dwelling flightless rails in the world. By understanding its behaviour and ecology, we would be able to improve its conservation management in the future.

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Chapter 3

General observations

Motutapu Island and Maungatautari translocated takahē breeding season 2014/2015, and recommendations for future habitat restoration

3.1 Introduction

Takahē populations have been translocated to many pest-free fenced sites and offshore islands across New Zealand (NZ) for conservation management (Lee & Jamieson 2001). Motutapu Island (1509 ha) is the largest of these, and it is expected to hold up to 20 breeding pairs in the future (Hazel Speed and Phil March, DOC, pers. comm.). However, since the island is still composed of about half pastoral grassland, it may need habitat restoration management (Griffiths et al. 2014). In contrast, the pest-fenced Maungatautari mainland site (3400 ha) has dense mountainous forest (3363 ha of 3400), with little grassland (37 ha) at forest edges. Maungatautari also has a wetland fenced site whose habitat and size can support one pair of takahē. Habitats are likely to change on Motutapu Island as it is subject to active restoration management. Similarly, Maungatautari is not actively maintaining the grassland pastoral sites, which means that natural forest succession at these sites might decrease food availability for takahē in the future (Connell & Slatyer 1977).

Qualitative observations were made at these two sites during the 2014/15 breeding season and the findings will be discussed. I will also consider recommendations for future habitat restoration management according to takahē requirements, according to my observations and findings. These recommendations will be specific for these sites. To understand the conservation management of takahē, the ongoing debate about habitat requirements of takahē on offshore islands and mainland fenced sites will be discussed first.

3.2 Translocation of takahē – the debate

The ‘natural’ habitat of the takahē has been the topic of many debates in the past (Jamieson & Ryan 2001; Lee & Jamieson 2001). These initial debates concerning takahē population management need to be discussed first, to understand how conservation practice can be enhanced. As discussed previously, the purpose of translocation is often to transfer individuals of an endangered species to a habitat as similar as possible to an original historic one, with no invasive introduced predators, to aid its conservation and replenish their numbers (Jamieson & Wilson 2003a; Bellingham et al. 2010). Transferring some individuals to another similar habitat would also enable the establishment of several populations, in cases where the initial ‘natural’ population declines drastically due to a stochastic event (e.g. disease outbreak, cyclone etc.). New Zealand is a leading country for successful translocations, mainly on offshore islands, where introduced mammalian predators and browsers have been removed. Furthermore, many new pest-proof fencing mainland sites have also enabled the return of endangered species back to the mainland (Clout & Craig 1995; Jamieson & Wilson 2003a; Bellingham et al. 2010; Innes et al. 2012). This is the case for the takahē, which is now highly accessible to the public via offshore islands (i.e. Motutapu Island, Tiritiri Matangi, Kapiti Island, etc.), mainland fenced sites, zoos and display sites (Kilduff et al. 2011).

Takahē translocation is a unique case of New Zealand conservation management, as takahē individuals were transferred to a very different habitat type compared to the initial one. Small numbers of takahē were transferred from an alpine tussock habitat in Fiordland to predator-free lowland islands with varying degrees of introduced grasslands and regenerating broadleaved forests. These sites are very different in elevation and habitat from the original Fiordland sites, with different associated food-plant species. There were many debates among ecologists prior to translocation on the advantages of establishing takahē outside their existing range in Fiordland (Lee & Jamieson 2001; Jamieson & Wilson 2003a).

The initial debate centred on whether either the climate and vegetation changes (Mills & Mark 1977; Mills et al. 1984) or the arrival of Polynesians were the main causes in their decline throughout New Zealand (Beauchamp & Worthy 1988). Mills et al. (1984) initially argued that takahē: (1) are specialised tussock-grassland feeders and have not changed these feeding adaptations since the last glacial period of the Pleistocene, (2) have a widespread subfossil distribution that occurred in the glacial periods of the Pleistocene when alpine and subalpine grasslands covered large areas of New Zealand, (3) have been reduced in numbers since the Pleistocene because of the replacement of most grasslands and scrubland forest, restricting the birds to smaller areas and making them vulnerable to Polynesian hunting.

Beauchamp and Worthy (1988), with the later support of Atkinson and Millener (1991), objected to these views by arguing that: (1) sub-fossil evidence was mostly found in lowland habitats dominated by forests, and that (2) takahē would have fed on a wide array of food before the present establishment of the last population in the Fiordland. This second argument was mainly based on the translocation of takahē individuals to Mana Island, conducted in 1984, where they seemed to feed readily on introduced grass and breed successfully (Beauchamp & Worthy 1988). It was further argued (Clout & Craig 1995) that takahē could even surpass the Fiordland initial population in terms of numbers and breeding success as they were not subject to any predators, competition for food, habitat loss or even extreme climate.

According to Clout and Craig (1995), it was predicted that island takahē would adapt on offshore island habitats so well that there would be egg and chick surplus for captive-rearing. One of their predictions was proved correct as island adults did have a longer life-span than the ones in the Fiordland, thus displaying more breeding attempts. However, their prediction of high population increase and surplus eggs and chicks has not been observed (Bunin et al. 1997). Although the island metapopulation has become self-sustaining, most pairs have high levels of egg infertility and low juvenile production compared to the Fiordland birds (Jamieson & Ryan 1999; Jamieson & Ryan 2001). Thus, island populations have increased at a slower rate than expected. It was also observed that on some islands, individuals were producing 2–3 times the number of eggs per year than they would normally do in Fiordland, starting breeding attempts around early September (while breeding in Fiordland normally starts in October) (Jamieson & Ryan 2001). This additional cost of reproduction has resulted in a significant decline in female egg size, which further aggravates the problem of low hatching success (Jamieson & Ryan 2001). This high rate of egg production could also potentially be the cause of a low rate of fecundity in later years and a shorter lifespan for the adults (Bunin et al. 1997; Lee & Jamieson 2001).

An examination of takahē reproductive successes on offshore islands (Kapiti, Mana, Maud and Tiritiri Matangi Islands here) was conducted by Jamieson and Ryan (1999) over a seven-year period. There were not many differences in egg infertility and breeding successes found between the offshore islands. It was found that over the last three years of this study, egg infertility was higher and juvenile production was lower. It was thought by Bunin et al. (1997) that island takahē may have problems with water loss inside their eggs and show unusual incubation methods, but no evidence was found by Jamieson and Ryan (1999).

The main plausible reasons of low reproductive success of takahē on islands are: (1) Fertility rates appear to improve with re-nesting and laying of a second clutch. Male and female reproductive systems may not be synchronized for the first clutches of the season, but may become so after these first attempts. According to these findings, it seemed that females were ready to breed before the males. The reason why is unclear, especially since female egg production is energetically demanding (Jamieson & Ryan 1999; Jamieson & Ryan 2001). (2) Territorial aggression was used as an explanation for the lower clutch success (Jamieson & Ryan 1999), although not many pairs were involved in fights at the time of the study, and in later years the second clutch was still more successful (Jamieson & Ryan 1999; Jamieson & Wilson 2003b). (3) Differences in diet were also suggested as an explanation, although no evidence was found (James et al. 2004; Jamieson 2004). (4) Inbreeding depression seems to be the best plausible explanation for poor reproductive success (Jamieson 2011). This is related to the fact that these inbred birds are transferred to habitats where they have no evolutionary history (Jamieson 2009; Jamieson 2011).

The Fiordland population may have been subjected to a major bottleneck event in the past and molecular evidence supports this theory (Lettink et al. 2002). Interesting findings were put forward with studies of pedigrees and genetics. It seems that reproductive failure is compounded more by inbred females rather than inbred males. Data analyses of offshore island takahē individuals (inbred vs non-inbred) hatching successes showed that it was significantly lower with pairs that had inbred females than non-inbred females (Jamieson et al. 2003; Jamieson et al. 2006). In the case of the males, no significant differences were found between inbred males and non-inbred males (Jamieson et al. 2003). It was recommended with further analysis of island takahē pedigree (Grueber & Jamieson 2008), that to avoid further loss of genetic diversity, new sites needed to be established, and about two new birds translocated every 4 to 5 years

However, even if inbreeding in females has a serious effect on breeding success, non-inbred island females still have poor success. This may be because all island takahē are inbred to some extent (Jamieson & Ryan 2001; Grueber & Jamieson 2008; Jamieson 2009). Novel detrimental or/and sub-lethal recessive alleles can be expressed (via infertile eggs, embryo and chick deaths) when an inbred population is subjected to new environmental conditions (Jamieson 2009; Jamieson 2011). Most recent research of takahē now focuses on molecular genetics and pedigrees, to counteract the natural occurring process of inbreeding in the long-term (Grueber & Jamieson 2008; Grueber et al. 2008; Grueber et al. 2010; Grueber & Jamieson 2011).

In retrospect, it is still unclear exactly why transferring takahē to islands causes physiological stresses such as low fecundity rate and high embryo deaths (Jamieson & Ryan 2001). It was proposed that exchanging eggs between Fiordland and island breeding pairs and monitoring subsequent breeding success of any chicks that survive could test the ‘environmentally induced inbreeding depression’ hypothesis (Jamieson & Ryan 2001). This type of research could not be conducted a decade ago because of the risk of spreading diseases to the initial population (Lee & Jamieson 2001). In 2007, island takahē individuals were released for the first time back in Fiordland after first being ‘winter trained’ with foster pairs at Burwood (takahē captive-reared facility) (Kilduff et al. 2011). Up to this time, there were no current studies that could be found assessing their success. As for egg manipulation research, it is only recently (2010) that eggs were successfully collected at mid-term (half-time incubation period, 15 days out of 30 days normal incubation) and translocated from islands for incubation at Burwood. Five out of seven eggs transferred from Mana Island hatched, and out of these five, three chicks were alive at 3 months of age (Kilduff et al. 2011). Thus, conducting an experiment on the 'environmentally induced inbreeding depression' hypothesis may be possible in the near future (Jamieson & Ryan 2001).

It was concluded by Grueber et al. (2012) that the island takahē populations were at their carrying capacity on offshore islands (Mana, Kapiti, Maud, Tiritiri Matangi islands) to which they were initially translocated. This was concluded from the fact that the proportion of breeding pairs (versus single individuals) have decreased in islands in recent years and that territorial aggression has increased in turn. A few possible solutions were put forward (Grueber et al. 2012), such as: (1) Increasing translocations between islands to avoid further inbreeding. (2) Establish a new island (or mainland fenced sites) for takahē to be translocated to, which the Takahē Recovery Group and the Department of Conservation (DOC) did with Motutapu Island in 2012. (3) Finally, transfer surplus birds that are not contributing to the breeding (single individuals fighting with pairs for territories) back to Fiordland or any other new sites, which the Takahē recovery group and DOC are also doing on Motutapu Island, with some of the birds from the Burwood (South Island, NZ) takahē captive-rearing facility.

3.3 Field research discussion

In total, 24 translocated takahē individuals were observed (Appendix 8). Motutapu Island (Hauraki Gulf, Auckland, NZ) is the largest offshore island where the takahē was translocated to, with approximately 7% of the total takahē population. There were 18 birds observed on Motutapu Island at the time of this study (Appendix 8). The 3-4 takahē that were not in pairs or family groups were not used in this study as they were not considered part of the breeding population. The territories were visited on foot, sometimes with Hazel Speed (DOC ranger), who was monitoring closely the breeding season on the island once a week (all nests visited in a day).

On Maungatautari (Waikato region, NZ), there were 4 takahē observed, in pairs, at the main mountain fenced site. There was one pair (two birds) in the Tautari Wetland (Appendix 8). As the mountainous enclosure was much larger in size (3400 ha fenced) and strenuous to hike around cf Motutapu (1509 ha), the fieldtrips were conducted in collaboration with the Maungatautari Ecological Island Trust (MEIT) volunteers, who were monitoring the takahē population on quadbikes at least once a week. The wetland pair was monitored the rest of the time, as they did not have telemetry sets and the site was easily accessible (Appendix 2).

Takahē foraging behaviour in the breeding season of 2014/2015 is the focus of this chapter. Three chicks in total were bred successfully and observed during the time period of this study. Feeding behaviour, plus difficulties encountered during this research and recommendations for takahē habitat management are also discussed.

3.3.1 Takahē breeding biology

The nesting period normally occurs between October and January. However, on offshore islands, nesting can start earlier in September (Bunin & Jamieson 1995; Bunin et al. 1997). The nests consist usually of a base of dead grass located under an overhanging canopy of tall tussocks or large shrubs. Nests are often found because takahē may have a latrine area with faecal deposits outside the nest entrance. Clutch size is usually two (one to three eggs), and each egg is relatively large (approximately 70 x 48 mm; 96g). Breeding failure can result in re-nesting later in the summer. The juveniles may remain with parents for 18–24 months, and participate in chick-rearing the following breeding season (Kilduff et al. 2011). If the juvenile or another translocated takahē (sometimes younger) joins a pair for chick-rearing, the group of birds then becomes a family group. This was essentially what happened on Motutapu Island, where three pairs were joined by another or several younger birds (two groups of four birds).

Breeding can start young, as soon as two years old. Some individuals are known to have bred for over 20 years (Lee & Jamieson 2001; Kilduff et al. 2011). The incubation and rearing is shared by the male and female takahē. The female will incubate during the day for approximately 12 hours and the male will incubate 12 hours overnight. The incubation period will normally last 30 days in total (Kilduff et al. 2011). It was also observed that chicks are vulnerable to spring wet weather events, especially on islands where introduced European grasses dominate the vegetation of their habitats. This is because the chicks have fine down feathers and if they are following the adults through wet grass, they can easily get wet, chilled and die (Kilduff et al. 2011).

Small chicks in tussock environments tend to have a higher survival rates because tussock dries quicker than introduced grass (Kilduff et al. 2011). Young chicks are fed a mixture of invertebrates and plant material by parents. Both parents and other members of the family groups feed the chicks constantly (Kilduff et al. 2011). Little pieces of food are clipped off by the adult birds and fed to the chicks. The chick feeding reduces as the chick grows and become more independent. The chick then begins to hold tussock or grass tillers in their feet and snip them off at the base, imitating adult feeding behaviour (Lee & Jamieson 2001; Lettink et al. 2002; Kilduff et al. 2011).

3.3.2 Field research findings

The research findings have been tabulated (Table 3.1) below to show the pairing and groups of takahē on Motutapu Island and Maungatautari during the breeding season. It also lists the general plant types that were used for their nests. Territory areas locations are mapped (Appendix 1 & 2).

Table 3.1: Summary of the Motutapu Island and Maungatautari takahē breeding season 2014/2015. 'Success' indicates that a chick hatched and left the nest with parents to be fed.

Pairs or Groups	Location (Area)	Nests plants used	Nests	Chick
Motutapu Island				
Raumati (F),Westy (M) & Ariki (M)	Nursery	Sedge + introduced European grass	1	0
	Islington Bay	Introduced European grass *(success)*	1	1
Bradshaw (M), Charlie (F) & Emelius (F)	Islington Bay	Bracken fern + introduced European grass	1	0
		Introduced European grass	1	0
He Maipa (M) & Autahi (F)	West Point & Pig Bay (nest located at Pig Bay)	Pampas grass + introduced European grass	1	0
Bligh (M) & Tautari (F)	Motutapu Education Camp (MOEC) & Pig Bay (nest located at MOEC)	Sedge	1	0
Beacon (M), Chalky (F), Bowen (F) & Te Rangi (M)	Mullet Bay	Raupo + sedge *(success)*	1	1 (died)
		Raupo	1	0
Hemi (M) & Ella (F) (death 8/2014), mate switch to Pearl (F), then Tarawera (F)	Home Bay	Pearl- Sedge + introduced European grass	1	0
	Central Gully	Tarawera- Introduced European grass	1	0
Maungatautari				
Te Wero & Marlee	Cooper & Garland (264-341)	Sedge + introduced European grass *(success)*	1	1
Ngutu Whero & Nancy	Brown & Ramsey (204-264)	Sedge + introduced European grass *(success)*	1	1
Hauhunga & Matariki	Tautari Wetland	Sedge + introduced European grass	2	0

3.3.3 Motutapu Island breeding season 2014/2015

Single female Peti on Motutapu Island was discounted, even if she was present on the island (translocated around January 2015), as she did not join any pair or family group at the time of the study. Tarawera (Central Gully) and Pearl (Central Gully) were also single takahē females on Motutapu Island, and were not observed when they were not paired. They were close to Home Bay territory, and at some point, were mated with Hemi after Ella's death (8/2014). Hemi (Male-Home Bay) switched mates three times this breeding season. First pairing was with Pearl (~8/2014), then Tarawera (~11/2014). Currently, Hemi has paired with Pearl again at Home Bay (3/2015).

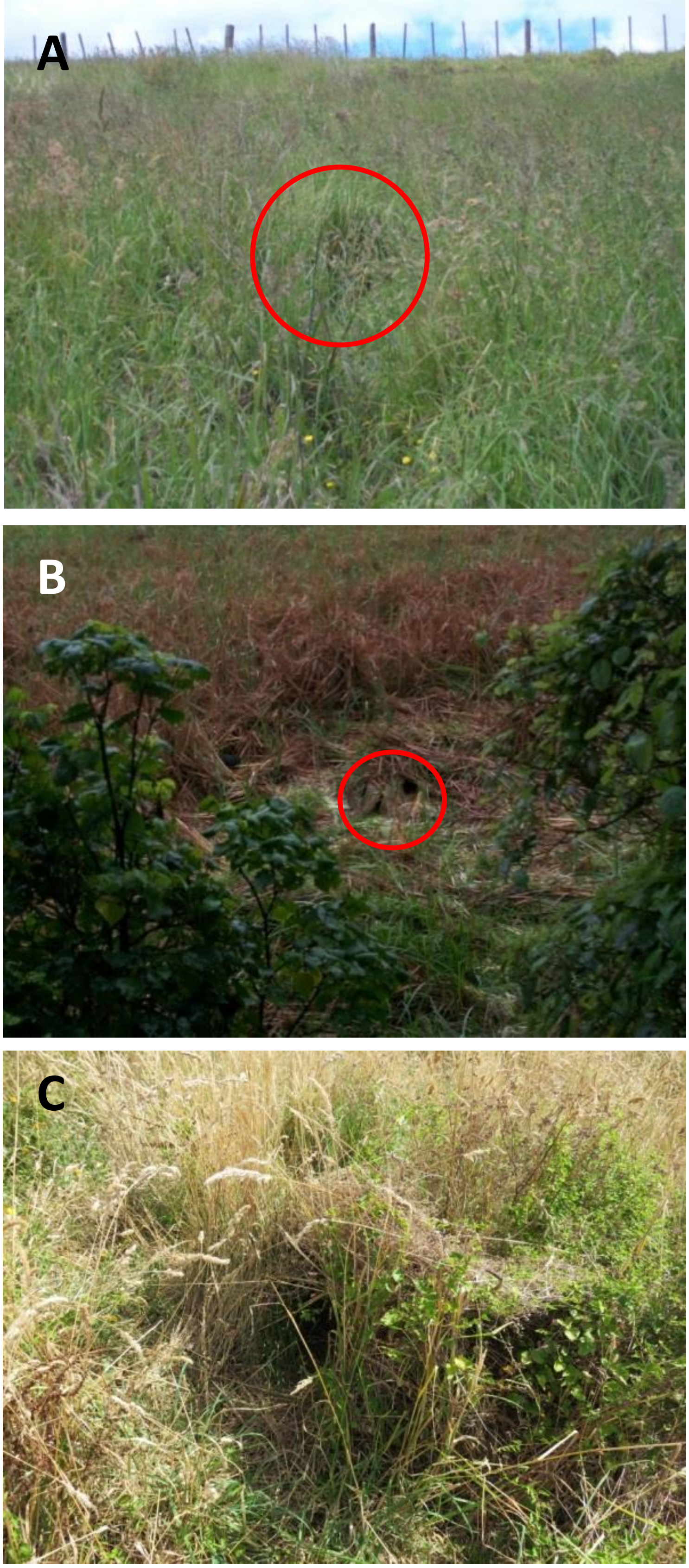
An early observation of mating behaviour was noted in July 2014, during a foraging behaviour observation in the field, with the group of Raumati (F), Westy (M) and Ariki (M) (Islington Bay area). This display of behaviour was made out of the normal breeding season period, and it was only an attempt from the male of the pair (Westy), which the female (Raumati) refused. In late August, displays of mating behaviours, even copulation, were also observed (Phil Marsh, Hazel Speed, DOC, pers. comm.).

Displays of mating behaviours were observed more often during the period of mid to late August, when breeding season usually starts at offshore islands (chasing, wing-flapping, mounting). Takahē are normally known to be very discreet while copulating (Phil Marsh, DOC, pers. comm.). It can be noted that the only known pair that displayed their copulation in the open were Bligh (M) and Tautari (F) at Motutapu Education Camp area (MOEC). They were also observed to be over-familiar by human presence. By late August-early September, many nests were found by Hazel Speed (DOC ranger) and her volunteers.

The only pair that did not attempt breeding and nesting as early as the others was He Maipa (M) and Autahi (F), which were introduced in July 2014 at West Point (Figure 3.1). This pair might have started nesting around late November-early December. The timing of the translocation may have been the cause, or it may be due to the fact that these individuals took a couple of weeks before establishing a mating bond (as they were not mated before their release) (Figure 3.1).

Figure 3.1: Release of He Maipa and Autahi in July 2014 by the iwi, Ngāi Ta ki Tamaki tribal trust, Motutapu Island Trust and Motutapu DOC staff. The author and her father (Roy Withers) were invited to open the containers by the iwi representatives- Jeff and Clarissa Lee. A video was filmed and released on Motutapu Island Trust Facebook page (Motutapu Restoration Trust facebook page 2014). Photo credit: Bridget Winstone.

Most of the nests were made out of introduced European grass (mostly pastoral grass, e.g. *Poa* spp., *Paspalum* spp., Poaceae) as padding, and sometimes as a overlaying cover. Native and/or introduced sturdy (strong leaf blades and stems, not easy to bend) plants were used, mostly sedges (e.g. *Carex* spp., Cyperaceae), fern (mostly *Pteridium esculentum*, Dennstaedtiaceae), introduced pampas grass (*Cortaderia selloana*, Poaceae) and/or raupo (*Typha orientalis*, Typhaceae) (Table 3.1 and Figure 3.2). A nest is considered successful if the chick has successfully hatched and left the nest to follow the pair or the family group for food.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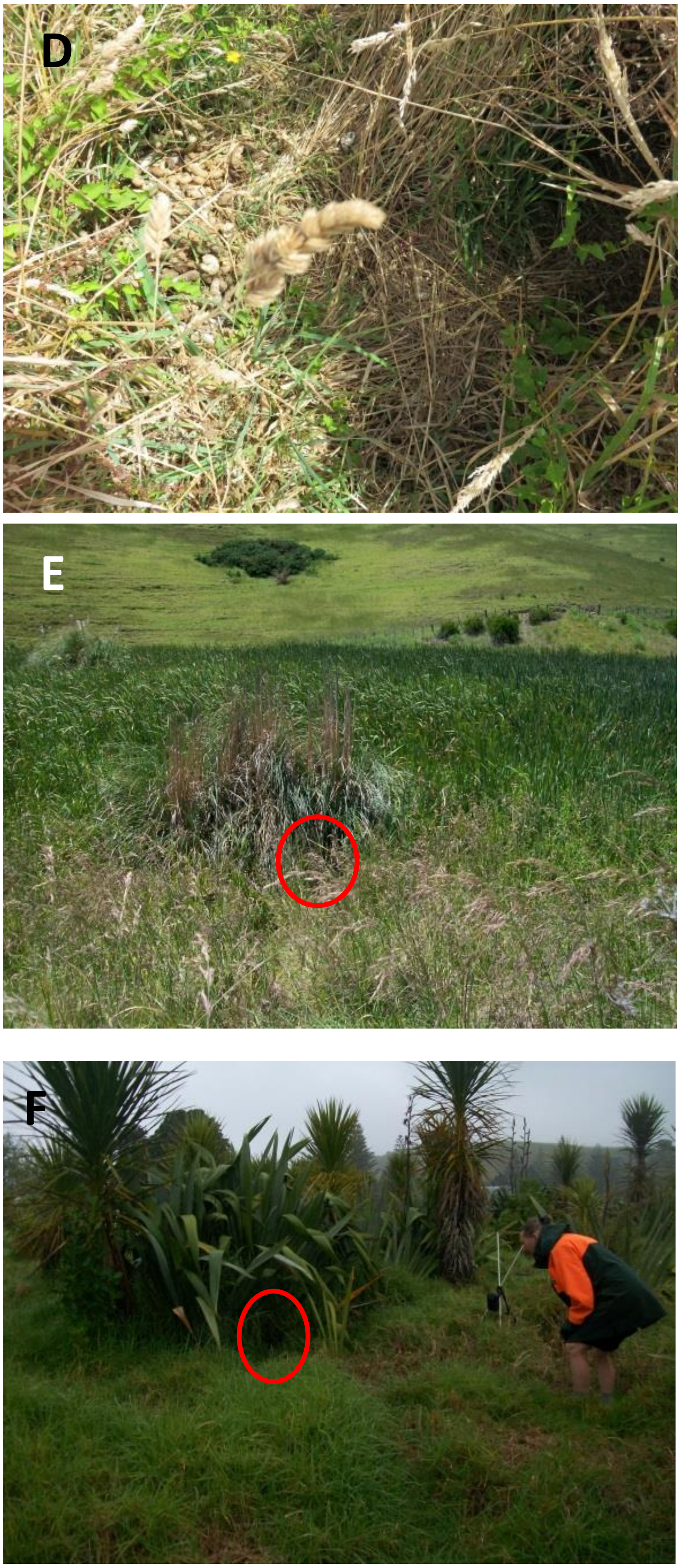
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E
F

Figure 3.2: From above to below: The two successful nests of Motutapu takahē breeding season: A. Raumati family group nest (introduced European grass-only) and, B. Beacon family group nest (raupo, sedge). The red circle indicates the nest location. C. Close-up of a grass-only unsuccessful and unoccupied nest (Bradshaw group), D. shows latrine (accumulation of dried faecal matter), often an indication of the nest presence and entrance. Unsuccessful nests with sturdy plants as upper cover: E. He Maipa & Autahi, F. Hemi & Pearl, G. Bligh & Tautari, H. Bradshaw & Charlie. Again the red circles indicate the nest locations. Nests with easy access were also monitored by cameras by DOC staff Hazel Speed in hopes to have footage of the chick for Motutapu residents and New Zealand general public. This was unsuccessful as no chick footage was collected that year.

The first successful nest where a chick was born was of the Beacon family group (Mullet Bay), which was made of raupo and sedge, with introduced European grass used for padding inside the nest. The second successful nest was Raumati family group's nest (Islington Bay area), which was mostly made of introduced European grass (Table 3.1). The takahē pairs and groups had a tendency to only use introduced European grass as nests even when other sturdy material (sedges, etc.) were available in the same area and the reason for this is unknown. Nests made only of pastoral grass have been observed to collapse easily (Kilduff et al. 2011). Age and/or inexperience of the birds, may be an explanation for their choices in nest material and cover. However, it was observed on one occasion that the Motutapu Island's only live chick (Islington Bay-Raumati's family group) was hatched from a nest that was composed of introduced European grass, without any shrub or tree cover (Figure A., 3.2). This success could have been a chance event as there were no major rain events that would have caused the nest collapse.

Most of these nests failed at the first attempt (5 out of 6), but one was successful. The chick was born from a group of four (Beacon, Chalky, Bowen and Te Rangi). It is still unclear which ones of the group are the parents of the chick. It has been assumed via behavioural observations that the main pair was Beacon (M) and Chalky (F), with Bowen (F) and Te Rangi (M) as helpers (Mullet Bay area). Te Rangi did not necessarily stay with the group at all times, unlike the other three. The chick was observed during a 2-hour observation period with one of the adults, Beacon, identified via leg-bands and radio-telemetry. Only Beacon was observed to be with the chick during the 2 hours and it is unknown where the others were (as these three had no radio-transmitters). A week later, with Hazel Speed, the body of the chick was found next to the nest (Figure 3.3). It was collected by Hazel Speed for an autopsy by the Takahē Recovery group. It was found that the chick was female (Hazel Speed, Phil Marsh, DOC, pers. comm.).

Figure 3.3: Dead chick of the Beacon group, found near nest area at Mullet Bay.

Three out of six first nesting attempts were abandoned. , Three out of four second nesting attempts were also abandoned, while two pairs did not re-attempt. It was verified by Hazel Speed (DOC ranger) that all the birds did have eggs, and the large amount of time spent on the nest meant that they were not sitting on empty nests. It has been observed before that takahē do have trial nest attempts, but would not spent too much time (less than a few days) on these (Kilduff et al. 2011). These trial nests were not taken into account here, but some were found for one or two for different pairs and groups (e.g. Bligh and Tautari, mid-August at Pig Bay area).

If no eggs were found after a nest was abandoned, direct observational monitoring was required to determine if there was a chick or not. It was sometimes unknown if the eggs did even hatch, either because they were infertile or were simply broken by parents during incubation. Takahē often remove broken eggs or eggshell from their nest when they accidentally break them or when the chick is born (Kilduff et al. 2011). Some of the nests had to be destroyed by DOC staff as the adults continued to incubate the eggs even when these were not going to hatch. Hemi (M) & Pearl (F) at Home Bay and Bligh (M) & Tautari (F) at MOEC were the two pairs that incubated their eggs longer (up to approximately 40-45 days) than the normal incubation period of 30 days (Hazel Speed, DOC, pers. comm.).

The eggs from the destroyed nests were collected and were not found to be infertile, but had become rotten, after the embryo death. The pairs may have either left the egg without incubation for too long or the nest had become wet from rainy periods, so that the egg became chilled, and not viable. The second nesting attempts started around mid-November to early December. These also failed for all pairs and family groups, except for one group (i.e. Raumati family group at Islington Bay area). The chick did hatch (Figure 3.4) and was raised successfully by the group. Finding the chick was quite difficult, as the family group was quite secretive. It was only when the chick was a month old, or so, and feeding by itself that the group was seen feeding in the open areas.

Figure 3.4: The only live takahē chick on Motutapu Island (Nursery-Islington Bay area) at the time of the fieldwork. The chick is fed and reared by the family group (3 adults: Raumati-female, Westy and Ariki-males). The chick is a month old, already starting to feed for itself in open introduced European grassland.

3.3.4 Maungatautari breeding season 2014/2015

As mentioned previously, there were two pairs in the main mountain fenced site, and one pair in the Tautari Wetland. There were four nests in total, one per each pair in the mountain fenced site and two in the Tautari Wetland. The two nests at the main mountain were successful while the two nests in the Tautari Wetland failed (Jane Reeves, MEIT, pers. comm.). Takahē territories on the main mountain were accessed via quadbikes (Figure 3.5).

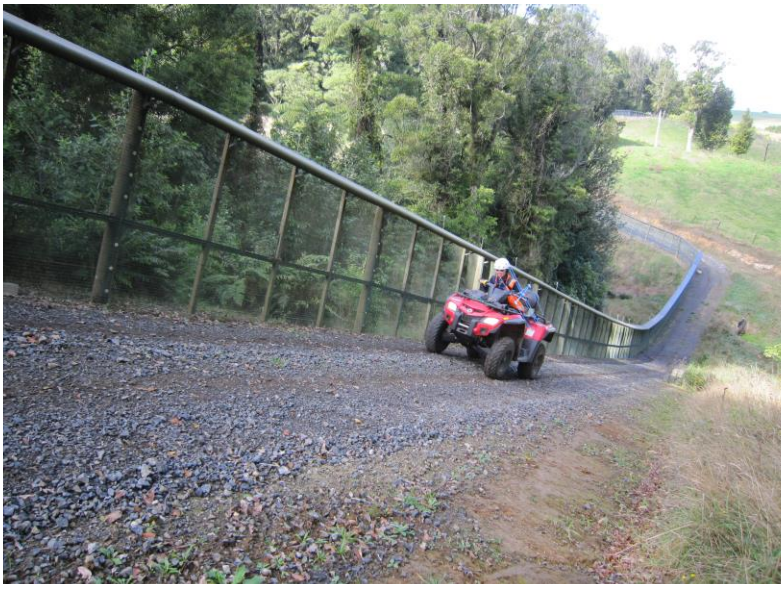

Figure 3.5: Jane Reeves on her quad bike monitoring for takahē (Photo credit: Jane Reeves)

Compared to Motutapu, Maungatautari takahē individuals were very secretive and highly aware of human presence, so locating them and finding their nests was a very difficult endeavour, especially for the ones that did not have transmitters to locate them. Being secretive is not a disadvantage for them as takahē pairs or family groups often need to protect their nests and chicks, from aerial predators, such as the Australasian harrier (*Circus approximans*).

No displays of mating behaviour were observed directly, but the nesting and incubation period was thought to have started around late September 2014. Just prior to the nesting period, the pairs were observed mainly occupying the two largest grassy areas between the main fence and the forest. The main areas visited were private lands named according to the owners, which were then Cooper, Garland (from fence pole 264 to 341), Brown, and Ramsey (from fence pole 204 to 264) (Appendix 2).

It was observed that Maungatautari takahē breeding season is closer to the Fiordland breeding period in terms of starting time (October). The wetland pair tried breeding twice, and failed twice at the incubation stage. The eggs were found to be infertile (Jane Reeves, MEIT, pers. comm.), and this phenomenon may be because the male (Hauhunga) is much older (11 years old) than any other takahē individual that was observed in this study. All nests were mainly a mixture of a sturdy plant (sedge, *Morelotia affinis*, *Carex* spp.-Cyperaceae) and pasture grass as padding.

The only female that had a transmitter was Marlee (main mountain fenced site), so it was the only nest that could be verified closely. The only known nest was observed closely as the female (Marlee) stayed longer than the normal incubation time. Even though one chick was born, the female tried to incubate the other egg that had not hatched, finally abandoning it after a couple of days (Figure 3.6).

Figure 3.6: Marlee's (F) nest (located at Cooper farmland area), one successful chick and one egg did not hatch. The egg was collected by Jane Reeves (MEIT) for analysis (Photo credit: Jane Reeves).

The locations of the other nests were established via the movements of the male, which stayed close to the nests, and communication between the adults (via 'booming' or loud alarm calls). When the chicks grew older, the pairs did not stay in the main grass areas and roamed in the grassy area between the fence and the forest (up to 15-20 km a week) and even took shortcuts throughout the forested areas (Jane Reeves, MEIT, pers. comm.). This made it even harder to get any feeding behaviour data or breeding data.

It seems that placing hoppers (feeding device for supplementary feeding) alongside the fence was the only way to observe the pairs at the main mountain. While these sites were accessed via quadbike, it was still time-consuming to travel alongside the fence to find the individuals (Figure 3.7). This is because there are only a few sets of doors and gates to access the fenced areas (Appendix 2), so even though the radio-telemetry has detected a signal, we had to drive to the next gate and walk back to the site, which gave time for the takahē to roam away. It was especially hard to find them when chicks were grown and the groups started to travel long distances from the main grassland sites, even taking shortcuts into the forest (Jane Reeves, MEIT, pers. comm.) (Figures 3.8 and 3.9).

Figure 3.7: From left to right- Jane Reeves assessing takahē presence via radio-telemetry along Maungatautari mountain fence, Marlee's family group at hopper along mountain fence (Photo credit: Jane Reeves).

Figure 3.8: Only photo of Ngutu Whero and Nancy's chick at Ramsey farmland (Appendix 2), at near-juvenile stage of growth (3 months old) (Photo credit: Jane Reeves).

Figure 3.9: Photos of Te Wero (M) and Marlee's (F) chick at different stages of growth (chick then juvenile; it survived to adulthood) at Cooper and Garland farmland area respectively (Appendix 2) (Photos credit: Jane Reeves).

These breeding observations can give some insights into which plant species should be used for habitat restoration, and/or other aspects of takahē habitat requirements. One main insight is that, even though some pairs use only introduced European grass, it is generally observed that sturdy (strong leaf blades and stems, not easy to bend) plants for overlaying nest cover was used by almost all groups of birds. Further, the takahē may just be using any plants which are sturdy enough for nesting (native or/and introduced). This would mean that no specific plant is particularly favoured more than another for takahē breeding success.

3.3.5 Plant species recommended for habitat restoration on Motutapu Island and Maungatautari

In the takahē husbandry manual for all offshore islands, a plant list for habitat requirement was provided by the Takahē Recovery Program (Kilduff et al. 2011) as a guide for DOC staff and the Island Trust members. As mentioned previously, introduced European grasses are not sturdy enough for nest or shelter, so sturdy (strong leaf blades and stems, not easy to bend and break) plant species that have little water retention, such as native tussock/grass, sedges, or rushes would be ideal to add into translocated takahē sites.

Tussock species seem to be the best species to use for takahē (the most equivalent to the Fiordland vegetation), as not only these can be used for nesting and shelter, they are a great food source (Williams et al. 1976; James et al. 2004). The main advantage of planting tussock is that these species do not retain water as much as European introduced grass. This means that wet chills would not cause death to the chicks or eggs (Kilduff et al. 2011).

A few examples that were cited in the husbandry were common, non-threatened tussock species such as *Chionochloa conspicua*, *C. pallens*, *C. rigida* var. *amara* and *C. rubra* (Poaceae). Some of these species are high-elevation montane species (snow tussock), thus not suitable for all habitats where takahē were translocated, especially lowlands such as Motutapu Island. These may be suitable for Maungatautari plant restoration on the main mountain. In addition, it is argued that only localized species already present on the sites should be used to avoid any biosecurity risk. However, if native species, not necessarily present on Motutapu Island or Maungatautari, are to be introduced, then the species selected for restoration purposes will need to be specific for each region. Plant species selected would need to be either specific to the Waikato region for Maungatautari, and Auckland region for Motutapu Island.

Sedges (*Carex* spp., *Eleocharis* spp., Cyperaceae), and/or other suitable species are the best alternatives for Motutapu Island. The few native sedges present, such as *C. pumila*, or *Eleocharis acuta*, should be multiplied at Motutapu Island trust nursery. Sedges (native: *Morelotia affinis*, Cyperaceae) were also used by Maungatautari takahē, for nesting (Figure 3.6).

The shrubland was often used as shelter against predation and human presence, according to the foraging behavioural study. General examples of plant species (other than sedges or rushes species) which could be used by takahē are toetoe (*Austroderia* since 2011, previously *Cortaderia* spp.), flax species, such as *Phormium* spp., *Aciphylla* spp., or dense shrub species such as *Coprosma* spp., etc. *Coprosma* spp. especially was used as a nest cover (with long pasture grass) in the 2013-14 breeding season (by Hemi and Ella- Home Bay, Hazel Speed, DOC, pers. comm.). Fern species was also used as a nesting cover (for one family group: Bradshaw-Islington, nest cover: *Pteridium esculentum*- Dennstaedtiaceae) at

Motutapu Island, but not on Maungatautari. However, ferns growing at the edge of the fences at the main mountain were used as a vegetation cover, when foraging (pers. observation) (Figure 3.8).

As for food, the general consensus by habitat use and foraging research studies (not only for takahē, but other ground-dwelling herbivorous bird species) (James et al. 2004; Soininen et al. 2010) is that pasture grass species (i.e. main takahē grass species: cocksfoot *Dactylis glomerata*, Poaceae) have especially high nutritional value. Soluble sugars in pasture grass species were found to be easier to digest compared to other native species (Suttie & Fennessy 1992; Gauthier & Hughes 1995; James et al. 2004; Soininen et al. 2010).

Clover (*Trifolium* spp., Fabaceae) was often observed to be another one of their main plant species chosen for food (qualitative data), so these should not be subjected to weed control. Not all pastoral or native grass species were identified during the direct observation, as some birds were too difficult to approach, but some main species, foraged on by island takahē, were identified (Table 3.2). If native grass equivalents were added to these areas, it could be argued from this study, that the takahē may not use these at all, since pastoral grass already provides a high content of soluble sugars.

A plant list (plant species grouped into categories) has been made from qualitative observations (when plant species were identified) and recorded for Motutapu Island (Table 3.2) (Ford et al. 2007; New Zealand Plant Conservation Network (n.d.)). The data collected from the Maungatautari site was insufficient to confirm exactly what species the takahē may be using there, especially in the forested areas. Further, as mentioned previously, foraging behaviours at Maungatautari were often observed when individuals were eating the supplementary food rather than vegetation. Main species that may have been used on Maungatautari were sedges (nesting), ferns (for cover), and mainly European introduced pastoral grass species for foraging.

Table 3.2: Summary plant species list (native and * introduced) and their use by translocated takahē on Motutapu Island , applicable for Maungatautari birds

Plant species groups	**Nest cover**	**Nest material**	**Food**
Sedge-e.g. *Carex* spp., *Eleocharis* spp.	+	+	-
Flax- e.g. *Phormium* spp., *Aciphylla* spp.	+	-	-
Typha orientalis (raupo)	+	+	-
Fern- e.g. *Pteridium esculentum*	+	-	-
Shrub- e.g. *Coprosma* spp.	+	-	-
Native grass- e.g. *Austroderia* spp. (toetoe)	+	+	+
Pastoral grass species*- e.g. *Poa* spp., *Paspalum* spp., *Dactylis glomerata* (cocksfoot)	+	+	+
Cortaderia spp.* (pampas grass)	+	-	+
Trifolium spp. * (clover)	-	-	+

Celmisia petriei (Asteraceae) is sometimes eaten by Fiordland takahē (Mills & Mark 1977; Mills et al. 1987; Mills et al. 1991). Equivalent montane *Celmisia* spp. would be more suitable to plant at Maungatautari than at Motutapu Island (no *Celmisia* spp. present on Motutapu Island). *C. gracilenta* is found on Maungatautari Main Mountain (McQueen 2004), but I have never personally observed takahē foraging for it. That may be because there were fewer hours of observation at Maungatautari compared to Motutapu Island, so less data available. Further, *Celmisia* may not be able to grow in the pastoral grassland at the forest edges of Maungatautari Main Mountain, although it may be readily available when takahē roam the forested area. It would be interesting to add more *Celmisia* spp. to observe if takahē would forage for it.

In Fiordland, it was found that fern rhizomes were only eaten in harsh winter conditions, when no tussock food was available due to deep snow (Mills et al. 1980). I have never directly observed any takahē forage for fern species' rhizomes/leaves, even when these species were present on Motutapu Island (e.g. *Pteridium esculentum*, Dennstaedtiaceae) and Maungatautari.

3.4 Difficulties encountered during the field research, suggestions for improvement and limitations to the study

The field work presented a number of challenges that are discussed below, with suggestions for how improvements can be made in further studies for takahē conservation management.

3.4.1 Logistics

On Motutapu Island, because I was on foot when locating and observing the birds, it was quite time-consuming to actually do multiple observations of different family groups during the day (maximum 2-3 groups per day). Due to DOC biosecurity and policies, using a bicycle or the cars present on the island were not available options for me. This type of study may be best if it was conducted over a longer time period with additional researchers and field assistants, especially if the work has to be carried out over a lengthy and/or difficult terrain by foot.

Traveling by quad bike around the mountain fenced site at Maungatautari was a slight disadvantage as the noise of the engine may have stressed the birds into hiding, flushing them out of the grassland sites into the forested areas. Further, these birds took shortcuts throughout the forests (Jane Reeves, pers. comm.) to access different grassland and roamed great distances making it difficult to use the telemetry sets, as the signal could not always be intercepted (especially in deeper areas of gullies).

It may be better to use bicycles in future research, but the path around the fence is not as easy to travel, even when hiking. I could not really go by myself as the closest sites were 8-10 km away from the MEIT building and car park. Also, even if the MEIT staff were allowed to go on quad bikes around the mountain for monitoring, they still had to ask permission from the surrounding farm owners, as it is private land (Jane Reeves, MEIT, pers. comm.). It was recommended that each time I visited the sites; I had to be with one member of the Maungatautari trust. This was to ascertain that I was not trespassing on any private land. There were then some time-related constraints as the trust members had to be free to accommodate my visits (often between 9.00am to 3.00pm).

3.4.2 Radio-telemetry

The main difficulty that was encountered was the fact that not all the birds studied had a transmitter attached to them. Some had lost their transmitter even during the time frame of the study, and if a bird was the only one of the group having a transmitter, the whole group could not be observed (e.g. Bligh and Tautari at MOEC). Another point that should be raised is that when takahē individuals are more than 4-5 years of age, their radio-transmitters had to be removed, as the harnesses prevent wing growth. This might then hinder any research on breeding success, and it is mainly by this age that the breeding success increases (Jamieson & Ryan 2001). Tautari (F) at MOEC for example has been one of the birds that had to have the transmitter and harness removed (Phil Marsh, DOC, pers. comm.).

On Maungatautari, as the Tautari wetland pair did not have transmitters, it was difficult to locate them, even if the area was small. Most of my time was spent waiting for them to forage in open spaces, where I had the best sightings of the birds. However, this is not representative of what habitat elements they might be using more often than any other elements. That is why the mountain pairs were mostly visited during this research study.

Another problem was that females were generally the ones without transmitters on Motutapu Island. Seven females out of 10 did not have transmitters, while three out of 8 males did not have them on Motutapu Island. However, finding one of the birds per pair or family group via radio-telemetry was often enough to find the other(s). It posed some difficulty during the nesting season, because the females normally sit on the nest during the day, so the nest location was unknown until the night when the males sit on the nest. For example, in the case of Beacon (M), Te Rangi (M), Chalky (F) and Bowen (F) at Mullet Bay, only Beacon (M) had the transmitter, meaning that when these individuals were hiding in the bush, only his presence in the area could be accounted for.

3.4.3 Proximity of observer and over-familiarity with people

The presence and locations of nests were mainly guessed, by the amount of times the birds with transmitters were roaming in the same areas, and if the signals indicated that birds were still active late at night (6 to 8pm), since the males start sitting on the nest around this time. Another important problem was that some of these individuals were too difficult to approach without causing stress, for example the foursome group (Beacon-M, Te Rangi-M, Chalky-F, Bowen-F) at Mullet Bay, which was discussed above, or even the pair He Maipa (M) and Autahi (F) at West Point. Main mountain pairs of takahē at Maungatautari were especially hard to approach, and if stressed, would be flushed into forested areas where radio-telemetry signals were difficult to intercept. A distance of 30-35 meters was the minimum distance allowed by these particular takahē groups. This may be due to the fact that human presence was not as common, compared to other sites such as in the children campsite (MOEC-Bligh and Tautari) or tourist camp site (Hemi-Ella-Home Bay).

When there is over-familiarity with human presence, takahē behavioural habits would not be typical of a wild bird (Moore et al. 2008). For example, Tautari (F) (MOEC) would stop foraging and approach me at a distance of 1-2 meters away. Similarly at Maungatautari, passing visitors to MEIT made it difficult to observe takahē natural foraging behaviour at Tautari Wetland. Even though feeding takahē is forbidden on Motutapu Island and Maungatautari, passing tourists may still feed and this has a serious impact on birds. Domestication can happen in the wild if the animal is often in contact with human presence, affecting its behaviour, and potentially its ecology (Moore et al. 2008).

3.5 Further recommendations according to direct observation and breeding data for habitat restoration on Motutapu Island and Maungatautari

3.5.1 Wetlands - management and restoration

On Motutapu Island (Figure 3.2), the birds were observed using flax, sedges, and sometimes shrubs, as shelter and cover. Some groups had no sturdy plants as cover, only European introduced grass (Figure A, C & D- 3.2). Many takahē territories on Motutapu had a field of raupo available for shelter and nesting. MOEC and West Point pairs used raupo field edges at Pig Bay. Only Home Bay used other vegetation cover (flax/long grass). Using raupo as nesting material may not have been the best option as this plant species usually grows in very wet areas (in large ponds, sources of water available on the island). A recommendation that could be made is not to remove raupo fields, but to definitely expand with more plant species around the raupo fields rather than leaving it as pasture grassland. Takahē individuals, on Motutapu Island, seem to use the edges of these raupo as cover for foraging, so adding flax, sedges, and large grass species (i.e. native equivalent, toetoe *Austroderia* spp., Poaceae) would be a good way to restore wetlands on Motutapu Island. Toetoe especially should be added at wetland sites, as it may provide food, shelter, nest cover and material.

Wetland restoration is definitely required for many of these territories on Motutapu, maybe more so than re-forestation. Another observation is that even though some individuals (i.e. Islington Bay-Raumati (F), Westy and Ariki (M)) had sedges and flax species available in their territories, the nest was still composed only of grass. This means that all that can be done for now is to make vegetation cover/shelter readily available by adding sturdy native plant species (especially wetland ones), even though the birds may not necessarily use these (Lindell 2008).

3.5.2 Egg and nest manipulation management techniques

The egg loss of this breeding season 2014/2015 was very high, especially on Motutapu Island. Another way to improve nesting conditions, as restoration planting will take many years, is to conduct egg manipulation (Jones & Merton 2012). The option would then be to collect the eggs, incubate them and then replace them into the nest just before hatching, which was done previously for the Fiordland birds (Maxwell & Jamieson 1997; Jones & Merton 2012).

Another option to avoid nest collapse would be to build small weatherproof shelters, which would then be gradually moved over the nest. These shelters would be tent-like in structure and camouflaged so the takahē may still incubate the nest. This type of management method should be tested on Motutapu Island, especially since this island has now the largest population of offshore island takahē. Hazel Speed (DOC ranger) and I observed that that the birds seemed to be using the same main areas for nesting. Some of the family groups or pairs sometimes use the exact same nest location that they used the year before. This was the case for Bligh (M) and Tautari (F) (MOEC) and the Bradshaw family group (Islington Bay).

Ground-dwelling nest management techniques has been developed mainly for seashore birds conservation (i.e. nest cage predator exclusion) (Isaksson et al. 2007). The problem with the method of nest cage management was that it made the incubating adults more vulnerable to predation (Isaksson et al. 2007). This is not necessarily the case for the takahē, which has only the Australasian harrier, as a predator now at these sites. It would then be very interesting to test these different types of nest manipulation management methods on offshore island takahē, and in the process, increase the chances of takahē chicks hatching.

3.5.3 Grassland- management and restoration

On Maungatautari, the grassland areas definitely need to be expanded. One large pastoral grassland area per pair is available at the main mountain (Appendix 2). However, main mountain takahē were observed to roam very long distances across the forested areas to smaller patches of pastoral grassland (Jane Reeves, MEIT, pers. comm.). It was also observed that main mountain takahē would roam and forage for vegetation across narrow grassland, which grows right next to the fence. This narrow grassland was often 5 metres wide or more, between the fence and the forest edge. Further, takahē travelling right next to the fence might cause them to be too visible to aerial predators, especially to the Australasian harrier. Adding native grass species, at the edge of the fence, may be recommended for habitat restoration. It would increase food resources and provide better cover for nesting and shelter than the current pasture grass.

As the natural re-forestation expands towards the edge of the fence, inhibiting sunlight and water for grassland growth (Connell & Slatyer 1977), it may be necessary in the future to actively maintain these grassland sites. Thus, cutting some trees from encroaching on pastoral grassland areas may be the best solution. Some areas next to the fence are covered by the canopy, thus hardly any pasture grasses grow there and these should be removed. The Maungatautari takahē population should be kept small (6 to 8 individuals maximum) if the grassland area cannot be expanded further to accommodate them.

As for the pair at Maungatautari Tautari wetland, they are restricted to one area, which may be not be large enough according to previous research on habitat size requirement. It is not clear from the literature on what is the exact size, a takahē pair territory should be, as it varies greatly in Fiordland, from around five to 60 hectares (for one pair). There were also contradictory findings, where the smaller the territory, the higher quality the habitat was. However, the fact that offshore islands are already small in size, may be the only reason why takahē movement are constrained to a small territory in the first place. It would be interesting to observe if Tautari Wetland takahē would leave their large pen if they were able to access the mountainous area that is next to them (separated by the fence). In addition, isolation at the mountain main site may increase their chances of breeding, as many visitors have visited their pen this year, perhaps causing disturbance and reducing breeding success. However, without transmitters (removal after 4-5 years of age, these individuals are 10 years old), it was quite difficult to know which areas of their fenced pen they preferred. It would be even more difficult to later find them in the forest if their foraging area was increased.

3.5.4 Invasive plant species removal

Introduced large grass species such as pampas grass (*Cortaderia* spp., Poaceae) should not be removed unless it can be replaced by native equivalents, which may be more appropriate for restoration. Pampas grass was occasionally used as a food resource and as a nest material and shelter. Thus, when controlling this particular introduced species, takahē foraging and nesting habits will need to be taken into consideration. Although, I observed only a few instances when takahē ate pampas grass, so removing pampas grass may not have any significant impact for restoration purposes. Another interesting observation about introduced species is that several invasive grass species were eaten by takahē, such as kikuyu (*Pennisetum clandestinum,* Poaceae). Takahē have been observed to forage on kikuyu occasionally in this research study, but not more so than any other introduced European pasture grass species. It would not necessarily be problematic for takahē if kikuyu or other invasive pasture species were to be controlled, but herbicides should not be used in their territories. Weeding should not also be conducted at these territories, during the breeding season, as it may disturb breeding and nesting sites. If nest locations are identified, weeding around the areas may be plausible for birds that are over-familiar with humans (i.e. Home Bay, MOEC), but not the ones that may get stressed by human presence (i.e. Mullet Bay or West point). This is applicable to Maungatautari too, especially on the main mountain.

3.6 Summary and further recommendations

The qualitative findings of this research has shown some interesting observations that could improve takahē foraging, breeding success, and future recommendations for restoration at Motutapu and Maungatautari sites.

Nest material and nest plant species were identified during the fieldwork, and a tentative list of plants used for this was made based on nesting, breeding and foraging qualitative data. During the breeding season of 2014/2015, two chicks were hatched out of ten nests found on Motutapu Island, but only one survived up to juvenile stage. Two chicks were also hatched on the Maungatautari main mountain, and both survived to adulthood. No chicks hatched in the Tautari Wetland, at Maungatautari. Qualitative information such as these about feeding behaviour and breeding seasons of takahē can inform how to conduct future habitat restoration. It may be unrealistic to use only native plants for habitat restoration as takahē were observed to be using many introduced species that are present at Motutapu Island and Maungatautari. In the future, many native equivalents could be introduced instead of introduced species, if the habitat restoration is done gradually.

A practical idea to improve this type of research may be to conduct a habitat restoration experiment at one or even at several of the breeding pairs territories (Lindell 2008). It would be interesting to replace introduced plant species with native species and conduct further behavioural research to determine if the plants would affect their foraging, hiding and nest-building behaviours. It would also be interesting to observe if replacing exotic species would affect the survival of chicks as well (Lindell 2008). Only localized plant species (specific to Auckland region at Motutapu Island, and to Waikato region, Maungatautari) should be used for restoration purpose.

As takahē translocations are still at early stages, with birds being too young yet to breed successfully, it may be interesting to repeat this type of behavioural research in the following years. Collecting this type of data, such as nest material, plants used for nest cover, and breeding success, etc. might be critical for future takahē conservation management. As these particular sites have not been studied extensively, this research thesis gives some preliminary insights on the difficulties that were encountered. A substantial amount of qualitative data has been collected and these have been important in identifying aspects of takahē behaviour, breeding and conservation practice. However, the data are only representative for Motutapu Island and Maungatautari translocated takahē. This is to be expected as the populations that were studied were very small, together with the fact that takahē are an endangered species. The challenges of the qualitative data collection has given some recommendations on how to improve further research with more researchers, reducing external stressors, example human presence and varying restoraton plants to observe their use by the takahē.

As the introductions of takahē are fairly recent at these sites, especially at Motutapu Island, it is important to collect this type of data every year for future habitat restoration at these sites. In addition, it may be that Maungatautari, at the time of the study, cannot be considered as having a whole population of takahē, with only six birds to sample from. Even though the takahē sample-size was low in numbers, there were still some interesting insights that may have not been thought of, such as the difficulty of monitoring ground-dwelling birds in such a large forested area. Finally, some behaviours were not typical of wild takahē, especially on Motutapu Island, due to over-familiarity with people, so impact of eco-tourism should be taken into account when conducting future behavioural research study. Overall, the qualitative results have given some ideas for future restoration at Motutapu and Maungatautari, as well as the difficulties that we face, in trying to understand foraging behaviour, choice of nest material and behaviour during breeding seasons at these specific sites.

Chapter 4

Conclusions and Further Recommendations

Implications of foraging behavioural studies for takahē conservation management and habitat restoration

4.1 Foraging behaviours of translocated takahē at Motutapu Island (offshore island) and Maungatautari (mainland pest-proof fenced site)

A foraging behavioural study was conducted at two protected sites, Motutapu Island (offshore Island) and Maungatautari (mainland pest-proof fenced site) on the North Island of New Zealand. A total of 24 free range translocated takahē (*Porphyrio hochstetteri*) were observed over the course of the study. Plot size and habitat variables such as percentage of vegetation cover and distance from takahē to habitat components (i.e. distance and presence of water, houses and roads) were recorded during these observations. Foraging behaviour was categorised into three main behaviours: (1) cutting for grass-blades (leaves), (2) tillering for grass meristems (leaf-base) and (3) stripping (grass seeds) (Lee & Jamieson 2001; Baber & Craig 2003b).

Habitat availablilty and use by takahē was estimated according to surface area and observational habitat data. Translocated takahē populations seem to be using a wide array of habitats, especially on Motutapu Island. While 83.6% of pastoral grassland is available, takahē used 56.6% of this habitat for foraging. On the other hand, tall vegetation (shrubland, wetland and forested) covers 16.4% of Motutapu Island, and 43.4% was used by takahē. It seems that takahē habitat use varied greatly between pastoral grassland and tall vegetation areas.

At the main mountain of Maungatautari, a pest-proof fenced site, even if pastoral grassland (1.1%) between forested areas (98.9%) and the fence is very disproportionate compared to forested habitat available, it was still mostly used by takahē during the time of the study (47.1%). Forested and shrubland habitat (52.5%) were also used by takahē, mostly along the fence (while roaming or foraging for grass), but this may only be a result of the small percentage of pastoral grassland available. It would be interesting to assess if the percentage of forested areas used would decrease if more grassland (pastoral or native grass) was available. The regression analysis of the foraging behaviours dataset found that, on Motutapu Island, takahē foraging behavioural habits were affected by the difference in percentages of vegetation cover (tree vs shrub vs grass) per site. The main finding was that takahē favoured sites with high percentage of shrub cover for time-consuming and conspicuous foraging behaviours (tillering and stripping) rather than cutting grass blades. When the percentage of tree cover (> 6m) was high, cutting was the most favoured takahē foraging behaviour, as natural succession of the forested areas would inhibit grass cover (Connell & Slatyer 1977). Takahē favoured stripping for grass seeds at sites with high percentage of tree cover and at restoration planting sites. This work supports the findings Baber and Craig (2003), who recommended that adding clusters of shrubs for hiding and dispersal, would improve foraging habits.

Other habitat elements, such as the distance of takahē from water, houses and roads, were also found to have affected foraging behaviours. The closer takahē were to a road, the more they favoured cutting grass blades rather than tillering meristems or stripping seeds. This implies that roads are avoided by takahē for time-consuming and conspicuous behaviours. Another interesting finding was that these birds tended to tiller grass meristems around water and houses. The takahē that have spent most of their time tillering close to houses were birds that were over-familiar with human presence, for example, the MOEC and Home Bay takahē pairs, which were the main campsites of Motutapu Island.

The study, however, did record instances of some takahē displaying peculiar behaviours, which may have affected the results of this study. Over-familiarity caused some birds to display tillering in open grassland, thus foraging in areas easily viewed by aerial predators, such as the Australasian harrier (*Circus approximans;* (Reed 1999; Baber & Craig 2003b). Thus, human presence may have a significant impact on normal foraging behaviour of wild takahē.

The behavioural data collected at Maungatautari was insufficient to conduct the statistical data analyses, so most of the findings here are representative of Motutapu Island translocated takahē. Qualitative data on Maungatautari takahē (i.e. behavioural habits and difficulties encountered during field work) were still discussed, as it offered useful insights on translocated takahē behavioural habits at mainland pest-proof fenced sites. The behavioural data collected on Motutapu Island was analysed via a multinomial regression analysis on R statistical software, with 95% confidence intervals (Venables & Ripley 2002; R Core Team 2013).

It was found that many behavioural traits in this research study were not consistent across takahē individuals at Motutapu Island and Maungatautari. It also varied greatly among different pairs or family groups of takahē individuals within each site (especially Motutapu Island). We also need to assess how much takahē individuals' over-familiarity with humans affects their behavioural habits and breeding success (eco-tourism effects on behaviour) (Moore et al. 2008). Poor habitat selection may be another behavioural habits that takahē display, which was not previously studied (Reed 1999; Moore et al. 2008).

Foraging behaviour is different between Fiordland takahē and island takahē (Mills et al. 1984; Bunin et al. 1997). However, the translocated and island-bred takahē may be different between each different island sites and mainland sites. Some birds may be island-specific in behaviour, not only due to the differences in vegetation cover and grassland available to forage from, but also with the presence of invertebrates, human presence and their structures (houses, camp-sites, etc.). Many birds from Motutapu Island were raised at Burwood (takahē captive facility), so behaviour may be affected by originated area too (Appendix 7).

Perhaps, another method of monitoring takahē at these sites may be needed to assess thoroughly the differences in ecology and foraging behaviour between vegetation types (e.g. wetland vs pastoral grassland). An easier and less-time consuming method of behavioural observation may be required, as it sometimes took a long time to even locate the birds themselves. There is only one other study on the foraging behaviour of translocated takahē on offshore islands (Baber & Craig 2003b), where the number of birds observed was much lower than in this current study (10 versus 24 individuals).

A takahē foraging behavioural study should probably be conducted across many more islands using a standard protocol. It would be interesting to use the protocol in this study, with improved behavioural methods, and perhaps across an even larger population of takahē. With more time to carry out research, sites and numbers of birds, this type of research may offer significant data representative of offshore islands takahē population. When takahē populations (currently too small) of mainland sites increases in the future, we may find significant differences in behaviour and ecology. Mainland pest-proof fenced sites may have to be treated separately from offshore islands for future takahē research. Current high-tech technologies, like cameras with live-feed, may be required for forested sites that are too large or difficult to access, saving valuable time for data collection and analyses (Kays et al. 2010). The effects of eco-tourism may be another factor affecting takahē behavioural habits, and so has to be assessed thoroughly (Moore et al. 2008).

Finally, a tentative plant list was made from the qualitative information collected. It has been found that takahē feed on some pastoral and long introduced grass species. It would be interesting to measure the grass meristems of these species to know exactly how pastoral nutrients and soluble sugars at different part of the grass species (seeds vs meristems vs leaves) might drive foraging behaviours. Further, knowing the specific species of grass eaten might be essential for future habitat management. The next step, in future research, would be to assess the distribution of these identified species, which could then inform us on how to conduct future re-vegetation at these sites. It would be interesting to plant native grass and sedges, and re-conduct this type of research to assess if native plant species have an impact on takahē foraging behaviour. Present research findings show that takahē may be using mostly introduced species, which seems logical, as these plant species seem to grow pre-dominantly in their habitat.

4.2 Motutapu Island and Maungatautari translocated takahē breeding season 2014/2015 and recommendations for future habitat restoration

Nest material and nest plant species were identified during the breeding season monitoring fieldwork. The nests were mostly made of ‘sturdy’ plants (not easily bent plants) with pastoral grass as nest material for the egg laying. Most sturdy nests were found to be made of native species (sedge, or flax species), exotic long grass species (i.e. pampas grass *Cortaderia* spp., Poaceae) or simply only pastoral species. A nest was considered successful if the chick survived hatching and was observed following the parents outside of the nest vicinity. A nest was considered a failure if egg were found rotten in the nest. In some cases, if parents broke the egg while incubating, then eggshells were found. However, it was not always easy to find either egg or eggshell so visual confirmation was needed.

A plant list, showing usage and consumption by takahē, was made, based on nesting and foraging qualitative data. During the breeding season of 2014/2015, two chicks hatched out of ten nests found on Motutapu Island (Islington Bay and Mullet Bay), and only one survived up to juvenile stage (Islington Bay) (Appendix 1). Two chicks also hatched and survived to adulthood at Maungatautari Main Mountain (Brown-Ramsey, Cooper-Garland farmland pasture areas) (Appendix 2). No chicks were hatched at Tautari Wetland, as well as at Maungatautari.

The main conclusions found are that the direct observations of foraging and nesting behaviours during the breeding season of takahē can inform how to conduct future habitat restoration. It may be unrealistic to remove all exotic plants for restoration purposes as takahē seems to use many of these introduced plant species for foraging and nesting on Motutapu Island and Maungatautari. Removing exotic plants could be done, but adding native localized equivalents need to be carried out at the same time. When conducting habitat restoration, re-introducing or adding native species may be required to gain full health of the systems, especially in wetland sites. Plant species selected may be specific to regions. At Motutapu Island, selected plant species would need to be specific to Auckland region; while Maungatautari selected species would be specific to Waikato region.

It would be interesting to investigate whether or not extensive habitat restoration of native species would provoke any changes in takahē foraging and improve breeding success. In addition, natural forest succession will need to be taken into account at these two sites (Connell & Slatyer 1977), especially at Maungatautari as the forest is now reducing extensively the availability of grassland. Extensive forest restoration may be beneficial for takahē on Motutapu Island as it may add cover. But wetland restoration should also be another goal too, to add species that may be used as takahē nest cover/material or food.

As takahē translocations are still at early stages, birds may be too young yet to breed successfully (2-3 years old at the time of the study) (Lee & Jamieson 2001), it may be interesting to re-conduct this type of behavioural research in the next few years. Collecting this type of data, such as nest material and nest plant species cover, might be critical in the future for takahē conservation management. As these particular sites have not been studied extensively, this research thesis gives a preliminary insight on the kinds of plant species that takahē have used for foraging, nest cover and their foraging behaviour during the breeding season and in the presence of other factors like humans, houses/buildings and water. Difficulties encountered during the study period as well as limitations such as behaviour modification when other factors were taken into account have also been discussed. A substantial amount of qualitative data has been collected and this has been important in identifying aspects of takahē foraging habits and breeding success for conservation practice. However, the quantitative data is not extensive and this is to be expected as the populations studied were still very small, since the takahē are an endangered species.

As the introduction of these birds is fairly recent at these sites (Smuts-Kennedy & Parker 2013; Griffiths et al. 2014), especially Motutapu Island, it is important to gather this type of data set for future takahē conservation management. Maungatautari, at the time of the study, cannot be considered as having a viable population of takahē, with only four on the fenced mountain site and two at the wetland fenced site. The extensive qualitative data obtained have provided some general observations, but quantitative data was insufficient to provide any generalisations (low numbers of birds and difficult terrain). Despite the lack of quantitative data, there were still some interesting insights compared to offshore island takahē. These included the difficulty of monitoring these birds in a large forested area and the fact that their breeding were observed to start later than the Motutapu Island takahē population. It would be interesting to use cameras instead of direct observations for future monitoring. Plant species eaten and used for nests may be easier to identify via live-feed cameras rather than direct monitoring (Kays et al. 2010).

Monitoring translocated takahē at these protected sites is essential to the conservation of the species. In fact, while the translocation may have been successful (self-sufficient adults which feeds and breed), the most important issue afterwards would be to inquire if these takahē would prosper (breeding success) at these new sites. Although translocated takahē adapted rapidly to these sites, in terms of breeding, the island takahē has not been as successful as was predicted. The increase in population size at offshore islands and mainland pest-proof sites is very low, and the reasons for this are still unclear. It is therefore, important to do a thorough assessment of the present habitat and monitor their well-being to improve future breeding success of the takahē.

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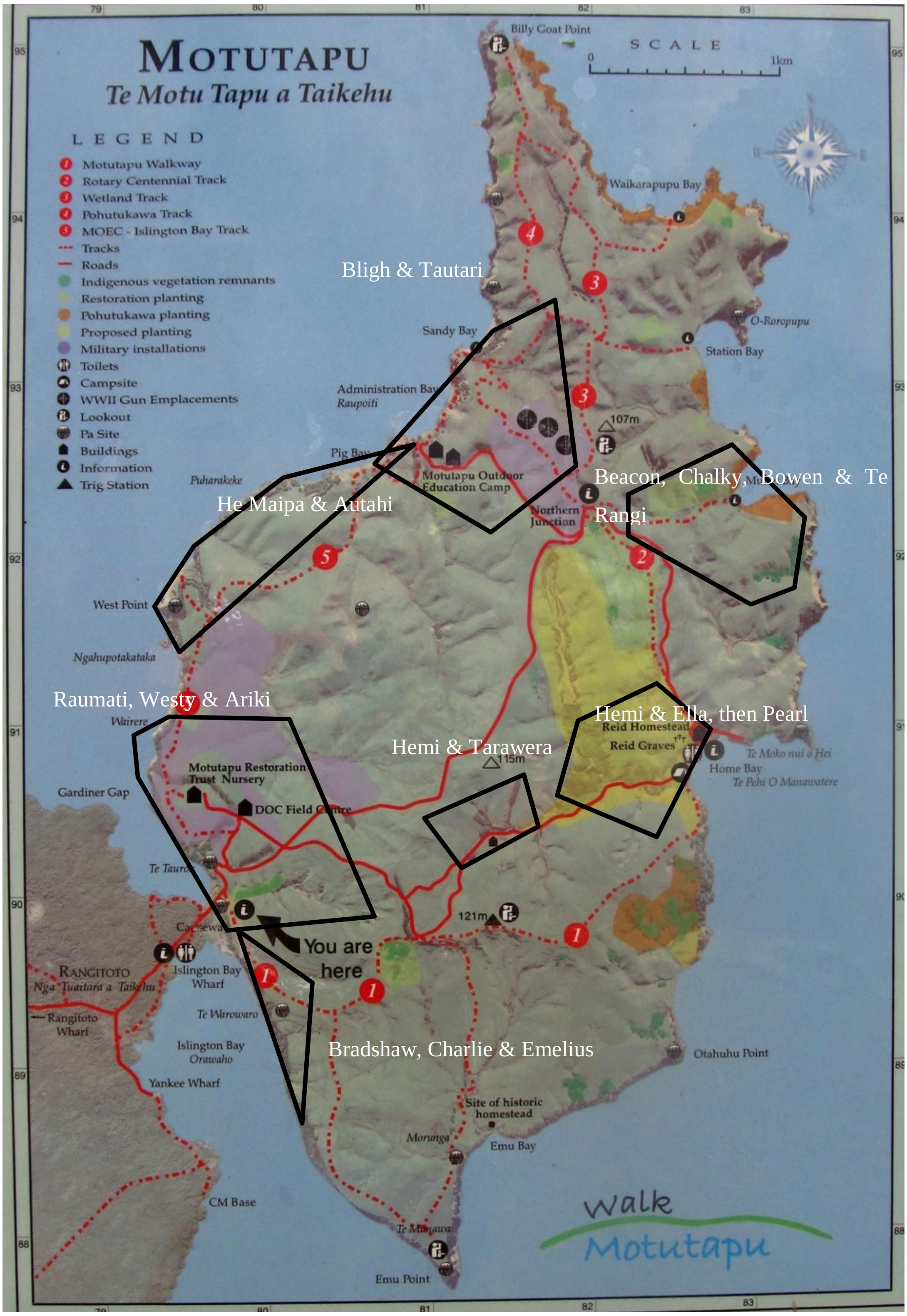
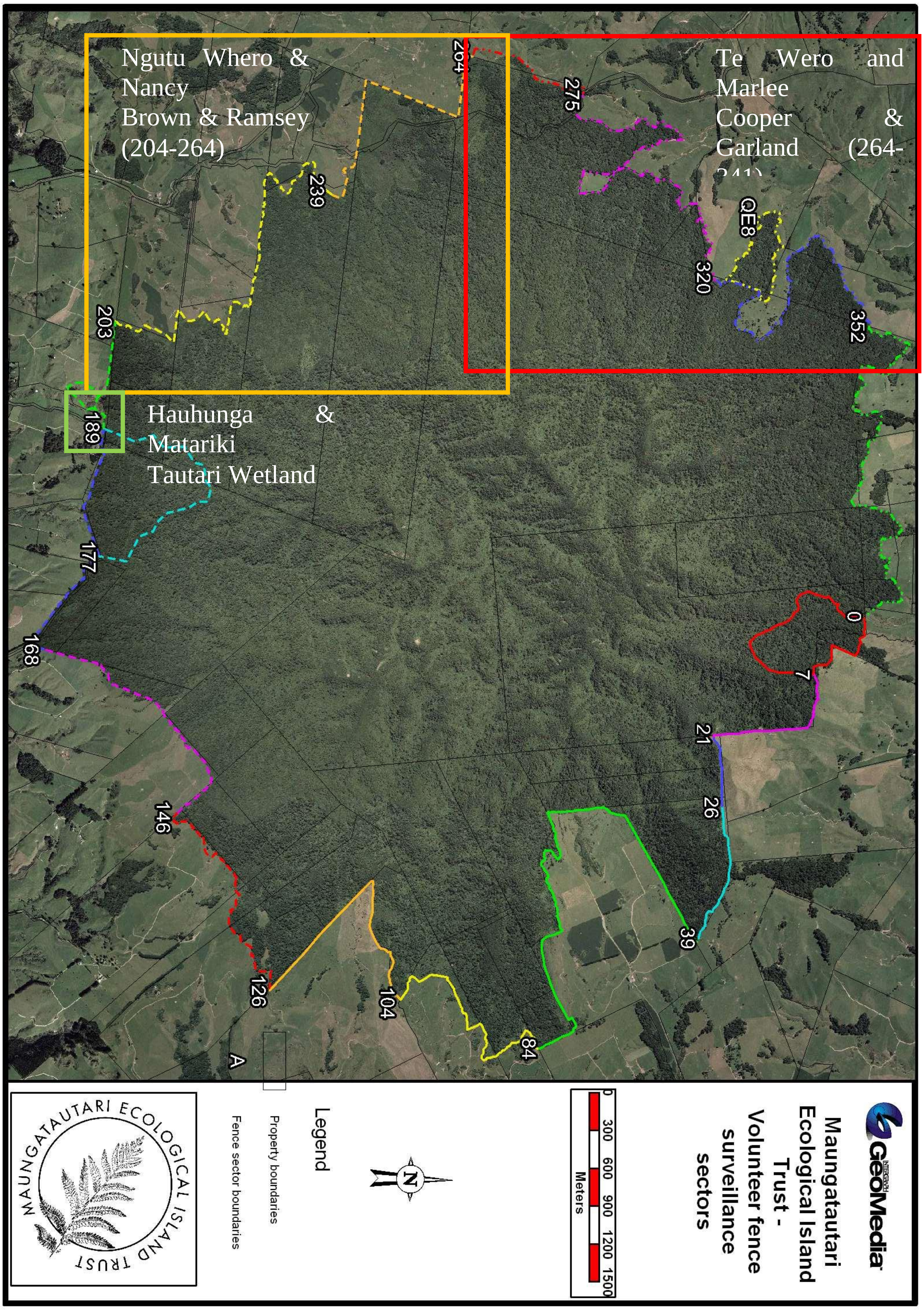
Appendices

Appendix 1: Motutapu Island takahē territories (DOC Map- provided by Hazel Speed, DOC ranger), modified by author.



Appendix 2: Maungautari (map provided by Jane Reeves, MEIT). Map modified by author: different coloured outline show main territories of takahē pairs inside the fenced site. They are not limited to these areas only; they may roam to another area on the other side of the mountain



Appendix 3: Motutapu Island complete recorded observations- plot size and habitat variables

Birds (name)	Territory	Date	Weather	coverTree	coverShrub	coverGrass	canopyHeight	plotLength	plotWidth	Native	Exotic	Planted	Natural	DistHouse	DistRoad	water
Te Rangi	Mullet Bay	28/01/2014	sunny	NA	NA	NA	NA	5	5	NA	NA	NA	NA	NA	NA	NA
Bradshaw, Charlie and Emelius	Islington Bay	28/01/2014	sunny	30	20	50	8	5	5	50	50	0	100	NA	NA	15
Ariki, Westy and Raumati	Islington Bay	29/01/2014	sunny	20	20	60	6	5	5	60	40	0	100	35	15	10
Bradshaw, Charlie and Emelius	Islington Bay	29/01/2014	sunny	30	20	50	8	15	5	50	50	0	100	NA	NA	20
Te Rangi	Mullet Bay	30/01/2014	sunny	NA	NA	NA	NA	5	5	NA	NA	NA	NA	NA	NA	NA
Ella, Hemi	Home Bay	31/01/2014	sunny	10	20	70	6	15	15	20	80	20	80	5	15	25
Ariki, Westy and Raumati	Nursery	1/02/2014	sunny	10	40	50	4	10	5	55	45	60	40	5	30	8
Bligh, Tautari	MOEC	2/02/2014	sunny	5	15	80	6	20	10	40	60	30	70	15	10	5
Bradshaw, Charlie and Emelius	Islington Bay	3/02/2014	sunny	30	20	50	8	5	5	50	50	0	100	NA	NA	15
Beacon, Bowen, Chalky	Mullet Bay, different gully	4/02/2014	sunny	15	20	65	10	5	5	70	30	0	100	NA	NA	25
Ariki, Westy and Raumati	Nursery	5/02/2014	sunny	5	25	70	5	5	5	60	40	60	40	1	5	2
Bradshaw, Charlie & Emelius	Islington Bay	16/07/2014	sunny	30	20	50	8	5	5	50	50	0	100	NA	NA	15
Ella, Hemi	Home Bay	17/07/2014	sunny	0	40	60	0	20	15	30	70	10	90	10	5	5
Ella, Hemi	Home Bay	17/07/2014	sunny	0	10	90	0	10	10	10	90	60	40	3	3	1
Bligh, Tautari	MOEC	18/07/2014	cloudy	5	15	80	6	15	5	40	60	30	70	5	0	10
Bligh, Tautari	MOEC	18/07/2014	cloudy	NA	NA	NA	NA	10	10	NA	NA	NA	NA	12	10	1
Ariki, Westy & Raumati	Islington Bay	19/07/2014	cloudy, rain	1	39	60	5	10	10	60	40	0	100	35	25	1

Bradshaw, Charlie & Emelius	Islington Bay	22/07/2014	sunny	30	20	50	8	25	5	50	50	0	100	NA	NA	10
Bligh, Tautari	MOEC	24/07/2014	sunny	5	15	80	6	15	15	40	60	30	70	5	0	20
Bradshaw, Charlie & Emelius	Islington Bay	18/08/2014	sunny	45	15	40	6	8	3	10	90	0	100	NA	NA	30
Ariki, Westy & Raumati	Islington Bay	19/08/2014	sunny	10	20	70	8	15	10	80	20	0	100	NA	0	5
Ariki, Westy & Raumati	Islington Bay	19/08/2014	sunny	0	10	90	0	10	10	50	50	0	100	NA	30	5
Bligh, Tautari	MOEC	20/08/2014	cloudy, rain	10	30	60	3	10	5	40	60	30	70	10	8	5
Bligh, Tautari	MOEC	20/08/2014	cloudy, rain	NA	NA	NA	NA	10	10	NA	NA	NA	NA	NA	NA	NA
Bradshaw, Charlie & Emelius	Islington Bay	21/08/2014	cloudy	10	40	50	4	20	10	20	80	0	100	NA	NA	10
He Maipa, Autahi	West Point	22/08/2014	sunny	30	40	30	5	25	10	40	60	30	70	NA	NA	25
Beacon, Bowen, Chalky	Mullet Bay	23/08/2014	sunny	0	70	30	4	15	5	60	40	0	100	NA	NA	1
Bligh, Tautari	Pig Bay	25/08/2014	cloudy	5	55	40	NA	5	5	30	70	0	100	NA	NA	5
Hemi	Home Bay	27/08/2014	rainy	0	40	60	3	5	5	80	20	0	100	NA	50	20
Bradshaw, Charlie & Emelius	Islington Bay	22/09/2014	cloudy	10	60	30	6	5	5	80	20	0	100	NA	NA	30
He Maipa, Autahi	West Point	23/09/2014	cloudy	15	35	50	7	5	5	70	30	0	100	NA	NA	5
Beacon, Bowen, Chalky & Te Rangi	Mullet Bay	24/09/2014	cloudy	30	40	30	8	5	5	70	30	0	100	NA	NA	1
Ariki, Westy & Raumati	Nursery	25/09/2014	sunny	10	15	75	8	15	5	80	20	70	30	10	15	10
He Maipa, Autahi	West Point	26/09/2014	sunny	10	50	40	4	5	5	70	30	10	90	NA	NA	10
Bligh,	MOEC	26/09/2014	sunny	5	35	60	3	10	5	30	70	50	50	5	1	8

Tautari																
Bligh, Tautari	MOEC	26/09/2014	sunny	5	35	60	3	5	5	30	70	50	50	10	15	15
Bradshaw, Charlie & Emelius	Islington Bay	29/09/2014	sunny	10	60	30	6	5	5	80	20	0	100	NA	NA	30
He Maipa, Autahi	West Point	30/09/2014	sunny	15	35	50	8	5	5	60	40	20	80	NA	NA	30
Hemi, Pearl	Home Bay	1/10/2014	sunny	10	30	60	4	5	5	30	70	60	40	5	20	1
Beacon, Bowen, Chalky, Te Rangi?	Mullet Bay	27/10/2014	rainy	10	25	65	4	15	5	60	40	0	100	NA	NA	5
Hemi, Pearl	Home Bay	29/10/2014	rainy	0	60	40	3	15	15	70	30	40	60	25	15	10
Beacon, Bowen, Chalky, Te Rangi?	Mullet Bay	30/10/2014	cloudy	10	25	65	6	10	5	85	15	0	100	NA	NA	15
Bligh, Tautari	MOEC	1/11/2014	cloudy, rainy	5	35	60	3	10	5	30	70	50	50	5	7	5
He Maipa, Autahi	Pig Bay	1/11/2014	cloudy	30	35	35	3	5	5	40	60	0	100	NA	NA	3
Ariki, Westy & Raumati	Nursery	3/11/2014	rainy	5	70	25	6	20	5	80	20	90	10	5	8	2
Bradshaw, Charlie & Emelius	Islington Bay	4/11/2014	cloudy	5	45	50	5	5	3	70	30	0	100	NA	NA	30
Hemi, Pearl	Home Bay	4/11/2014	cloudy	10	30	60	5	5	5	40	60	30	70	5	20	1
Ariki, Westy & Raumati	Nursery	5/11/2014	cloudy	5	70	25	6	10	10	80	20	90	10	7	15	5
He Maipa, Autahi	Pig Bay	1/12/2014	cloudy	0	15	85	2	5	5	80	20	0	100	NA	NA	15
Ariki, Westy &Raumati	Islington Bay	1/12/2014	cloudy	0	30	70	5	5	5	70	30	0	100	NA	NA	25
Bradshaw, Charlie & Emelius	Islington Bay	1/12/2014	cloudy	5	25	70	7	5	5	15	85	0	100	NA	NA	15
Hemi, Tarawera	Central Gully	2/12/2014	sunny	15	45	40	6	5	5	70	30	0	100	NA		20	5

Beacon, Bowen, Chalky, Te Rangi	Mullet Bay	2/12/2014	sunny	10	25	65	6	15	20	85	15	0	100	NA	NA	5
Bligh, Tautari	Pig Bay	3/12/2014	sunny	5	35	60	3	10	10	10	90	0	100	NA	NA	3
He Maipa, Autahi	Pig Bay	3/12/2014	sunny	5	25	70	4	5	5	60	40	0	100	NA	NA	5
Hemi, Tarawera	Central Gully	4/12/2014	sunny	10	40	50	7	5	5	40	60	30	70	NA	5	5
Beacon, Bowen, Chalky, Te Rangi	Mullet Bay	5/12/2014	sunny	30	40	30	6	5	5	95	5	0	100	NA	NA	1
Bradshaw, Charlie & Emelius	Islington Bay	7/12/2014	sunny	5	25	70	7	5	5	15	85	0	100	NA	NA	10
Hemi, Tarawera	Central Gully	7/12/2014	sunny	10	40	50	5	5	10	40	60	0	100	NA	30	1
Hemi, Tarawera	Central Gully	20/01/2015	sunny	30	20	50	8	5	5	40	60	40	60	30	NA	1
Ariki, Westy & Raumati	Nursery	21/01/2015	sunny	10	5	85	7	15	5	80	20	30	70	1	5	30
He Maipa, Autahi	West Point	22/01/2015	sunny	15	35	50	7	5	10	30	70	60	40	NA	NA	10
Ariki, Westy & Raumati	Nursery	23/01/2015	sunny	5	80	15	7	5	5	80	20	90	10	5	15	5
He Maipa, Autahi	West Point	23/01/2015	sunny	30	40	30	8	5	5	40	60	30	70	NA	NA	5
Ariki, Westy & Raumati	Islington Bay	24/01/2015	sunny	5	5	90	5	15	5	10	90	10	90	30	15	25
Beacon, Bowen, Chalky & Te rangi	Mullet Bay	25/01/2015	sunny	10	70	20	8	5	5	10	90	0	100	NA	NA	5
Hemi, Tarawera	Central Gully	26/01/2015	sunny	20	40	40	8	20	5	20	80	80	20	20	30	25
Hemi, Tarawera	Central Gully	26/01/2015	sunny	30	50	20	6	5	5	10	90	0	100	15	1	5
Ariki, Westy & Raumati	Nursery	19/02/2015	sunny	5	35	60	3	10	5	80	20	60	40	15	5	3

Ariki, Westy & Raumati	Nursery	19/02/2015	sunny	0	0	100	NA	1	3	NA	NA	NA	NA	7	0	10
He Maipa, Autahi	West Point	21/02/2015	cloudy	20	50	30	6	5	5	40	60	30	70	NA	NA	2
Bradshaw, Charlie & Emelius	Islington Bay	22/02/2015	cloudy	20	10	70	8	5	5	20	80	0	100	NA	NA	10
Hemi, Tarawera	Central Gully	24/02/2015	cloudy	10	5	85	7	5	5	30	70	80	20	15	8	0
Beacon, Bowen, Chalky & Te Rangi	Mullet Bay	24/02/2015	cloudy	5	0	95	6	5	5	0	100	0	100	NA	NA	32
Beacon, Bowen, Chalky & Te Rangi	Mullet Bay	24/02/2015	cloudy	10	15	75	5	20	10	40	60	0	100	NA	NA	NA
Bradshaw, Charlie & Emelius	Islington Bay	25/02/2015	sunny	10	20	70	7	5	5	70	30	0	100	NA	NA	15
Hemi, Tarawera	Central Gully	25/02/2015	sunny	20	15	65	7	5	5	30	70	80	20	NA	NA	5
Ariki, Westy & Raumati	Nursery	27/02/2015	sunny	2	3	95	6	5	8	15	85	90	10	1	7	15
He Maipa, Autahi	West Point	27/02/2015	sunny	25	55	20	7	5	5	60	40	0	100	NA	NA	20

Appendix 4: Maungatautari dataset- plot size and habitat variables

Birds (name)	Territory	Date	Weather	%cover			canopy height (m)	Plot (m)		Canopy (%)			
				tree	shrub	grass		length	width	native	exotic	planted	natural
Ngutu Whero, Nancy	Brown (204-230)	16/09/2014	cloudy	35	25	40	12	10	10	95	5		100
Te Wero, Marlee	Cooper (264-275)	16/09/2014	cloudy	35	15	50	10	15	15	95	5		100
Hauhunga, Matariki	Wetland	18/09/2014	cloudy	5	35	60	6	15	3	80	20	15	85
Ngutu Whero, Nancy	Brown (204-230)	7/10/2014	sunny	35	25	40	12	5	5	95	5		100
Te Wero, Marlee	Cooper (264-275)	7/10/2014	sunny	35	15	50	10	5	5	95	5		100
Hauhunga, Matariki	Wetland	9/10/2014	sunny	5	35	60	6	5	3	80	20	15	85
Ngutu Whero, Nancy	Brown (204-230)	14/10/2014	cloudy	35	25	40	12	5	5	95	5		100
Te Wero, Marlee	Cooper (264-275)	14/10/2014	cloudy	35	15	50	10	5	5	95	5		100
Hauhunga, Matariki	Wetland	16/10/2014	sunny	10	30	50	6	5	5	80	20	15	85
Ngutu Whero, Nancy	Brown (204-230)	23/10/2014	cloudy	35	25	40	12	5	5	95	5		100
Te Wero, Marlee	Cooper (264-275)	23/10/2014	cloudy	35	15	50	10	5	5	95	5		100
Hauhunga, Matariki	Wetland	24/10/2014	sunny	5	35	60	6	5	5	80	20	15	85
Ngutu Whero, Nancy	Brown (204-230)	11/11/2014	sunny	35	25	40	12	5	5	95	5		100
Te Wero, Marlee	Cooper (264-275)	11/11/2014	sunny	35	15	50	10	5	5	95	5		100
Hauhunga, Matariki	Wetland	13/11/2014	sunny	5	35	60	6	5	5	80	20	15	85
Ngutu Whero, Nancy	Brown (204-230)	18/11/2014	cloudy	35	25	40	10	5	5	95	5		100
Te Wero, Marlee	Cooper (264-275)	18/11/2014	cloudy	0	15	85	5	5	5	95	5		100
Hauhunga, Matariki	Wetland	20/11/2014	cloudy	20	35	45	6	5	5	80	20	15	85
Ngutu Whero, Nancy	Brown (204-230)	25/11/2014	sunny	40	25	35	10	5	5	90	10		100
Te Wero, Marlee	Cooper (264-275)	25/11/2014	sunny	30	30	40	8	10	5	95	5		100
Hauhunga, Matariki	Wetland	13/01/2015	sunny	5	20	75	6	5	3	80	20	15	85

Hauhunga, Matariki	Wetland	3/02/2015	sunny	5	20	75	6	5	5	80	20	15	85
Te Wero, Marlee	Dean(341-352)	5/02/2015	sunny	50	40	10	10	5	5	85	15		100
Ngutu Whero, Nancy	?<146	5/02/2015	sunny										
Te Wero, Marlee	Garland(275-341)	10/02/2015	sunny	40	40	20	12	20	3	95	5		100
Ngutu Whero, Nancy	?<146	10/02/2015	sunny										
Te Wero, Marlee	fence 320	17/02/2015	sunny	45	35	20	10	10	3	95	5		100
Ngutu Whero, Nancy	fence206	18/02/2015	sunny	25	35	40	7	5	5	70	30		100

Appendix 5: Motutapu Island foraging behavioural data in total minutes (only observations >30 minutes to 120 minutes max analysed statistically), in relation to habitat variable. The data was summarized for the multinomial regression analysis into dataset 1 (Summer 2013/2014) and dataset 2 (Year 2014/2015)

Dataset 1

Date.	Feed	Till	Strip	Other	Totalmin	Tree	Shrub	Grass	canopyHeight	plotLength	plotWidth	Native	Exotic	Planted	Natural	DistHouse	DistRoad	water
29/01/2014	21	0	5	5	31	20	20	60	6	5	5	60	40	0	100	35	15	10
29/01/2014	12	1	0	12	25	30	20	50	8	15	5	50	50	0	100	NA	NA	20
31/01/2014	2	7	3	19	31	10	20	70	6	15	15	20	80	20	80	5	15	25
31/01/2014	24	1	1	15	41	10	20	70	6	15	15	20	80	20	80	5	15	25
31/01/2014	20	28	1	12	61	10	20	70	6	15	15	20	80	20	80	5	15	25
1/02/2014	1	33	10	40	84	10	40	50	4	10	5	55	45	60	40	5	30	8
1/02/2014	11	36	0	26	73	10	40	50	4	10	5	55	45	60	40	5	30	8
2/02/2014	2	6	5	39	52	5	15	80	6	20	10	40	60	30	70	15	10	5
2/02/2014	32	2	0	19	53	5	15	80	6	20	10	40	60	30	70	15	10	5
2/02/2014	14	14	0	8	36	5	15	80	6	20	10	40	60	30	70	15	10	5

Dataset 2

Date.	Feeding.	Tilling.	Stripping.	Other.	Totalmin	Tree	Shrub	Grass	canopyHeight	plotLength	plotWidth	Native	Exotic	Planted	Natural	DistHouse	DistRoad	water
17/07/2014	2	0	0	29	31	0	40	60	0	20	15	30	70	10	90	10	5	5
17/07/2014	28	4	0	29	61	0	40	60	0	20	15	30	70	10	90	10	5	5
17/07/2014	58	22	0	11	91	0	10	90	0	10	10	10	90	60	40	3	3	1

18/07/2014	3	4	0	19	26	5	15	80	6	15	5	40	60	30	70	5	0	10
18/07/2014	10	21	0	15	46	5	15	80	6	15	5	40	60	30	70	5	0	10
18/07/2014	7	8	0	16	31	5	15	80	6	10	10	40	60	30	70	12	10	1
19/07/2014	56	28	0	17	101	1	39	60	5	10	10	60	40	0	100	35	25	1
19/07/2014	63	43	0	15	121	1	39	60	5	10	10	60	40	0	100	35	25	1
19/07/2014	25	7	0	24	56	1	39	60	5	10	10	60	40	0	100	35	25	1
22/07/2014	17	14	15	50	96	30	20	50	8	25	5	50	50	0	100			10
24/07/2014	80	17	0	24	121	5	15	80	6	15	15	40	60	30	70	5	0	20
24/07/2014	13	0	0	21	34	5	15	80	6	15	15	40	60	30	70	5	0	20
24/07/2014	42	24	0	10	76	5	15	80	6	15	15	40	60	30	70	5	0	20
24/07/2014	20	5	0	6	31	5	15	80	6	15	15	40	60	30	70	5	0	20
18/08/2014	11	11	4	43	69	45	15	40	6	8	3	10	90	0	100			30
19/08/2014	17	32	0	13	62	10	20	70	8	15	10	80	20	0	100		0	5
19/08/2014	25	35	0	1	61	10	20	70	8	15	10	80	20	0	100		0	5
19/08/2014	17	26	0	18	61	0	10	90	0	10	10	50	50	0	100		30	5
20/08/2014	46	9	1	5	61	10	30	60	3	10	5	40	60	30	70	10	8	5
20/08/2014	29	1	0	22	52	10	30	60	3	10	10	40	60	30	70	10	8	5
20/08/2014	25	21	0	15	61	10	30	60	3	10	10	40	60	30	70	10	8	5
23/08/2014	12	32	0	20	64	0	70	30	4	15	5	60	40	0	100			1
25/09/2014	12	6	0	13	31	10	15	75	8	15	5	80	20	70	30	10	15	10
26/09/2014	15	0	0	16	31	5	35	60	3	5	5	30	70	50	50	10	15	15
30/10/2014	2	6	0	23	31	10	25	65	6	10	5	85	15	0	100			15
1/11/2014	6	16	1	13	36	5	35	60	3	10	5	30	70	50	50	5	7	5
2/12/2014	0	19	0	12	31	10	25	65	6	15	20	85	15	0	100			5
24/01/2015	0	2	31	11	44	5	5	90	5	15	5	10	90	10	90	30	15	25
26/01/2015	0	20	18	9	47	30	50	20	6	5	5	10	90	0	100	15	1	5

Appendix 6: Foraging behaviour recorded for Maungatautari takahē (qualitative data)

Territory	Time	N. individuals	**Activity**										**Food**		
			feeding	tillering	stripping	moving	preening	allo-preening	still	agonistic	courtship	unknown/other	invs	Plant sp.	other
Brown	11:00	2		1											
	11:01		1												
	11:02		1												
	11:03			1											
	11:04		1												
	11:05						1								
	11:06											1		Hooper food	
Tautari Wetland	7:30	2	1												
	7:31			1											
	7:32			1											
	7:33			1											
	7:34			1											
	7:35			1											
	7:36		1												
	7:37			1											
	7:38		1												
	7:39			1											
	7:40			1											
	7:41		1												

	7:42			1		
	7:43		1			
	7:44			1		
	7:45		1			
	7:46			1		
	7:47			1		
	7:48		1			
	7:49		1			
	7:50		1			
	7:51		1			
	7:52		1			
	7:53		1			
	7:54				1	
	7:55				1	
	7:56				1	
	7:57				1	
	7:58				1	
	7:59					1
	8:00					1
	8:01					1
	8:02					1
Brown	12:00	1			1	
	12:01				1	
	12:02				1	
	12:03				1	

	12:04				1			
	12:05						1	
Cooper	1:39						1	Hooper food
	1:38		1					
	1:37		1					
	1:36					1		
	1:35				1			
	1:34				1			
Brown	12:02	1		1				
	12:03		1					
	12:04				1			
	12:05				1			
	12:06				1			
Brown	10:00	1		1				
	10:01			1				
	10:02			1				
	10:03				1			
	10:04				1			
	10:05						1	
Cooper	10:35	1		1				
	10:36			1				
	10:37				1			

	10:38						1
	10:39					1	
	10:40					1	
Ramsey	10:15	2+chick	1				
	10:16		1				
	10:17					1	
Tautari wetland	6:00	2			1		
	6:01				1		
	6:02				1		
	6:03				1		
	6:04			1			
	6:05			1			
	6:06				1		
	6:07				1		
	6:08			1			
	6:09				1		
	6:10			1			
	6:11				1		
	6:12				1		
	6:13			1			
	6:14				1		
	6:15			1			
	6:16				1		

	6:17			1								
	6:18				1							
	6:19				1							
	6:20				1							
	6:21				1							
	6:22			1								
	6:23				1							
	6:24			1								
	6:25				1							
	6:26				1							
	6:27				1							
	6:28		1									
	6:29		1									
	6:30					1						
	6:31											1
	6:32											1
	6:33					1						
Garland	10:55	2+chick			1							
	10:56				1							
	10:57				1							
	10:58				1							
	10:59				1							
	11:00					1						

Appendix 7: Sex, age, origin, radio-telemetry frequency and leg-bands for translocated takahē on Motutapu Island and Maungatautari.

Name	Sex	Age in 2014 (years)	Origin (South Is. vs North Is.)	Radio-telemetry number (timer)	Bands*
Motutapu Island translocated takahē population					
Tarawera	F	7	Burwood (SI)	7-1 (6.40-18.40)	Gm-RR
Ariki	M	3	Tiritiri Matangi (NI)	14-2 (8.00-20.00)	Rm-GB
Beacon	M	3	Tiritiri M. (NI)	30+1.5	Rm-BK
Raumati	F	4	Tiritiri M. (NI)	38	YY-Km
Hemi	M	3	Burwood (SI)	83-1	K-Ym
Bradshaw	M	3	Burwood (SI)	90+0.5 (6.50-18.50)	Wm-Yo
He Maipa	M	6	Burwood (SI)	32-2.5	RB-Om
Autahi	F	3	Burwood (SI)	64-3.5	OB-Rm
Ella	F	-	Tiritiri M. (NI)	DEAD (8/2014)	OG-Bm
Emelius	F	3	Burwood (SI)	-	KR-Km
Chalky	F	3	Burwood (SI)	-	YK-Wm
Westy	M	3	Tiritiri M. (NI)	-	Rm-KG
Pearl	F	5	Burwood (SI)	-	Rm-GR
Charlie	F	4	Burwood (SI)	-	Rm-WK
Bowen	F	3	Burwood (SI)	-	KB-Km
Tautari	F	5	Maungatautari (NI)	-	Km-GO
Bligh	M	3	Burwood (SI)	-	Ym-WB
Te Rangi	M	5	Mana I. (SI)	-	m-R
Maungatautari translocated takahē population- Main Mountain fenced site					
Te wero	M	9-10	Rarotoka/Burwood (SI)	23-1	Om-R
Marlee	F	3	Burwood (SI)	22+1.5	BO-Gm
Ngutu Whero	M	9	Mana Is. (SI)	24-2.5	RM-WB
Nancy	F	3	Burwood (SI)	-	Bm-KB
Maungatautari translocated takahē population- Tautari Wetland fenced site					
Hauhunga	M	11	Mana Island (SI)	-	Wm
Matariki	F	5	Mana Island (SI)	-	Bm-YG

* Band colour from left-leg to right-leg, B (blue), G (green), R (red), Y (yellow), O (orange), W (white), K (black), m (metal).