Manaaki Whenua
Landcare Research

Monitoring the ecological integrity of the indigenous forests of Rakiura, 1970–2024

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Monitoring the ecological integrity of the indigenous forests of Rakiura, 1970–2024

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Summary

Project and client

In January 2024, the Department of Conservation (DOC) contracted Manaaki Whenua – Landcare Research (MWLR) to review historical and current ecological monitoring activities in indigenous forests on Rakiura.[1] This work was completed in May 2024.

Objectives

Use information from the National Vegetation Survey (NVS) databank, published and unpublished literature sources, and information from DOC staff to do the following.

- Undertake a stocktake of forest monitoring that has been done over the last 50 years on Rakiura, including monitoring during 2024 funded by Te Uru Rākau – New Zealand Forest Service (within Ministry for Primary Industries) through the Maximising Forest Carbon workstream. The scope includes monitoring methods used for vegetation, deer, possums, and bird communities.
- Prepare a report describing available data and outlining recommendations for remeasurement to meet the departments' objective of reporting every 10 years on the forest health of Rakiura.
- Prepare a PowerPoint presentation for DOC to present to the Southland Conservation Board and other groups interested in the forest health of Rakiura.

Methods

We searched for ecological monitoring data sets relevant to this scope using:

- the NVS databank and ancillary data sets on animals
- a database of five-minute bird count (5MBC) data curated by James Mortimer and Terry Greene at DOC Christchurch
- the National Ungulate Pellets (NUP) database curated by James Mortimer and Terry Greene at DOC Christchurch
- the ecological monitoring data set maintained by DOC Southland (acquired from George Ledgard, DOC Te Anau) and original data files associated with that data set
- correspondence with individuals who have worked on Rakiura and who collected primary data on vegetation composition and structure, deer, possums, or bird communities
- searching the library catalogue at MWLR as this holds details of unpublished reports by the New Zealand Forest Service and other agencies that might have conducted systematic ecological monitoring in the past.

[1] We will use Rakiura to mean Stewart Island/Rakiura throughout this report – unless referring to surveys or NVS data that use 'Stewart Island' or some other name. Similarly we follow the New Zealand Gazetteer (NZG) (https://gazetteer.linz.govt.nz/place/16422) for official names and dual names, but use original survey names.

Results

- We identified 180 permanent forest plots, and most data from these plots were held in the NVS databank. We also identified three studies using the foliar browse index method, and three studies of tree seedling communities.
- We identified two large surveys of deer and possum relative abundance based on pellet counts, one sampling northern Rakiura and the other sampling southern Rakiura. Both had repeated measures and data were held in the NUP database held by DOC.
- We identified 5MBC data sets collected during the period 1979–1985 that were held by DOC. Some of these 5MBC data sets were collected from permanent vegetation plots in eastern Rakiura. However, we also identified 5MBC data collected from permanent forest plots in eastern and northern Rakiura during 1998-2000 that were not held by DOC.

Recommendations

We make the following recommendations to DOC based on our review.

- Remeasuring Tier Two permanent vegetation plots in northern and southern Rakiura to achieve island-wide coverage.
- Adopting the Tier One philosophy of measuring multiple elements of ecosystems at the same places using comparable methods. This will allow the Department to knit together a picture of vegetation change that can clearly be linked to deer and possum change, and its flow-on effects for bird habitat. If the Department (DOC) chooses to measure foliar browse indices, add these to permanent vegetation plots where the population consequences can be measured and where local possum numbers are also assessed.
- Installing new permanent vegetation plots on Codfish Island / Whenua Hou to provide a benchmark for Rakiura. Only Codfish Island / Whenua Hou can provide the benchmark of forest ecosystem dynamics in the absence of all non-native mammal species.
- Locating, entering and mobilising the outstanding data needed to build historical context and trends (i.e. DOC's 5MBC data from 1998–2000).
- Considering investment in more samples in successional communities to understand canopy-replacing processes with respect to deer abundance and deer management.

1 Introduction

In January 2024, the Department of Conservation (DOC, or 'the Department) contracted Manaaki Whenua – Landcare Research (MWLR) to review historical and current ecological monitoring activities in indigenous forests on Rakiura.[2] The work was completed in June 2024.

2 Background

Forests cover 89% of the area of Rakiura, with podocarp–hardwood forest or hardwood forest covering 63.5% and low forest and scrub 25.5% of the area; Figure 1). Given the dominance of forests across Rakiura, it follows that the Stewart Island/Rakiura Conservation Management Strategy (CMS) and Rakiura National Park Management Plan 2011–2021 (Department of Conservation 2012) focuses particularly on the island's forests. It includes a 10-year milestone that the Department of Conservation will produce a 'report detailing the forest health of Stewart Island/Rakiura'. A major focus of the Strategy and plan is on the effects of introduced deer populations on the health of forests on Rakiura, and also the effects of introduced brushtail possums (*Trichosurus vulpecula*). The report that was due to be presented to the Southland Conservation Board and other stakeholders at the end of the 2022/23 financial year needed to summarise data on forest health (hereafter ecological integrity, defined as 'the full potential of indigenous biotic and abiotic features and natural processes, functioning in sustainable communities, habitats, and landscapes'(see McGlone et al. 2021, p. 3); and especially the effects of deer populations on ecological integrity.

There are two species of deer on the island: red deer (*Cervus elaphus*) introduced to Rakiura in 1901, and white-tailed deer (*Odocoileus virginianus*) introduced in 1905 (King & Forsyth 2021). Brushtail possums were introduced to Rakiura in 1890 (Department of Conservation 2012). Pervasive browsing by deer and possums directly affects forest ecological integrity because browsing can greatly reduce the abundance of some plant species at local scales. This will ultimately shift the composition of forests away from species that these mammals consume preferentially towards unpalatable species (Peltzer et al. 2014; Hawcroft et al. 2024), which in turn can affect ecosystem services such as carbon storage and soil nutrient cycling (Wardle & Bardgett 2004; Tanentzap & Coomes 2012). If browsing pressure is not reduced, these effects may be irreversible (Coomes et al. 2003).

The last report of the state of forest vegetation from Rakiura, which also focussed on the effects of deer populations on ecological integrity, was delivered in 2010 (Duncan et al. 2010). Local-scale monitoring of ecological integrity has not been conducted since then. The only new data collection has been through the national Biodiversity Monitoring and

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Reporting System's Tier One Monitoring Programme (Bellingham et al. 2020). Tier One data provide a broad overview of forest ecological integrity throughout public conservation land and, although inferences can be drawn about changes in ecological integrity in the forests of Rakiura from them (MacLeod et al. 2024), they do not suffice for the spatial and temporal resolution that the local-scale, Tier Two monitoring infrastructure on Rakiura could provide and has provided in the past (e.g. Bellingham & Allan 2003). Tier Two monitoring includes regional- or catchment-scale networks of vegetation plots often installed to understand the outcomes of specific management activities or pressures (Richardson et al. 2024). Tier One and Tier Two monitoring complement one another: Tier One reveals large-scale spatial patterns and emerging trends (the 'big picture') while Tier Two allows managers and researchers to investigate particular forest types and to assess specific pressures (Richardson et al. 2024).

Tier One data include data on vegetation composition and structure, measures of the relative abundance of possums and ungulates, and data on bird communities (Bellingham et al. 2020). Data on bird communities have not typically been collected from catchment-scale or regional-scale long-term permanent plot networks. To meet the catchment- and regional-scale needs required under the Stewart Island/Rakiura CMS and Rakiura National Park Management Plan 2011–2021 (Department of Conservation 2012), and to achieve comparability with Tier One monitoring, DOC need to maintain and remeasure long-term permanent vegetation plot networks on Rakiura and include measurement of the relative abundance of deer and possums, and bird communities.

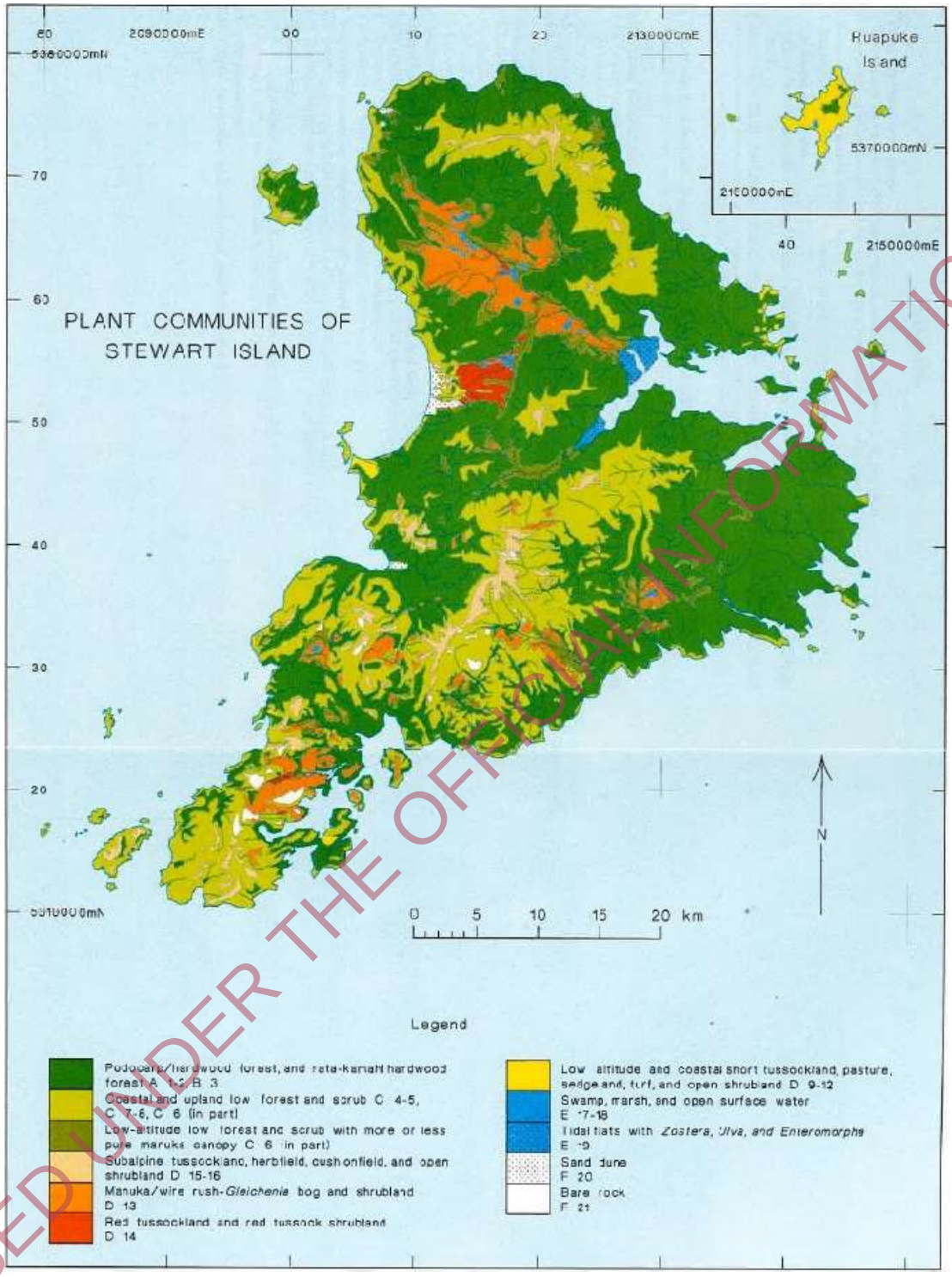

Figure 1. Map of plant communities on Stewart Island/Rakiura (Source: Wilson 1987, Fig. 8. Crown Copyright).

3 Objectives

Use information from the National Vegetation Survey (NVS) databank, published and unpublished literature sources, and information from DOC staff to do the following.

- Undertake a stocktake of forest monitoring that has been done over the last 50 years on Rakiura, including monitoring during 2024 funded by Te Uru Rākau – New Zealand Forest Service (within Ministry for Primary Industries) through the Maximising Forest Carbon workstream. The scope includes monitoring methods used for vegetation, deer, possums, and bird communities.
- Prepare a report describing available data and outlining recommendations for remeasurement to meet the departments' objective of reporting every 10 years on the forest health of Rakiura.
- Prepare a PowerPoint presentation for DOC to present to the Southland Conservation Board and other groups interested in the forest health of Rakiura.

4 Methods

Our project's scope was the forest monitoring of vegetation, deer, possums, and bird communities on Rakiura. Data on bird communities concerns forest birds but not seabirds, such as yellow-eyed penguin (*Megadyptes antipodes*), that nest in forests on Rakiura (Massaro & Blair 2003). Although data have been collected on rodents on Rakiura (e.g. Harper et al. 2005), these data were out of scope of this report. Data on single species of plants and animals (e.g. reptiles, southern brown kiwi [*Apteryx australis*]) were also out of scope. We searched for ecological monitoring data sets relevant to this scope using:

- the NVS databank and ancillary data sets on animals
- a database of five-minute bird count (5MBC) data curated by James Mortimer and Terry Greene at DOC Christchurch
- the National Ungulate Pellets (NUP) database curated by James Mortimer and Terry Greene at DOC Christchurch
- the ecological monitoring data set maintained by DOC Southland (acquired from George Ledgard, DOC Te Anau) and original data files associated with that data set
- correspondence with individuals who have worked on Rakiura and who collected primary data on vegetation composition and structure, deer, possums, or bird communities
- searches of the library catalogue at Manaaki Whenua – Landcare Research as this holds details of unpublished reports by the New Zealand Forest Service and other agencies that might have conducted systematic ecological monitoring in the past.

We considered these aspects of ecological monitoring data in forming our recommendations.

- Whether they were quantitative data that can be compared statistically among sites and across years to derive trend estimates.
- Whether they used consistent methods across sample points and through time.
- Whether they offered unbiased (representative or objective) sampling so that insights from sample points can be assumed to represent a wider area.
- Their spatial coverage.
- The length of time series and number of repeat measures.
- Their relevance to key issues (e.g. exclosure plots and mammal-free islands are particularly relevant for the issue of white-tailed deer management).
- Their alignment of multiple measures (e.g. vegetation, deer, possums, and bird communities measured at the same sites in the same years).

5 Results

We found that the last comprehensive measurement of forest ecological integrity on Rakiura was undertaken by the Department of Conservation over 1999 and 2000. It was referred to as the 'Stewart Island Forest Health Survey 1999/2000'. The survey considered both northern (Joyce et al. 1998) and southern (Allan 1999) Rakiura. The plans for both these surveys included measures of vegetation, deer, possums, and birds. These surveys were unbiased and inferences from the data were assumed to represent a wider area.

5.1 Forest vegetation monitoring

Permanent forest plots

Permanent vegetation plots are a robust method that have been used widely in New Zealand to report state and trends in tree populations, forest composition and stature, and ecological processes such as succession. There is no surrogate for ground-based monitoring if the goal is to report on components of ecological integrity such as maintenance of tree populations (Phillips 2023).

We identified 180 permanent forest plots across Rakiura in NVS (Table 1; see also Figure 3 in Section 6.1). As Table 1 shows, some plots have been measured five times – but others only once.

Following a review of Tier Two monitoring plot networks throughout New Zealand (Richardson et al. 2024), and a request from Te Uru Rākau – New Zealand Forest Service to select plot networks where the canopy tree species were highly palatable to deer and possums, a subset of 67 permanent forest plots in coastal forests were selected for remeasurement during April–September 2024 (shown in Table 1). These plots make a key contribution to monitoring forest ecological integrity on Rakiura, but alone, they will not suffice because they only sample coastal forests in north-eastern Rakiura. The 'Stewart Island North' network (see Table 1) samples forests objectively, and measures of deer and possum relative abundance have been made on these plots (Williamson 1976; Slater 1982; Lovelock 1987; Bellingham & Allan 2003). The only permanent plots in southern Rakiura

are in the Port Pegasus area. These plots were installed relatively recently (in 1999) and remeasured in 2008, but not since then. No deer, possum, or bird community measures have been collected from these plots.

We located reports and data sets from surveys of temporary vegetation plots around Rakiura and these are listed in Appendix 1 for reference purposes.

Foliar browse index studies

The foliar browse index (FBI) is a method that was developed in New Zealand to estimate the proportion of individual tree canopies that had been browsed by possums (Payton et al. 1999). The method uses an estimate of canopy openness and apparent browse damage (Payton et al. 1999). The method has been used to interpret trends in tree mortality following possum control operations, and to report on the outcomes of possum control operations (Payton et al. 1997; Nugent et al. 2002; Holland et al. 2013).

We identified three studies that used the FBI method (Table 2). One of these ('Stewart Island FBI on permanent plot transects') uses FBI plots that are associated with permanent vegetation plots, and one ('Stewart Island north coast FBI') with plot locations that broadly overlap with the areas sampled by permanent forest plots (Table 1).

We also found metadata describing a study of individual trees that have been fitted with aluminium bands to prevent possums from climbing trees and accessing canopies for browse. These banded trees were insufficiently replicated, and this work was discontinued.

Tree seedling studies

We found three studies of forest tree seedlings. One was based on tagged seedlings. Tagged individuals provide statistically powerful data for determining rates of growth, mortality, and recruitment. As such, they are the ideal data for determining whether tree recruitment is limited, and for identifying the causes of it (Clark et al. 1999; Bellingham & Richardson 2006; Forsyth et al. 2015). The set of tagged seedlings on the north coast of Rakiura have been remeasured at least eight times (Table 3). These tagged seedlings are on permanent forest plots that can provide valuable context for interpreting seedling vital rates and allowing seedling dynamics to be linked to rates of canopy tree recruitment on plots.

The other two studies used counts of untagged seedlings (Table 3). One has been discontinued; one has not been maintained. These studies focused on seedling densities and seedling community composition in relation to rat abundance and rat eradication (Clayton et al. 2008).

Table 1. Permanent forest vegetation plots on Rakiura. All plots are 400 m² (20 m × 20 m) except those at Ackers Point (Liddicoat 2014) that are 25 m² (5 m × 5 m)

Name	Plot network name in NVS	No. plots	Remeasured 2024	Cumulative no. plots	Years measured	Justification for remeasurement	References
Bench Island/ Te Wāhitauā	Stewart Island East Bench Is	5	Yes	5	1979/80, 1985, 1998/9, 2008	An island analogue for mainland Rakiura that has never had non-native mammals.	Stewart & Burrows 1989; Duncan et al. 2010
Ulva Island	Ulva Island	8	Yes	13	1999, 2008	Predator-free island; inferences will need to account for rat and possum removal and reinvasions, alongside deer.	Clayton et al. 2008; Duncan et al. 2010
Exclosures	Stewart Island Exclosures and WACEM (Wild Animal Control for Emissions Management) Project	12-15 (varies by measurement year	Yes	28	1979/80, 1984, 1999, 2007, 2009-2010 (WACEM)	Experimental exclosures provide a robust comparison with adjacent forest plots; exceptional number of remeasurements.	Stewart & Burrows 1989; Duncan et al. 2010
Chew Tobacco Bay	Stewart Island East (Chew Tobacco Bay)	8 (the original survey was 33 but many have been discontinued)	Yes	36	1979/80, 1985, 1999/2000, 2008	Ambient herbivory, these plots were established concurrently with Bench Island to serve as a direct contrast.	Stewart & Burrows 1989; Duncan et al. 2010
Port Adventure	Stewart Island East (Port Adventure)	9 (the original survey was 31 but many have been discontinued)	Yes	45	1979/80, 1985, 1999/2000, 2008	Ambient herbivory, these plots were established concurrently with Bench Island to serve as a direct contrast.	Stewart & Burrows 1989; Duncan et al. 2010
Northern Coastal	Stewart Island North (STEWN)	24	Yes	69 (67 excluding Tier One plots)	1976, 1980/1, 1985/6, 1999/2000	The longest-running plot network on Rakiura (1976–2023) providing a 47-year perspective on lowland, coastal forests.	Cuddihy 1983; Bellingham & Allan 2003
Northern Widespread	Stewart Island North (STEWRT)	44-57 (varies by measurement year)	No	126	1980/81, 1998/1999, 2008/2009	Widespread, objective (unbiased) survey with plots on transects.	Slater 1983; Bellingham & Allan 2003; Duncan et al. 2010

Name	Plot network name in NVS	No. plots	Remeasured 2024	Cumulative no. plots	Years measured	Justification for remeasurement	References
Port Pegasus/ Pikihatiti	Stewart Island South Port Pegasus	21	No	147	1999/2000, 2008	Valuable network for extending spatial coverage to the SW part of Rakiura.	Duncan et al. 2010
Possum Control Study	Stewart Island Permanent Plots	21	No	168	2002	Includes experimental exclosures that were placed to sample canopy gaps.	None found
Ackers Point	–	12	No	180	2006, 2014	We did not find digitised data in NVS. Focused on outcome monitoring following pest animal control.	Liddicoat 2014

Table 2. Foliar browse index (FBI) studies on Rakiura

Monitoring Programme	Site(s)	Measurements	Notes
Stewart Island FBI on permanent plot transects	Northern Stewart Island, Ulva Island, Bench Island / Te Wāhitauā	1999/2000	Part of the 'Stewart Island forest health survey 1999/2000'. FBI plots were added to each vegetation line in the Stewart Island North permanent plot survey using the method developed by Payton et al. (1997). FBI plots were located at each vegetation plot, and at intervals of at least 100 m along the vegetation lines (up to 10 plots per line). Additional plots were added to permanent vegetation plots on Bench and Ulva Islands. Based on data provided by G. Ledgard (pers. comm. June 2023). FBI plots sampled *Brachyglottis rotundifolia, Griselinia littoralis, Metrosideros umbellata, Podocarpus laetus, Raukaua simplex, Pterophylla racemosa,* and *Carpodetus serratus.*
Stewart Island north coast FBI	North coast Stewart Island	2002, 2005, 2009, 2011	–
Stewart Island Rakeahua FBI	Rakeahua River	2002	–

Table 3. Seedling studies on Rakiura

Monitoring Programme	Site(s)	Measurements	Notes
Stewart Island tagged seedling exclosure plots	North coast Stewart Island	2002, 2003, 2004, 2005, 2006, 2008, 2010, 2012	Tagged seedlings on 24 existing permanent plots, including 10 exclosure plots ('Stewart Island Permanent Plots' and 'Stewart Island Exclosures'). Newly recruited seedlings were added after 2006. On average, 26 tagged seedlings per plot at each measurement. Species sampled were *Pterophylla racemosa, Pectinopitys ferruginea, Podocarpus laetus, Pseudopanax crassifolius, Raukaua simplex, Carpodetus serratus, Coprosma ciliata, Elaeocarpus hookerianus, Griselinia littoralis,* and *Pseudowintera colorata.*
Stewart Island rat seedling plots on islands	Five islands (Bench / Te Wāhitauā, Native, Anchorage, Pearl, Iona)	2005, 2006, 2009 (2009 but only Native and Bench / Te Wāhitauā Islands)	Seedling counts on 1 m × 1 m plots. Designed to compare islands with different rat densities. Planned rat eradication failed on one or possibly two of the islands.
Ulva Island seedling plots	Ulva Island	1991, 1993, 1994, 2003	Seedling and sapling counts in 5 m × 5 m plots. Project finished (Clayton et al. 2008).

5.2 Deer and possum monitoring in forests

Deer have been studied widely on Rakiura, and monitoring has almost exclusively used pellet counts to estimate relative abundance (Table 4). Pellet count surveys commonly record white-tailed deer and red deer, or 'deer' collectively, and possums. Pellet count methods have also sometimes included data on cats (*Felis catus*) – including scats and sightings – and sometimes kiwi (including probe holes and sightings).

Nearly all data sets that we found in unpublished reports were also in DOC's National Ungulate Pellet (NUP) database (Table 4). More recent surveys (1999/2000) were comprehensively described in the 'Stewart Island forest health survey 1999/2000' (electronic files provided by George Ledgard, DOC Te Anau).

In the Stewart Island forest health survey 1999/2000, possum relative abundance was additionally estimated using trap catch indices, in the same locations as pellet counts and vegetation plots (Table 4).

The Department has a spreadsheet register of Residual Trap Catch (RTC) data from at least 2007 until 2020 (unpublished data provided by George Ledgard and 9(2)(g)(ii) , May 2024). These data are used for compliance monitoring of contractors used to kill possums but the underlying data – trap catch indices – are the same as those used in the Stewart Island forest health survey 1999/2000. The RTC data will provide useful background data for interpreting any changes in possum relative abundance, but the RTC data are not coupled with measures of vegetation, deer, or birds.

We found no data on deer or possums derived from other methods such as camera trapping, fur samples, hoof prints, or visual estimates.

Table 4. Deer and possum monitoring data sets in forest ecosystems on Rakiura

Region sampled	Method	Species monitored	Relationship to non-permanent vegetation plots (if any)	Relationship to permanent vegetation plots (if any)	Reference(s)	Report numbers in NUP database
Northern Rakiura	Pellet frequency and counts	Red deer; white-tailed deer; possums; sheep; cats (also by sightings)	RECCE[3] plot data from the same survey are held in NVS. Some of the plots were later revisited and used as the basis for installing permanent plots.	Stewart Island North (STEWRT).	Williamson 1976	STH 22
Northern Rakiura	Pellet frequency and counts	Red deer; white-tailed deer; possums; sheep; cats (also by sightings); kiwi (by probe holes)	None.	Pellet counts repeat those in Williamson (1976) and are associated with permanent vegetation plots in the Stewart Island North (STEWRT) survey.	Slater 1982	STH 20
Northern Rakiura	Pellet frequency and counts	Red deer; white-tailed deer; possums; sheep	None.	Pellet counts repeat and add additional lines to those in Williamson (1976) and Slater (1982) and some are associated with permanent vegetation plots in the Stewart Island North (STEWRT) survey.	Lovelock 1987	STH 25
Northern Rakiura (Stewart Island forest health survey 1999/2000)	Pellet frequency and counts	Deer (collectively); possums; cats; kiwi	None.	Pellet counts repeat some of those in Williamson (1976) and Slater (1982). Data are associated with permanent vegetation plots in the Stewart Island North (STEWRT) survey.	Bellingham & Allan 2003	DOC-STH004, DOC-STH005

[3] RECCE is a method for collecting data on vegetation composition and foliar cover (Department of Conservation 2019)

Region sampled	Method	Species monitored	Relationship to non-permanent vegetation plots (if any)	Relationship to permanent vegetation plots (if any)	Reference(s)	Report numbers in NUP database
Northern Rakiura (Stewart Island forest health survey 1999/2000)	Trap Catch index	Possums	None.	Three trap catch lines on a set compass bearing from the vegetation line at >200m intervals (e.g. at permanent vegetation plots) in Stewart island North (STEWRT). Each trap catch line used 20 Victor No.1 traps at 20 m spacings for three fine nights. Recorded weights, sex, and presence of joey.	Data provided by G. Ledgard (pers. comm. June 2023)	
Southern Rakiura	Pellet frequency and counts		RECCE plot data from the same survey are held in NVS. Ross (1977) surveyed vegetation and deer and possums across southern Rakiura. Vegetation data are in NVS (survey name is STEWART ISLAND SOUTH FOREST 1976). *N* = 254 RECCE plots and 2,218 pellet plots. Same sample design as Williamson (1976). We could not locate these pellet data in DOC's NUP database.	None.	Ross 1977	–
Southern Rakiura	Pellet frequency and counts	Possums (by pellets); sheep (by pellets); cats (by sightings and scats); kiwi (by probe holes)	RECCE plot data from the same survey are held in NVS.	None.	Cuddihy 1982	STH 07
South-eastern Rakiura (south of Paterson Inlet to the Kopeka River)	Pellet frequency and counts	Deer and possum pellet counts and frequencies from *n* = 35 transects	NVS had a southern Rakiura pellet survey from 1979 – this may correspond with Cuddihy (1982) but the absence of metadata made it difficult to reconcile the two data sets with confidence.	None.	None found	

5.3 Forest bird monitoring

Bird communities on Rakiura have been sampled using the five-minute bird count (5MBC) method. The Department's database of 5MBC data contained data collected on Rakiura during the period 1979–1985 (Table 5). Of the data sets that were in the DOC database, one – collected by the New Zealand Forest Service– was missing count data, four data sets were collected by s.9(2)(a) for a research project and these are coincident with vegetation plot locations (Bench Island / Te Wāhitauā, Lauras Leg, Port Adventure, Chew Tobacco Bay), and the remaining data sets were collected as part of a training exercise from forests in north-eastern Rakiura (Table 5).

We also found a published study reporting 5MBC data that were collected by DOC staff along 1000 m transects in podocarp-broadleaf forest in 1998–2000 (Harper 2009). These data were collected alongside vegetation, deer, and possum data as part of the Stewart Island forest health Survey 1999/2000, including on Bench Island / Te Wāhitauā (Harper 2009). These data were not in the DOC database of 5MBC data. The lack of ready access to these data is a significant gap in the ability to understand trends in ecological integrity of the forests of Rakiura so it is imperative that these primary data, including locations of sample points, are obtained, and included in the Department's database of 5MBC data.

DOC staff on Rakiura informed us of bird count data collected on Ulva Island using a distance sampling method, and 5MBC data collected around Halfmoon Bay /Oban by a community group. No further details were available, and these data are not in the DOC database of 5MBC data.

Table 5. Bird monitoring data sets in forests on Rakiura

Group	Survey name	Measurements	Survey number in DOC's 5MBC database
New Zealand Forest Survey widespread monitoring (Hartley 2012)	Stewart Island NZFS	1977-1979	Count data missing
s.9(2)(a) research projects	Bench Island	Dec 1979, Sep 1980, March & June 1981	198
	Port Adventure (pre- and post- a pest control operation)	Nov 1979, Jan 1980, Sep 1980, Nov 1980, Feb 1981 (all pre-) and Nov 1981, Sep 1981, Feb 1982 (all post-)	274
	Chew Tobacco	Nov 1979, Jan 1980, Sep 1980, Nov 1980, Feb 1981, Mar 1981, Jun 1981, Sep 1981, Nov 1981, Feb 1982	225
	Lauras Leg	Dec 1979	195
Training exercises	Vala Voe	1983, 1984, 1985	654
	Bungaree	1983, 1984, 1985	656
	Māori Beach	1983, 1984, 1985	650
	Little River	1983, 1984, 1985	649
	Horseshoe	1983, 1984, 1985	653
	Christmas Village	1983, 1984, 1985	655
	Hicks Road	1983, 1984, 1985	652
	North Arm	1983, 1984, 1985	614
	Fern Gully	1983, 1984, 1985	646
	North Arm(b)	1983, 1984, 1985	645
	Garden Mound	1983, 1984, 1985	651
Department of Conservation (Harper 2009)	Locations unknown	1998–1999	–
	Locations unknown	1999–2000	–
	Bench Island	Apr 1999	–
Grant Harper research project (Harper 2009)	Whenua Hou	Aug 2001	–
Department of Conservation	Ulva Island	'last 5 or 6 years' (9(2)(g)(ii) pers. comm. 2024)	–
Community group	Around Oban	5MBC data	–

6 Discussion

The Department can achieve the strongest scientific inference of state and trend in ecological integrity by measuring multiple components of ecosystems concurrently, at the same sites. This has been the guiding philosophy of Tier One monitoring of biodiversity at a national scale (Bellingham et al. 2020), and we recommend adopting that philosophy with Tier Two while acknowledging and balancing the need to build on the past and use historical data.

The ability to draw inferences will be greatest when multiple measures of ecological integrity are collected from the same locations, with similar sampling designs, ideally in the same years (Pereira et al. 2013; Bellingham et al. 2020). Measures of vegetation structure and composition, bird communities, and pest animal abundances collected simultaneously, from the same locations will enable DOC to interpret not only changes in each measure, but co-ordinated changes across all measures. The measures interact directly, and elements of ecosystems are linked through processes such as herbivory, pollination, nutrient cycling, weather, and disturbance events (Figure 2); interpretation of measures in isolation of one another will lead to limited insights.

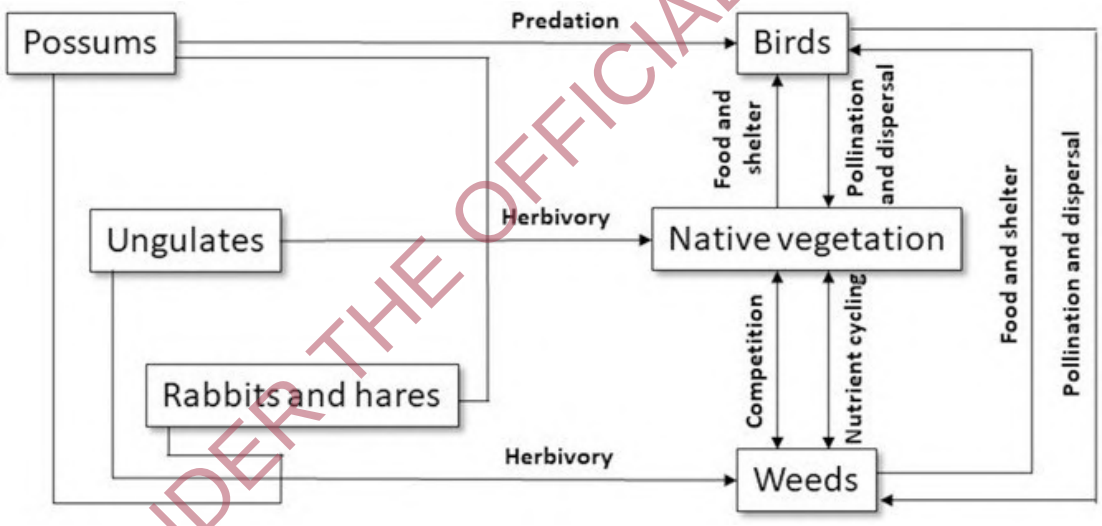

Figure 2. Interrelationships among measures of ecological integrity such as native vegetation, bird communities, weeds, and pest mammal species (possums, ungulates, and rabbits and hares) (Source: Bellingham et al. 2020, Fig. 1. © the authors, reproduced with their permission)

We strongly recommend that the next report on forest ecological integrity builds on past investment (Allen et al. 2003) and on the powerful design of combining the information that both Tier One and Tier Two sampling points can provide for assessing the ecological integrity of forests on Rakiura – and how pressures on them from deer and possums can be assessed. For example, DOC can compare and contrast the same measures of ecological integrity from systematically placed Tier One samples with those from subjectively placed Tier Two samples. This can help to determine whether issues found locally, in Tier Two data, are also found at larger scales. For example, intense browsing by deer of understorey tree species may be concentrated in coastal forests sampled by Tier

Two plot networks, but be less intense across the Tier One network sampling all forest types. These contrasts can be used to target management interventions – for example, to particular ecosystems or particular parts of the landscape – and to identify future research questions.

Most Tier Two monitoring on Rakiura has focused on the podocarp–hardwood areas and on coastal rather than upland forests, and there has been some monitoring in successional forests. We lack data about historical trends and current state within most mānuka shrublands and the short podocarp-dominated forests of the Tin Range and its flanks. The Department could consider increased focus across short forests and successional communities as well as the tall forests in assessing state and trends in ecological integrity, and threats to all the island's forests.

6.1 Vegetation

We recommend maintaining a set of permanent forest plots on which bird communities, and pest mammal relative abundances are also measured.

In addition to the 67 forest plots (including exclosure plots) that are being measured throughout 2024, we recommend remeasuring the Stewart Island North plots (n = 57 plots) and remeasuring the Stewart Island South Port Pegasus plots (n = 21 plots) in the next year so that data from those plots can be analysed alongside data from the 67 forest plots being remeasured in 2024. These additions will ensure representative sampling of woody communities across Rakiura, including those that are more common in southern Rakiura (Duncan et al. 2010). Plot locations are shown in Figure 3 and survey names from the NVS are listed here:

- Stewart Island East Bench Is (in progress, May 2024)
- Ulva Island (completed May 2024)
- Stewart Island Exclosures (including remeasures in the WACEM PROJECT) (in progress, May 2024)
- Stewart Island East (Chew Tobacco Bay) (in progress, May 2024)
- Stewart Island East (Port Adventure) (in progress, May 2024)
- Stewart Island North (STEWN) (in progress, May 2024)
- Stewart Island North (STEWRT)
- Stewart Island South Port Pegasus.

We recommend measuring vegetation every 10 years, and animals (deer, possums, birds) every 5 years (MacLeod et al. 2024). This approach will allow frequent reporting on animal populations, which can change quickly, while providing a longer time for vegetation change. We recommend using standard protocols (Department of Conservation 2019; Hurst et al. 2022) to ensure that data are comparable with past measurements and with Tier One data (Bellingham et al. 2020).

We recommend maintaining a network of fenced exclosures, including those in the 67 forest plots being remeasured during 2024 (Richardson et al. 2024). However, at least two of those historical exclosure plots ('Stewart Island Exclosures' and 'WACEM plots' in Table

1) have been damaged (s.9(2)(a) pers. comm. May 2024). This elevates the value of the exclosure plots that were installed in 2002 ('Stewart Island Permanent Plots' in Table 1) but never remeasured, and underscores the need for annual maintenance checks of all fenced exclosure plots.

Figure 3. Map of Rakiura showing the locations of permanent forest plots that collectively would form the basis of island-wide monitoring of forest ecological integrity. There are no plots on Codfish Island / Whenua Hou.

The near absence of monitoring data from Codfish Island / Whenua Hou is surprising. The Department planned to install new vegetation monitoring plots on Whenua Hou during the Stewart Island Forest Health Survey 1998–2000 but the plan was not implemented. The only monitoring data from Codfish Island / Whenua Hou that could be used to assess its forests' ecological integrity is a small sample of 5MBC bird community data conducted in 2001, with no remeasurement (Harper 2009) (Table 5). Given the investment of conservation resources on the island, and given the significance of the island to mana whenua (i.e. the iwi/hapū associated with possession and occupation of this specific area

who claim authority over it derived from this), we strongly recommend – in partnership with Rakiura mana whenua – installing new forest plots on Codfish Island/ Whenua Hou. It is the ideal ecological analogue to provide a benchmark of forest ecosystem dynamics in the absence of all non-native mammal species.

Foliar browse index measurements could help to inform understanding of spatial or temporal trends in tree mortality rates across the plot network, but ideally, the browse measures would be made on the same tagged trees from which other data are collected on the permanent plots. As far as we could tell from the data we received, this was only the case for the FBI plots that were added to permanent vegetation plots as part of the Stewart Island forest health survey 1999/2000. Remeasurement of these FBI plots will provide the ability to link foliar browse to tree mortality on an individual-tree basis and to address whether individual tree mortality has population-level consequences (i.e. whether mortality is offset by recruitment of young trees of the same species). This makes it possible to draw inferences about forest ecological integrity. We do not recommend remeasurement of FBI plots that are not part of any permanent vegetation plots (Table 1).

We encourage maintenance of tagged seedling data from permanent forest plots as a research opportunity to complement monitoring activities.

6.2 Deer and possum relative abundance

The plot remeasurements being done during 2024 are collecting pellet count data that are being coupled to vegetation plots using the Tier One method. The Tier One method counts intact pellets and pellet groups.

We recommend repeating the historical pellet counts on the Stewart Island North Survey (Williamson 1976; Slater 1982; Lovelock 1987; Bellingham & Allan 2003) to provide a >48-year record of deer and possum relative abundance across northern Rakiura. A challenge will be deciding whether to retain the historical method, or shift to the Tier One method. The location and length of transects, and the number and size of subplots will vary between historical data sets and the current Tier One method. If we assume that historical and future pellet counts sample the area around vegetation plots with statistical objectivity, we cautiously suggest that any index of deer relative abundance will be robust to differences in transect length, subplot number and subplot size. If time allows, it would be instructive to use both methods, i.e. the method used historically on Rakiura (Williamson 1976; Slater 1982; Lovelock 1987; Bellingham & Allan 2003) and the Tier One method, to determine whether the two methods yield comparable estimates of deer relative abundance.

The historical method scored the presence/absence of intact pellets in subplots (c.f. the Tier One method that uses counts of intact pellets and pellet groups). Both methods can be used to derive a common type of data – presence or absence of at least one intact pellet in subplots along a transect. That data can be used to report on pellet frequency (i.e. the proportion of subplots per line or per plot that contained at least one intact pellet) (Forsyth et al. 2007; Forsyth et al. 2011; MacLeod et al. 2024) as a measure of deer relative abundance. Because historical data provide a valuable opportunity to report on deer relative abundance over several decades, we recommend reporting on pellet frequency.

A third challenge will be linking historical methods used to estimate possum relative abundance (i.e. pellet counts), with trap catch index methods used in the Stewart Island forest Health Survey 1999/2000, and then to current methods based on chew cards used by Tier One. We recommend recording the presence of at least one intact possum pellet in the pellet count subplots used for deer, and then adding chew cards to all vegetation plots (10 cards, 20 m apart along a 200 m transect, following the Tier One method as outlined by the Department of Conservation 2019). Possum pellet data will provide continuity with historical data sets; the chew card data will provide comparability with Tier One.

Lastly, the conservation management strategy for Rakiura urges adoption of new methods for monitoring animals (Department of Conservation 2012). Pellet counts are a proxy for animal abundance, and direct estimates of deer and possum abundance (i.e. densities per unit area) would be preferable so that management prescriptions can determine intervention densities (Husheer & Tanentzap 2024). New methods (e.g. camera traps with distance sampling, or thermal surveying) may yield estimates that are closer to true animal densities. While incorporating these methods into existing monitoring schemes may bring efficiencies in the future, they are not appropriate for adoption at present.

6.3 Bird communities

Indigenous bird species are a key focus of conservation management interventions in New Zealand. We recommend collecting 5MBC data from all permanent plot locations in Figure 3. Collecting bird data in the same year as vegetation, deer, and possum data will maximise the potential for reporting on integrated measures of ecological integrity (Bellingham et al. 2020). We recommend using the Tier One protocol (Department of Conservation 2020) or a subset of the methods in that protocol. For example, the Tier One method prescribes five counts, each repeated twice, on each plot with distance sampling. If this is not achievable, collect at least one count, repeated twice, from the centre of each plot.

Acoustic recorders are increasingly being used to measure bird communities in forests (Leach et al. 2016; Department of Conservation 2019). Key advantages are: that they provide data on nocturnal birds as well as diurnal birds (Markova-Nenova et al. 2023); and data are reproducible because a recording can be played many times, interpreted by more than one analyst, and stored for reanalysis in the future (Leach et al. 2016). Key disadvantages are: that they only capture birds that are vocal, not those that might have been seen by a field observer (Castro et al. 2019); it is difficult to derive estimates of abundance, relative to counts in the field (Leach et al. 2016); and they require repeat visits (deployment and collection) and post-processing, both of which increase the time required to acquire data (Markova-Nenova et al. 2023). However, post-processing costs may decline over time with advances in automated methods for detecting bird calls. Acoustic monitoring is often viewed as complementary to field counts because using both methods maximises the species richness of birds detected, and covers both nocturnal and diurnal species (Bombaci & Pejchar 2019). Tier One monitoring uses this approach (Department of Conservation 2019). Acoustic monitoring would make a valuable contribution to Tier Two monitoring on Rakiura.

6.4 Data storage and management

All monitoring data need to be easily discoverable and readily linked to one another. Our experience was that vegetation data from permanent plots in NVS were easy to find, deer pellet data were readily located within DOC, but possum data were not held centrally and relied on us being provided with individual data sets. Some 5MBC data were found within DOC, but other key data sets were missing (Harper 2009). New data are being collected by community groups and research organisations and we recommend that the Department builds effective partnerships with those groups and organisations to support data management in a collective repository. Lastly, we recommend that the Department stores ancillary data in NVS and uses DOC's data management system to create explicit links between data sets collected from the same locations.

7 Recommendations

We make the following recommendations to DOC based on our review.

- Remeasuring Tier Two permanent vegetation plots in northern and southern Rakiura to achieve island-wide coverage.
- Adopting the Tier One philosophy of measuring multiple elements of ecosystems at the same places using comparable methods. This will allow the Department to knit together a picture of vegetation change that can clearly be linked to deer and possum change, and its flow-on effects for bird habitat. If the Department (DOC) chooses to measure foliar browse indices, add these to permanent vegetation plots where the population consequences can be measured and where local possum numbers are also assessed.
- Installing new permanent vegetation plots on Codfish Island / Whenua Hou to provide a benchmark for Rakiura. Only Codfish Island / Whenua Hou can provide the benchmark of forest ecosystem dynamics in the absence of all non-native mammal species.
- Locating, entering and mobilising the outstanding data needed to build historical context and trends (i.e. DOC's 5MBC data from 1998–2000).
- Considering investment in more samples in successional communities to understand canopy-replacing processes with respect to deer abundance and deer management.

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Appendix 1 – Other vegetation data

We found four vegetation surveys that used non-permanent plot-based sampling.

Williamson (1976) completed 690 relevé plots (similar to the RECCE method used by Tier One) across the northern part of Rakiura. Plots were located along transects and the transect origins were permanently marked. Plot size was not reported so we assumed these plots were unbounded, and plots were not permanently marked. The presence/absence of an intact faecal pellet was noted in 6,300 circular 4 m^2 plots along the same lines as vegetation plots. Data were used to classify forest vegetation communities across northern Rakiura and relate forest composition to animal densities. Vegetation data are in the NVS (survey name 'STEWART ISLAND NORTH FOREST 1975-1976'). The same sample design was later used to assess southern Rakiura (Ross 1977).

Ross (1977) surveyed vegetation and deer and possums across southern Rakiura. Vegetation data are in NVS (survey name 'STEWART ISLAND SOUTH FOREST 1976'). There were n = 254 RECCE plots and 2,218 pellet plots. Ross used the same sample design as Williamson (1976).

Woolmore (1982) surveyed canopy tree size class structures (≥ 2 m tall, ≥ 1 cm dbh) by species (rimu, miro, tōtara, southern rātā, kāmahi) in logged forests in north-eastern Rakiura. There were 1,763 plots, each 0.01 ha, none were permanently marked, and data were not found in NVS (they may be archived there but not digitised).

Wilson (1987) measured vegetation composition in 436 unmarked plots across Rakiura. The goal was to summarise vegetation communities across Rakiura and to produce a species list for the island.