

# Rangitāhua soil chemistry: A technical report on the chemical properties of Rangitāhua soils

Kendall Morman<sup>1,2</sup>, Jacqueline Beggs<sup>1</sup>, Peter Bellingham<sup>3</sup>, Gavin Lear<sup>1</sup>

1 University of Auckland, Auckland, New Zealand

2 Te Ara Whānui Research Centre, Te Pahi, New Zealand

3 Bioeconomy Science Institute, Manaaki Whenua - Landcare Research, Christchurch, New Zealand

Corresponding author: Kendall Morman ([kendall.morman@auckland.ac.nz](mailto:kendall.morman@auckland.ac.nz))

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## Abstract

This report characterises the soil chemistry beneath kahika trees (*Metrosideros kermadecensis*) on two remote, subtropical oceanic islands in the South Pacific, Rangitāhua, which currently has a lower abundance of seabirds but supported dense populations until the 20<sup>th</sup> century, and North Meyer Island, which supports a dense seabird population. Soil was collected from five locations on both islands in November 2023. Soil Chemistry testing was conducted by Maanaki Whenua Environmental Laboratory, and, for Rangitāhua samples, further testing was carried out by Hills Laboratory.

### Key results:

- Soil pH was  $6.16 \pm 0.22$  (mean  $\pm$  SE) on Rangitāhua and  $4.12 \pm 0.25$  on North Meyer Island.
- Soil organic carbon was  $10.36\% \pm 1.09$  on Rangitāhua and  $11.39\% \pm 3.51$  on North Meyer Island.
- Total soil nitrogen was  $0.58\% \pm 0.039$  on Rangitāhua and  $0.77\% \pm 0.226$  on North Meyer Island.
- Soil C:N ratios were  $17.74 \pm 0.93$  on Rangitāhua and  $14.16 \pm 0.72$  on North Meyer Island.
- Total phosphorus was  $856.8 \text{ mg/kg} \pm 81.53$  on Rangitāhua and  $3462.8 \text{ mg/kg} \pm 908.74$  on North Meyer Is.

Soil nutrient concentrations offer critical insights into soil fertility, forest health and the functioning of soil microbial communities. The differences observed between the two islands may reflect variations in seabird abundance and disturbance history (including invasive mammals) and can inform future ecosystem management and conservation strategies. These results suggest that seabird presence is linked with lower pH and elevated phosphorus on North Meyer. Meanwhile, carbon and nitrogen values remain within a comparable range across both islands.

## Keywords

Island Ecosystems, Rangitāhua, Seabirds, Soil Chemistry, Subtropical Islands

## Background

Soil chemistry is influenced by natural processes such as weathering of bedrock, atmospheric deposition, and biological inputs. On islands with seabird populations, nutrient enrichment from guano significantly alters soil properties – typically, increasing levels of nitrogen and phosphorus concentrations while reducing soil pH (Mulder

and Keall 2001). These changes in soil chemistry can affect the entire terrestrial ecosystem, including microbial communities that drive nutrient cycling (Colwell 1997; Astudillo-García et al. 2019). Understanding these chemical dynamics is essential for assessing ecosystem health, nutrient cycling, and potential impacts on native vegetation.

Commonly reported soil indicators include pH, carbon, nitrogen, and phosphorus.

- **Soil pH** indicates the level of acidity and alkalinity of soil, which alters the availability of soil nutrients to plants (Sparling et al. 2008). Most plants and soil organisms have an optimum pH range where they grow best. In mainland New Zealand's native forests, most soils are acidic, with a pH ranging from 5–7 (Ballinger and Macdonald 2020).
- **Soil carbon** includes both inorganic and organic matter (Sparling et al. 2008; Hamilton and Anderson 2022). Soil carbon enhances soil structure, promotes aggregation to protect against physical degradation, supplies nutrients through mineralisation, supports microbial activity, improves water storage, and aids nutrient cycling; all of which contribute to better plant growth (Shepherd et al. 2001; Sparling et al. 2008; Hamilton and Anderson 2022).
- **Nitrogen** is essential for plant growth and a key limiting nutrient in most ecosystems (Sparling et al. 2008; United State Department of Agriculture 2014). It is mostly found in organic forms and needs to be mineralised into inorganic forms (ammonium and nitrate) before it can be used by plants (Cabello et al. 2009).
- **The carbon to nitrogen ratio (C:N)** typically gives an indication of the decomposition of organic matter (McLaren and Cameron 1990). A lower ratio indicates more readily available nitrogen in the soil, while a higher ratio indicates a larger source of slow-decomposing organic matter (Cabello et al. 2009). In New Zealand's native forests, ratios of 15–17 are considered adequate for supporting plant growth (Sparling et al. 2008).
- **Phosphorus** is another essential nutrient that is found in many different forms in the soil, with phosphate the form that is biologically available to most plants (Sparling et al. 2008). Total phosphorus includes all forms, both available and unavailable. Native forest soils in New Zealand tend to have low P concentrations, with most native plant species well adapted to these nutrient-poor conditions (Sparling et al. 2008). In contrast, plants typically used in horticulture and pasture require higher soil phosphorus concentrations, and these requirements are often met through the addition of phosphorus in fertilisers.

This report examines how soil nutrient concentrations are related to seabird abundance and historical disturbance on two neighbouring islands, Rangitāhua and North Meyer Island, to better understand their role in ecosystem processes and to inform future conservation management.

## Methods

### Study location

This study compares soils from Rangitāhua (29°15'S, 177°55'W) and nearby North Meyer Island. They are

located approximately 1,000 km north of Aotearoa, New Zealand and a similar distance south of Tonga. Rangitāhua is a remote, volcanically active island of immense cultural significance to many Māori as a traditional stopping point in ancestral Polynesian migrations (Brown 2024). It lies within the rohe of Ngāti Kuri.

The soils of Rangitāhua are composed from a mixture of basalt, andesitic ash, and pumice. They are generally young and relatively fertile, shaped by recent volcanic activity and ongoing erosion (Wright and Metson 1959). The terrain of the island is steep, with the highest peak, Moumoukai, reaching 516 m above sea level, and is dominated by mature Kahika (*Metrosideros kermadecensis*) forest (Townes 2023). However, its ecosystem has been historically impacted by mammalian pests such as goats, rats, and cats, and transformer weed species, introduced by European settlers in the 1900's (Cieraad 2006; Gentry 2013). Since the eradication of mammalian pests, completed by 2003, and conservation efforts to remove transformer weeds, Rangitāhua's ecosystem has recovered substantially (Cieraad 2006). However, seabird breeding populations have yet to return to their pre-disturbance levels (Gaskin 2011).

In contrast, North Meyer Island (130 m asl.), is a remnant of older volcanic activity in the region and has remained pest-free, serving as a refuge for seabirds and other terrestrial birds (Lloyd and Nathan 1981; Veitch et al. 2004). The soils are developed on weathered andesitic tuff that has been strongly modified by nesting seabird species. (Oliver 1910). North Meyer is predominantly a seabird colony (Townes 2023), supporting 13 seabird species, including surface-nesting and burrowing types (Gaskin 2011). The topography is steep, and the dominant tree is Ngaio *Myoporum rapense*, with a number of kahika trees at higher elevations.

### Soil collection

Sampling was carried out beneath kahika (*Metrosideros kermadecensis*) which is the dominant canopy tree species on Rangitāhua. To ensure consistency in overlying vegetation structure across sites on both islands, all soil samples were collected from beneath kahika trees (see Figure 1).

Soils were collected beneath kahika trees within five permanent plots in forests (30 × 30 m) on Rangitāhua and from beneath 10 kahika trees at a single location on North Meyer Island (Figure 2). The Rangitāhua plots were established in 1993 to track the impact of rat eradication on vegetation on the island, and the canopy is dominated by kahika (Cieraad 2006). All five plots have been dominated since their establishment by a mature kahika canopy (Cieraad 2006).

Soil samples were collected between 10–19 November 2023 using a 25 mm diameter soil auger to a depth of 10 cm. At each Rangitāhua plot, soil from 15 trees was combined into a single pooled sample for analysis. On North Meyer, samples were pooled from beneath 10 trees (see Suppl. material 1: table S2), and five of these were analysed individually (see Suppl. material 1: table S1).



**Figure 1.** Flowering Kahika forest on Rangitāhua. K Morman 2023. All rights reserved.

## Seabird abundance

On North Meyer, nesting Kermadec petrels (*Pterodroma neglecta*) and masked boobies (*Sula dactylatra*) were observed near the sampled kahika trees. Burrowing wedge-tail shearwaters (*Ardenna pacifica*) were also present. Seabird burrows and nesting birds were ubiquitous and difficult to avoid while sampling. In contrast, no seabird burrows or signs of recent nesting were observed at any of the Rangitāhua sites, and burrow density was not quantified. However, seabird burrows have been reported elsewhere on Rangitāhua, though at a lower density (Gaskin 2011).

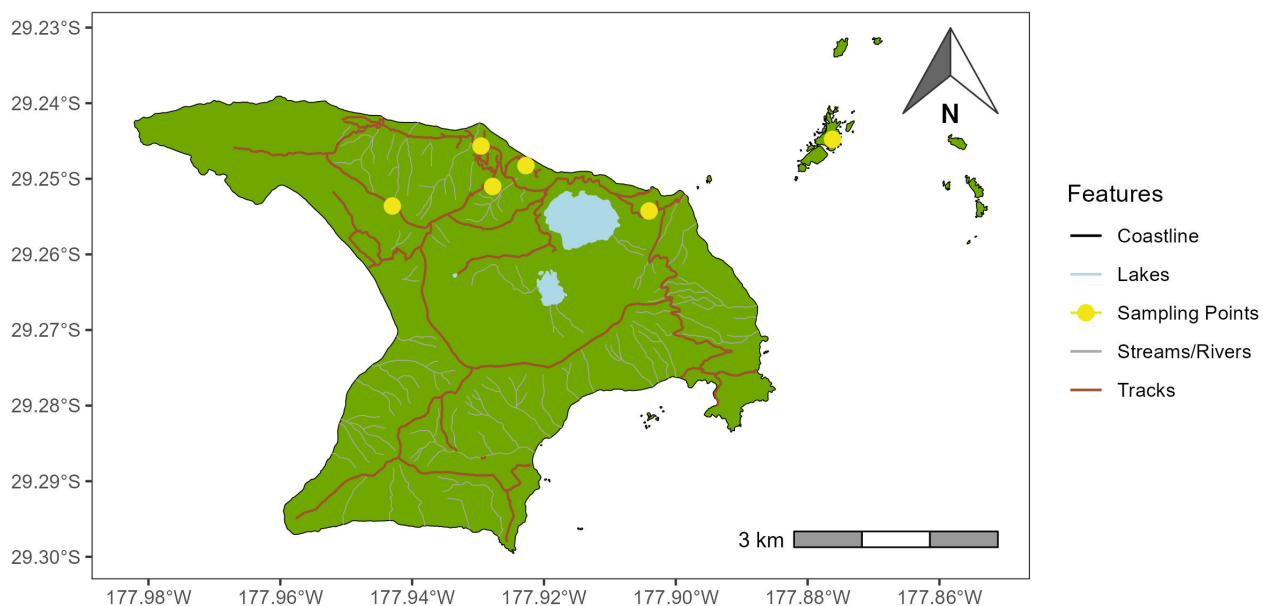
## Soil chemistry

The soil nutrient concentrations of the Rangitāhua samples and the North Meyer samples were analysed by the Manaaki Whenua Environmental Chemistry Laboratory in Palmerston North. Rangitāhua soils were analysed as composite samples only. For North Meyer, ten samples were collected in total. Five were analysed individually, and an additional composite sample was prepared by combining equal amounts of soil from all ten samples and analysed separately (Table 1.). All analyses were performed on air-dried soils.

Each soil sample was air-dried at 35 °C and then ground and sieved to <2 mm (Metson 1971). Soil pH was measured in a 1:2.5 soil-to-water suspension after an

overnight equilibration using a pH electrode (Blakemore et al. 1987). Organic carbon and total nitrogen were measured using a CN98 analyser, which uses the Dumas principle of dry combustion (Leco Corporation 2003). Samples were combusted in pure oxygen at 1050 °C. An aliquot was subsampled and passed through a heated copper catalyst, which measures forms of nitrogen (N<sub>2</sub>) and organic carbon (CO<sub>2</sub>), and was measured using an infrared detector cell. C:N was calculated based on the ratio of nitrogen to organic carbon. Total phosphorus was determined by igniting the soil at 550 °C for 60 minutes, extracting the residue with 0.5 M sulphuric acid for 16 hours, and analysing the extract using a flow injection analyser (Blakemore et al. 1987).

Additional soil testing was conducted on the composite samples at RJ Hill Laboratories (Hamilton) using their General Soil and Organic Soil profiles. These samples were also air-dried at 35–40°C overnight (Hill Laboratories 2025b). Soil pH was determined using a 1:2 (v/v) soil to water slurry, followed by potentiometric measurement (Hill Laboratories 2025b). Soil total carbon and total nitrogen were determined using the Dumas dry combustion analyser (Hill Laboratories 2025a). C:N was calculated based on the ratio of total carbon to total nitrogen (Hill Laboratories 2025c). Olsen phosphorus was measured using a 0.5 M sodium bicarbonate (pH 8.5) extraction, followed by molybdenum blue colorimetry (Hill Laboratories 2025b). Total phosphorus was determined by heating soil at 550 °C for 60 minutes, extracting with 0.5 M sulphuric acid for 16 hours and analysing with a flow injection analyser (Blakemore et al. 1987).



**Figure 2.** Map of Rangitāhua and Meyer Islands. Yellow circles indicate where soil was collected in November 2023 from five locations on Rangitāhua and one on neighbouring North Meyer Island. Created using R version 4.4.1 using data from OpenStreetMap.

**Table 1.** Location, date and collection details of soil samples collected from Rangitāhua and North Meyer Island. CC BY 4.0.

	Island	Sample location	Sample type	Altitude (m)	GPS locations
10/03/2023	Rangitāhua	Terraces	Composite	60	Corner A: 29.24567°S, 177.92955°W Corner B: 29.24588°S, 177.92964°W Corner C: 29.24587°S, 177.92989°W Corner D: 29.24559°S, 177.92981°W
11/03/2023	Rangitāhua	Rayner Point	Composite	140	Corner A: 29.25426°S, 177.90405°W Corner B: 29.25400°S, 177.90395°W Corner C: 29.25403°S, 177.90369°W Corner D: 29.25435°S, 177.90381°W
12/03/2023	Rangitāhua	Denham Bay track	Composite	189	Corner A: 29.25102°S, 177.92778°W Corner B: 29.25127°S, 177.92786°W Corner C: 29.25120°S, 177.92812°W Corner D: 29.25095°S, 177.92807°W
13/03/2023	Rangitāhua	Low Flat	Composite	5	Corner A: 29.24826°S, 177.92274°W Corner B: 29.24849°S, 177.92287°W Corner C: 29.24841°S, 177.92320°W Corner D: 29.24817°S, 177.92308°W
14/03/2023	Rangitāhua	Pukekohu	Composite	450	Corner A: 29.25360°S, 177.94301°W Corner B: 29.25341°S, 177.94299°W Corner C: 29.25346°S, 177.94269°W Corner D: 29.25360°S, 177.94301°W
19/03/2023	North Meyer	Mey	Composite	72–130	Tree 1: 29.24493°S, 177.87753°W Tree 2: 29.24493°S, 177.87701°W Tree 3: 29.24467°S, 177.87622°W Tree 4: 29.24479°S, 177.87628°W Tree 5: 29.24479°S, 177.87621°W Tree 6: 29.24468°S, 177.87613°W Tree 7: 29.24466°S, 177.87604°W Tree 8: 29.24467°S, 177.87611°W Tree 9: 29.24463°S, 177.87614°W Tree 10: 29.24471°S, 177.87619°W
19/03/2023	North Meyer	Mey 1	Individual	72	Tree 1: 29.24493°S, 177.87753°W
19/03/2023	North Meyer	Mey 2	Individual	95	Tree 2: 29.24493°S, 177.87701°W
19/03/2023	North Meyer	Mey 4	Individual	130	Tree 4: 29.24479°S, 177.87628°W
19/03/2023	North Meyer	Mey 5	Individual	128	Tree 5: 29.24479°S, 177.87621°W
19/03/2023	North Meyer	Mey 6	Individual	128	Tree 6: 29.24468°S, 177.87613°W

Concentrations of the cations calcium (Ca), potassium (K), magnesium (Mg), and sodium (Na) were measured in 1 M neutral ammonium acetate extracts using inductively coupled plasma optical emission spectrometry (ICP-OES) (Hill Laboratories 2025b). Cation Exchange Capacity (CEC) was calculated as the sum of these four cations and reported in me/100 g (Blakemore et al. 1987; Hill Laboratories 2025b).

## Statistical tests

Mean values and standard errors were calculated from the soils tested by Manaaki Whenua. Welch's t-tests were then used to assess whether pH, total carbon, total nitrogen, C:N ratio, and total phosphorus differed significantly between Rangitāhua and North Meyer. All statistical analyses were conducted in R version 4.4.1 (R Core Team 2024). Data and R script related to the statistical analyses can be found in Suppl. materials 2–4.

## Results

This report focuses on interpreting five key soil chemistry results: pH, total carbon, total nitrogen, C:N ratio, and total phosphorus. Full data are provided in Suppl. material 1: tables S1, S2.

### Soil pH

All soils on Rangitāhua were mildly acidic, with a mean pH of  $6.16 \pm 0.22$  (SE). In contrast, soils on North Meyer had a lower mean pH of  $4.12 \pm 0.25$  (Figure 3). A Welch's t-test showed that pH was significantly lower on North Meyer than on Rangitāhua (Table 2).

### Organic carbon

Rangitāhua sites had a mean organic soil carbon level  $10.36\% \pm 1.09$  and North Meyer soils a mean of  $11.39 \pm 3.51$  (Figure 4). A Welch's t-test indicated that soil carbon levels were not significantly different at both locations (Table 2). CC BY 4.0.

**Table 2.** Mean ( $\pm$  SE) and Welch's t-test results for soil chemistry properties across Rangitāhua and North Meyer Islands  $n = 5$ . Values are means  $\pm$  SE. CI = 95% confidence interval (North Meyer – Rangitāhua). Negative CI values reflect higher means in Rangitāhua. CC BY 4.0.

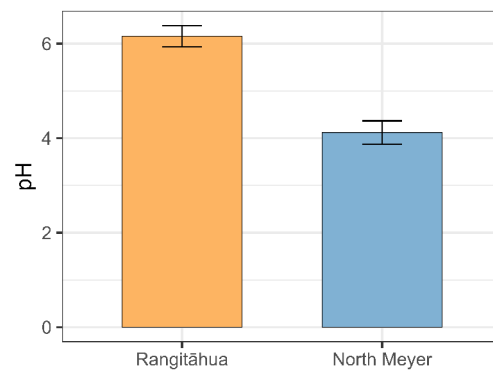
Variable	Mean and standard error		Welch's t	P value	CI low	CI high
	North Meyer	Rangitāhua				
pH	$4.12 \pm 0.25$	$6.16 \pm 0.22$	-6.09 (7.92)	0.000304	-2.81	-1.27
Organic Carbon %	$11.39 \pm 3.51$	$10.36 \pm 1.09$	0.28 (4.77)	0.791	-8.55	10.61
Total Nitrogen %	$0.77 \pm 0.23$	$0.58 \pm 0.04$	0.84 (4.23)	0.443	-0.43	0.82
CN ratio	$14.16 \pm 0.72$	$17.75 \pm 0.94$	-3.04 (7.53)	0.0174	-6.35	-0.83
Total Phosphorus (mg/kg)	$3462.80 \pm 908.75$	$856.80 \pm 81.53$	2.86 (4.06)	0.0452	88.53	5123.47

## Total nitrogen

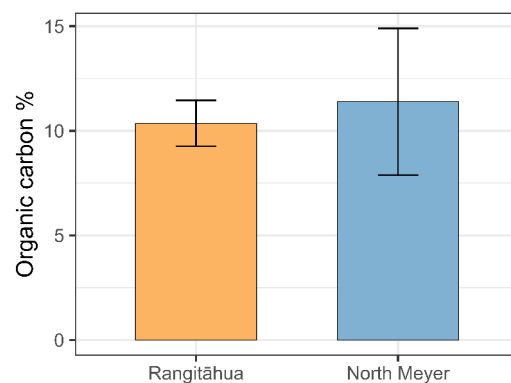
The mean total soil nitrogen was  $0.58\% \pm 0.04$  on Rangitāhua and  $0.77\% \pm 0.23$  on North Meyer (Figure 5). A Welch's t-test indicated that total nitrogen levels did not differ significantly between the two sites (Table 2).

## Carbon: Nitrogen

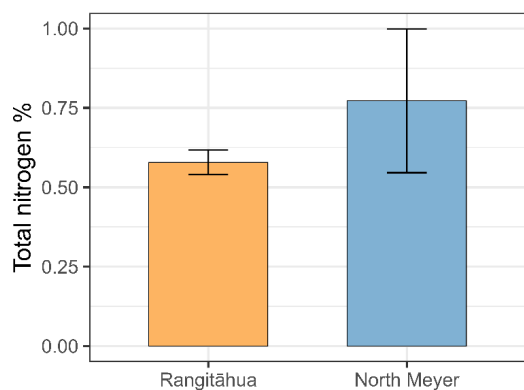
The mean C:N ratio was  $17.75 \pm 0.94$  for Rangitāhua soils and  $14.16 \pm 0.72$  for North Meyer soils (Figure 6). A Welch's t-test indicated that North Meyer had a significantly lower C:N ratio than Rangitāhua (Table 2).



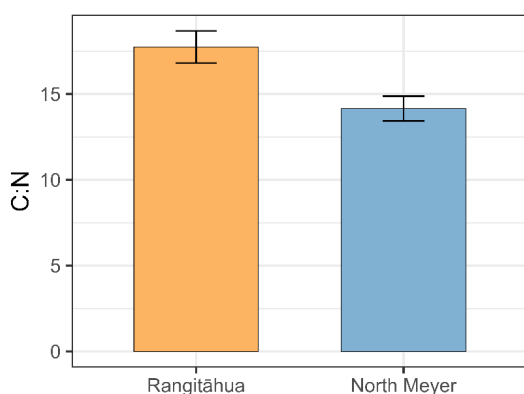
**Figure 3.** Mean soil pH in soils from Rangitāhua and North Meyer Island collected in November 2023. Error bars show standard error. Number of samples per location = 5. CC BY 4.0.



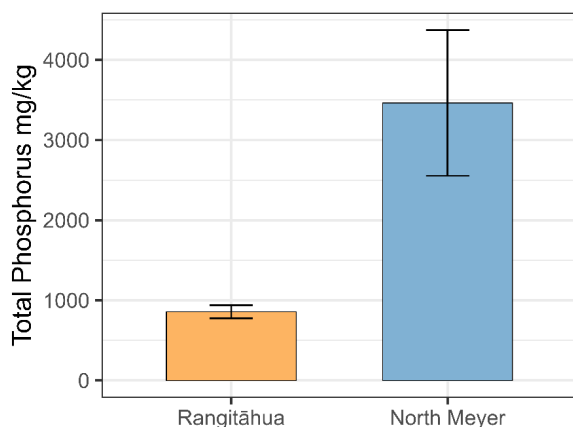
**Figure 4.** Mean soil organic carbon (%) in soils from Rangitāhua and North Meyer Island collected in November 2023. Error bars show standard error. Number of samples per location = 5.



**Figure 5.** Mean total nitrogen in soils from Rangitāhua and North Meyer Island collected in November 2023. Error bars show standard error. Number of samples per location = 5. CC BY 4.0.



**Figure 6.** Mean carbon:nitrogen ratio in soils from Rangitāhua and North Meyer Island collected in November 2023. Error bars show standard error. Number of samples per location = 5. CC BY 4.0.



**Figure 7.** Mean phosphorus (mg/kg) in soils from Rangitāhua and North Meyer Island collected in November 2023. Error bars show standard error. Number of samples per location = 5. CC BY 4.0.

## Total phosphorus

The mean total phosphorus was  $856.80 \pm 81.53$  mg/kg on Rangitāhua and  $3462.80 \pm 908.75$  mg/kg on North Meyer (Figure 6). A Welch's t-test indicated that total phosphorus was significantly higher on North Meyer than on Rangitāhua (Table 2).

## Discussion

Our results are consistent with ecological expectations based on seabird presence and island histories. Soils of North Meyer Island, characterised by dense seabird colonies, were markedly more acidic, had reduced C:N and enriched total phosphorus compared to Rangitāhua soils. This reflects the strong influence of seabird nutrient inputs on soil chemistry. These findings are consistent with a large body of literature showing that seabird activity has a significant impact on soil dynamics (Markwell 1999; Mulder and Keall 2001; Fukami et al. 2006; Durrett et al. 2014; Orwin et al. 2016). The observed statistical lower pH and more acidic soils on North Meyer are likely a result of the high numbers of seabirds contributing guano, which is known to acidify soils (Mulder and Keall 2001). Guano also contributes to high soil phosphorus levels which we also observed in this study (Mulder and Keall 2001).

Previous work on Rangitāhua soils was undertaken in 1959 by Wright and Metson, who conducted extensive sampling across the island. Soils were categorised, described, and mapped, and chemical analyses were also carried out (Wright and Metson 1959). When compared with our 2023 results, there are significant differences in soil carbon, nitrogen, and phosphorus, but little change in pH or C:N ratios (Suppl. material 1: tables S3, S4). These discrepancies may reflect differences in testing methodologies, the approximate nature of site locations, and the long-time span between measurements. However, it is notable that the 1959 study predates the eradication of rats and goats from Rangitāhua. Mammalian pests are known to have major impacts on soil nutrient levels by reducing nesting seabird populations, consuming seeds, and removing vegetation all of which alter nutrient cycling in soils.

Despite the absence of historic soil chemistry data for North Meyer Island, its ecological history differs significantly from Rangitāhua due to the absence of mammalian pests contributing to status as major site of seabird nesting. In contrast, Rangitāhua's soils appear typical of a recovering island forest, with most nutrient levels higher than in 1959 but still lower overall compared to North Meyer. North Meyer's soils reflect a contrasting trajectory driven by persistent seabird activity.

It should also be highlighted that though Rangitāhua and North Meyer are oceanic islands in close proximity; they have major geological differences in size, volcanic history and human disturbance histories that also shape soil chemistry. These findings highlight how seabird activity, invasive mammals, and differing disturbance histories may contribute to shaping soil nutrient dynamics on Rangitāhua and North Meyer, offering important insights into soil dynamic of island ecosystems. These results contribute to our understanding of nutrient cycling on Rangitāhua, informing future conservation and restoration planning on Rangitāhua and across other offshore islands.

## Artificial Intelligence (AI) use

Regarding the use of AI in the preparation of this manuscript, the authors declare the following:

**Description:** Artificial intelligence platforms, including OpenAI and Google Gemini, were used to assist with coding and graph generation in R.

## Acknowledgements

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## Supplementary material 1

### Full soil chemistry results from Rangitāhua and North Meyer

Authors: Kendall Morman

Data type: docx

Explanation note: This document provides a comprehensive list of soil chemistry tests conducted on samples from Rangitāhua and North Meyer Island, conducted by Manaaki Whenua Environmental Chemistry Laboratory and RJ Hills Laboratory. It also contains an analysis of the key results from this report and historical soil chemistry data published by Wright and Metson in 1969.

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Link: <https://doi.org/10.32912/papahou.60.176367.suppl1>

## Supplementary material 2

### Rangitāhua soil technical report data analysis

Authors: Kendall Morman

Data type: xlsx

Explanation note: This spreadsheet contains soil chemistry results and the statistical values calculated to compare soils from Rangitāhua with those from North Meyer Island, as well as to compare current Rangitāhua soils with historical data collected by Wright and Metson in 1969. All analyses were conducted using RStudio.

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Link: <https://doi.org/10.32912/papahou.60.176367.suppl2>

## Supplementary material 3

### R script for statistical analysis of soil chemistry comparing Rangitāhua and North Meyer Island

Authors: Kendall Morman

Data type: R

Explanation note: R script for statistical analysis of soil chemistry comparing Rangitāhua and North Meyer Island.

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## Supplementary material 4

### R script for statistical analysis of soil chemistry comparing 2023 Rangitāhua soils to 1969 soil

Authors: Kendall Morman

Data type: R

Explanation note: R script for statistical analysis of soil chemistry comparing 2023 Rangitāhua soils to 1969 soil. Historic soil data was published by Wright and Metson 1969.

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