

# Pattern and process of vegetation change (succession) on two northern New Zealand island volcanoes

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## ABSTRACT

Pattern and process of vegetation change (succession) were compared on two northern North Island volcanoes: Whakaari (White Island) and Rangitoto Island where the endemic woody tree *Metrosideros excelsa* is the primary colonizer of raw volcanic substrates. Quantitative data from our previous publications (see References) and the references therein illustrate sequences of vegetation succession following significant volcanic eruptions. New information on Rangitoto Island *M. excelsa* patch dynamics and updated vascular species statistics for Whakaari have also been included. We also draw on supporting data from *M. excelsa* forest on the mainland and long-inactive volcanic islands in the Bay of Plenty, to provide a context for understanding the vegetation dynamics on Whakaari and Rangitoto Island. Species facilitation, light availability, humidity, substrate and disturbance history are all key determinants of vegetation succession across these volcanic landscapes.

## INTRODUCTION

Volcanic activity (including lava flows, debris flows and tephra eruptions) has been a regular feature of many northern New Zealand landscapes, causing long-lasting impacts on the vegetation. Over the last 40 years we have been using a combination of the chronosequence and direct monitoring methodologies (Clarkson 1998; Walker et al. 2010) to research the pattern and process of vegetation change (succession) across young volcanic landscapes (currently active to <600 years), and long-inactive volcanoes (>6000 years).

### *Whakaari (White Island)*

Whakaari is a 238 ha island volcano (highest point 321 m a.s.l.) located 50 km north of North Island mainland in the Bay of Plenty (Fig. 1). It has been in the state of continuous solfataric activity, with intermittent small steam and tephra eruptions

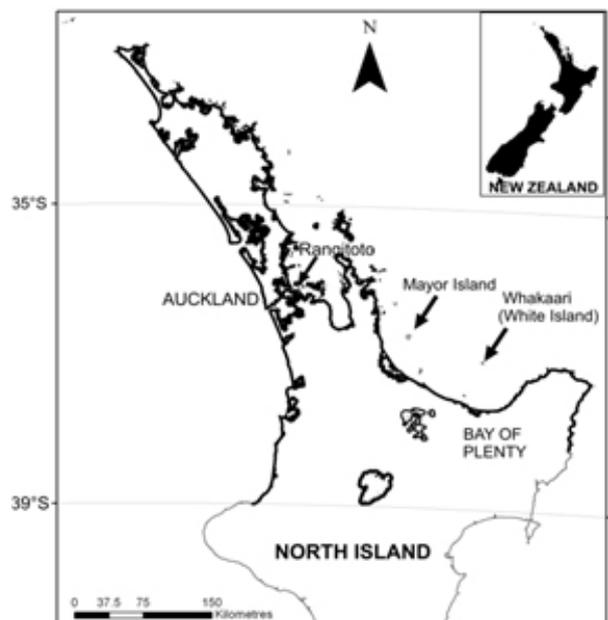


Figure 1: Map showing location of study sites, North Island, New Zealand. Dark line indicates general distribution of *Metrosideros excelsa*.

Table 1: Number of vascular taxa recorded on Whakaari (White Island) between 1912 and 2005 based on Oliver (1915), Hamilton (1959), Gillham (1965), Wilcox (1967), Clarkson & Clarkson 1994, Ecroyd & Clarkson unpubl. data (2005). \* = exotic

<b>Ferns</b>	
1	<i>Asplenium northlandicum</i>
2	<i>Histiopteris incisa</i>
3	<i>Paesia scaberula</i>
4	<i>Pteridium esculentum</i>
5	<i>Pteris tremula</i>
<b>Dicotyledonous herbs</b>	
6	<i>Cakile maritima</i> subsp. <i>maritima</i> *
7	<i>Chenopodium trigonon</i> subsp. <i>trigonon</i>
8	<i>Cirsium vulgare</i> *
9	<i>Conyza sumatrensis</i> *
10	<i>Coronopus didymus</i> *
11	<i>Disphyma australe</i> subsp. <i>australe</i>
12	<i>Euchiton involucratus</i>
13	<i>Gamochaeta purpurea</i> *
14	<i>Hypochoeris radicata</i> *
15	<i>Jacobaea vulgaris</i> *
16	<i>Lobelia anceps</i>
17	<i>Paronychia brasiliiana</i> *
18	<i>Phytolacca octandra</i> *
19	<i>Pseudognaphalium luteoalbum</i> agg.
20	<i>Senecio bipinnatisectus</i> *
21	<i>Senecio sylvaticus</i> *
22	<i>Solanum nigrum</i> *
23	<i>Solanum nodiflorum</i> *
24	<i>Sonchus asper</i> *
25	<i>Stellaria media</i> subsp. <i>media</i> *
26	<i>Symphyotrichum subulatum</i> *
<b>Dicotyledonous trees &amp; shrubs</b>	
27	<i>Coprosma repens</i>
28	<i>Metrosideros excelsa</i>
29	<i>Ozothamnus leptophyllus</i>
<b>Monocotyledons</b>	
30	<i>Cortaderia selloana</i> *
31	<i>Cyperus eragrostis</i> *
32	<i>Lachnagrostis filiformis</i>
33	<i>Phormium tenax</i>
34	<i>Poa anceps</i> subsp. <i>anceps</i>
35	<i>Poa annua</i> *
36	<i>Holcus lanatus</i> *

occurring since 1826. In recent times, major damage to the vegetation has resulted from significant and complex eruptive sequences between 1976–1981 and also 1984–1994. Further volcanic unrest began in July 2012 and has continued intermittently to the present day. Eruptive episodes have included explosive ejections of ash and gas emissions, with acid rain also

causing death and dieback of *M. excelsa* forest and *Disphyma–Chenopodium* herbfields. *Metrosideros excelsa* dominates a floristically depauperate forest community which, in places, comprises only two or three vascular species, namely *M. excelsa*, *Histiopteris incisa*, and *Phormium tenax*. The total vascular flora recorded on the island (36; Table 1) between 1912 and 2005 has ranged between seven and thirteen species before 1990, and approximately 33 species in 2005, which reflects the reduction in volcanic activity between these dates. The post-1990 arrivals, however, are mainly exotic dicotyledonous herbs, and *M. excelsa* remains the only tree species present on the island. *Metrosideros excelsa* is a mass seeder with wind dispersed seed and the ability to recover from canopy damage by epicormic resprouting. Direct succession of *M. excelsa* results from recovery and spread of an existing population or colonization of a newly emplaced surface by *M. excelsa* seed.

#### Rangitoto Island

Rangitoto Island, a basalt shield volcano covering 2311 ha and rising to 260 m a.s.l. is located in the Hauraki Gulf, 8 km north east of Auckland City (Fig. 1). It appears to have been active between 850 AD and 1800 AD, with a maximum lava activity around 1300 AD (Robertson 1986). The primary surface is mainly crusty aa basaltic lava but the summit consists of scoria cones. The last lava flows were followed by an emission of ash that filled most of the crevices and shallow hollows. *Metrosideros excelsa* is the prime lava colonizer and has coalesced to form continuous forest over large areas of the island. We have been monitoring *M. excelsa* patch establishment and development between 1980 and the present day in permanent plots established by one of us (JOJ). These plots were representative of the most extreme sites of largely un-vegetated aa lava. The number of vascular species is strongly positively correlated with the size of the *M. excelsa* patch ( $r^2 = 0.742$ ;  $n = 80$ ) with 1–4 species recorded in patches of  $<0.1 \text{ m}^2$  and 16–19 species in patches of  $>100 \text{ m}^2$ . Using patch size in six size classes (midpoints =  $1 \text{ m}^2$ ,  $3 \text{ m}^2$ ,  $6 \text{ m}^2$ ,  $12 \text{ m}^2$ ,  $24 \text{ m}^2$ ,  $48 \text{ m}^2$ ) and frequency of occurrence as a surrogate for age, it is possible to determine the orderly sequential establishment of species. Early establishers include *Coprosma robusta*, *Myrsine australis* and *Astelia banksii*. Middle and late establishers include *Pseudopanax*

*arboreus*, *Collospermum hastatum* and *Asplenium oblongifolium*. The fern, *Asplenium flaccidum*, which is mostly epiphytic on *M. excelsa*, is one of the last to arrive. Some species fluctuate in their frequency in relation to patch size, for example, *Brachyglottis kirkii*, *Ctenopteris heterophylla*, and *Asplenium flabellifolium*. These are usually patch edge dwellers and are sometimes lost as the *M. excelsa* canopy expands but may subsequently recolonise the edge of the patch. *Metrosideros excelsa* facilitates this deterministic establishment pattern by influencing the microclimate of the site. Surface temperature on open lava may exceed 50°C whereas in the interior of a large patch or extensive forest, it is less than 25°C. Relative humidity is less than 40% on open lava, exceeds 45% in large patches and is over 55% in the forest interior.

#### Comparison with *M. excelsa* forests elsewhere

Plant successions on volcanic landscape are extremely variable both in terms of rates of change and the sequence of species establishing. However, comparison of *M. excelsa* forest across young volcanic islands, long-dormant volcanic islands and the mainland illustrates some regularity in the patterns of succession that arise following disturbance. For example, Mayor Island (Tuhua), a dormant (c. 6000 years) volcano situated between Rangitoto and Whakaari c. 27 km east of the Coromandel Peninsula (Fig. 1), is dominated by *M. excelsa* forest. The current forest pattern there was likely initiated by Polynesian burning c. 450 BP. Vegetation change in permanent quadrats (1999–2009) shows proliferation of *Litsea calicaris* and the establishment of

*Dysoxylum spectabile* and *Corynocarpus laevigatus* in the forest understory. On the mainland, *L. calicaris*, *D. spectabile*, *C. laevigatus* commonly establish beneath closed canopy *M. excelsa* forest (usually >50 years old) and contribute to the replacement of *M. excelsa* in the canopy after a minimum period of c. 200 years. In contrast *Beilschmiedia tawa*, the most shade tolerant tree species to establish within *M. excelsa* forest, is late successional and requires c. 100 years before conditions are suitable for seedling establishment. On Rangitoto Island, *M. excelsa* facilitates the establishment of mid successional species; however their incursion is much slower than on less severe mainland sites and long-dormant volcanoes, where *M. excelsa* forest has largely been initiated by fire. On much older basaltic lava blocks flanking Mt Eden (c. 10 km SW of Rangitoto Island, on the mainland), *M. excelsa* shares dominance with *Vitex lucens*, *L. calicaris*, *D. spectabile*, *Alectryon excelsus* and *Myoporum laetum* and this might indicate future trends on Rangitoto.

Light is a key resource controlling plant species colonization of new sites and replacement in forest understories. The shade tolerance of key species in *M. excelsa* forest and scrub has been quantified using hemispherical photography (Bylsma et al. 2014). Light environment occupancy of key canopy species differs significantly ( $P < 0.001$ ) according to the distribution of understory light environments available. Pioneer and early successional species (e.g., *M. excelsa*, *Myrsine australis*, *Kunzea ericoides*) occupy the higher spectrum of light environments, whereas mid and late successional tree species (e.g., *Litsea calicaris*, *Dysoxylum spectabile*,

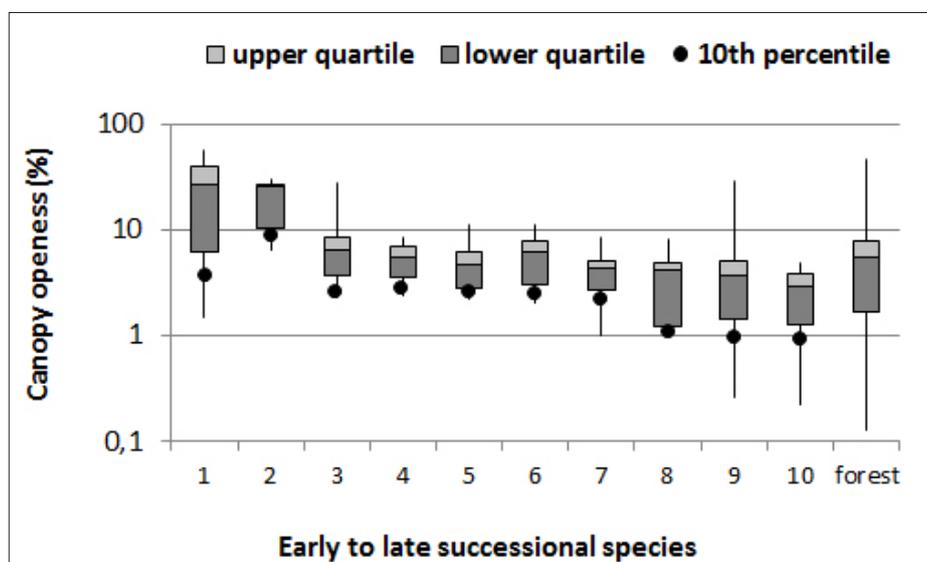


Figure 2: Species light environment distributions: (1) *Metrosideros excelsa*, (2) *Kunzea ericoides*, (3) *Piper excelsum*, (4) *Myrsine australis*, (5) *Geniostoma rupestre*, (6) *Hedycarya arborea*, (7) *Dysoxylum spectabile*, (8) *Corynocarpus laevigatus*, (9) *Litsea calicaris*, (10) *Beilschmiedia tawa*. Data collected from Ohope Scenic Reserve, Kohi Point Reserve and Matata Scenic Reserve, Bay of Plenty.

*Beilschmiedia tawa*) show bias towards the darker microsites (Fig. 2). Ranking species in order of their minimum light requirements (e.g., 10<sup>th</sup> percentile) approximates their order of arrival in *M. excelsa* forest development.

Comparison of vascular species richness, time since disturbance and island area reveals variable disharmonic floras. On Whakaari, continual volcanic disturbance, isolation and extreme soil conditions have resulted in a depauperate flora (36 spp.) and the simplest *M. excelsa* forest. On Rangitoto Island, the proximity to the mainland, less volcanic disturbance, larger size and relative stability since c. 1800 AD have contributed to a much higher number of species (582 spp.). In addition, the presence of beachside holiday homes since the 1930s has enabled the incursion of numerous exotic species.

#### ACKNOWLEDGMENTS

Special thanks for Rebecca Bylsma for allowing us to use her shade tolerance data. We also thank Chris Ecroyd for his contribution to the species list and lodging specimens in the National Forestry herbarium, Rotorua. BR Clarkson was funded in part by the Ministry of Business, Innovation and Employment (Contract C09X0503).

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