The island rule and its application to multiple plant traits

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*“The larger the island of knowledge, the longer the
shoreline of wonder”*

Ralph W. Sockman.

General Abstract

Aim The Island Rule refers to a continuum of body size changes where large mainland species evolve to become smaller and small species evolve to become larger on islands. Previous work focuses almost solely on animals, with virtually no previous tests of its predictions on plants. I tested for (1) reduced floral size diversity on islands, a logical corollary of the island rule and (2) evidence of the Island Rule in plant stature, leaf size and petiole length.

Location Small islands surrounding New Zealand; Antipodes, Auckland, Bounty, Campbell, Chatham, Kermadec, Lord Howe, Macquarie, Norfolk, Snares, Stewart and the Three Kings.

Methods I compared the morphology of 65 island endemics and their closest 'mainland' relative. Species pairs were identified. Differences between archipelagos located at various latitudes were also assessed.

Results Floral sizes were reduced on islands relative to the 'mainland', consistent with predictions of the Island Rule. Plant stature, leaf size and petiole length conformed to the Island Rule, with smaller plants increasing in size, and larger plants decreasing in size.

Main conclusions Results indicate that the conceptual umbrella of the Island Rule can be expanded to plants, accelerating understanding of how plant traits evolve on isolated islands.

Key words

Island Rule, Island Biogeography, Plant Evolutionary Ecology, Phytogeography

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Chapter 1: General Introduction

Insularity

Insularity in a biogeographical sense can be defined by a location's isolation. Islands are a frequently used as examples of isolation, and can be defined in two ways; either 'habitat islands' (where discrete habitat patches are surrounded by a contrasting environment) or 'true islands' (the classical interpretation of an island where land is surrounded by sea) (Whittaker & Fernández-Palacios, 2007). True islands are either oceanic or continental. Oceanic Islands are landmasses that have formed at oceanic plate boundaries totally isolated from continental landmasses. Continental islands have been in contact with a continent at some point in the past. Connection with the continent may have occurred via 'land-bridges' when global sea levels were lower, and later isolation may have taken place via tectonic processes such as continental drift, or rising sea levels.

Rather than a categorical term, insularity is dependent on the perspective, meaning a landmass can be both an 'island' and a 'mainland'. For example, individuals from Australia can disperse across the Tasman Sea and colonise New Zealand. In this instance, Australia can be considered the mainland and New Zealand could be considered the island. However, the satellite islands surrounding New Zealand could be populated by the North or South Island, and in this case New Zealand then acts as the mainland, and the satellite island acts as the island. In short, the location of the 'source' population location acts a mainland, and 'sink' population location is an island.

Island insularity and size may result in different levels of size changes and endemism. In relation to bigger areas, small areas house less species richness, with less diversity intraspecifically as well (Whitehead & Jones, 1969). Small islands may also have less habitat heterogeneity, making them harder to establish on (Whitehead & Jones, 1969). Competition between similar species is low, as the statistical likelihood that multiple species with a similar niche disperse to, inhabit and successfully persist on the same island is low. Dispersal probability and extreme interspecific competition reduces with island size. Small islands also have a reduced potential for available resources, leading to an increase in unique endemic adaptations (Falkland & Custodio, 1991; Whittaker *et al.*, 2014; see Figure 1.1 relating to this concept). Current extant distribution patterns of plants do not necessarily display past patterns

of dispersal but, for the purposes of this thesis it is an assumption that is held. Alternative mechanisms such as local extinctions could lead to the current distribution as well. The most parsimonious explanation for this is that lineages split from a progenitor in their respective areas where the lineage is maintained. It is less likely for a lineage to arise, disperse to a new locality, and for the progenitor to also become extinct or alter.

For this thesis, only islands within 1800km of the coast of New Zealand were included. These islands were identified as having species that most likely originated from New Zealand. The majority of these islands formed under oceanic processes. New Zealand and its islands isolated from Gondwana about 80 million years ago. Lord Howe, Norfolk and Macquarie islands are 7 million, 2.5 million and 300,000 years old respectively, having arisen through undersea volcanic activity (Diamond, 1984; Waters & Craw, 2006). Terrestrial taxa arriving to islands all had to disperse overwater. However, land bridges may have connected some of the smaller islands around New Zealand and aided in species dispersal abilities (Diamond, 1984; Waters & Craw, 2006). The islands that were considered for this study are: Antipodes, Auckland, Bounty, Campbell, Chatham, Kermadec, Lord Howe, Macquarie, Norfolk, Snares, Stewart and the Three Kings (Figure 2.2).

Figure 1.1 Probability for an endemic species persisting in relation to island size and relative location (in the absence of stochastic processes or abrupt climatic oscillations). Available resources and unused niche space generally decreases with Island size, making probability high on small islands. Inter-specific competition and niche competition increases while potential for genetic drift decreases with proximity to “mainland”, making persistence and survival probability lower on bigger islands.

Evolutionary size changes on islands

Size changes and species divergence occurs on islands via means of cladogenesis or anagenesis (see Figure 1.2). Species radiations (a form of cladogenesis) are popular study subjects, resulting in a bias of studies focused on cladogenesis, rather than anagenesis (Schluter, 2000; Stuessy *et al.*, 2006). Anagenesis is on average less prevalent as a model of evolution compared to cladogenesis, a fact which may explain the limited reporting on the subject (Stuessy *et al.*, 2006). In addition, Stuessy *et al.* (2006) states that anagenesis frequency seems to strongly depend on the island system. A classic example of radiation and cladogenesis is that of “Darwin’s finches” where multiple beak structures of Galapagos Island finches must have arisen from a single mainland ancestor (Grant & Grant, 2002). For plants as well, cladogenesis has been widely reported on, for example: Lord Howe has radiations of both palms, and *Coprosma* species, and Madagascar has *Canarium* (Savolainen *et al.*, 2006; Federman, *et al.* 2015). While there is significant study surrounding instances of cladogenesis, studies dealing with anagenesis are generally less frequent (Schluter, 2000; Stuessy *et al.*, 2006). However, since 2006, examples of plant anagenesis have become increasingly researched (Takayama, Sun & Stuessy, 2013).

Cladogenesis examples are the product of two or more sister taxa. In a clade formed by two sister taxa, one species may come from a geographic location larger, than the other species. According to the island section earlier, species from larger areas represent the mainland population, while the other species must therefore represent the island taxa. It is assumed that very little or no morphological change has occurred on the mainland, and that change is restricted to islands due to practical thesis limitations. For phylogenetic comparison of sister taxa, the ‘mainland’ species was a realistic proxy of the progenitor species.

Genetic changes between sister taxa due to speciation lead to three possible evolutionary size change scenarios. The divergent population may display larger traits, secondly that the divergent group may display smaller traits and thirdly that there is no distinct size change in the divergent group (see Figure 1.3). Changes to morphology are not necessarily uniform within or between sister taxa, meaning that while one insular trait may show evolutionary size change, such change may occur independently of other traits (Chapin III, Autumn & Pugnaire, 1993). If adaptive, size changes in different insular plant traits could be

the result of multiple island selection pressures acting independently of one another (Burns, Herold & Wallace, 2012; Kavanagh & Burns, 2014; Burns, 2016a).

Size range of a species will be somewhat dictated by the colonising individual or group. The first mainland ancestor population to establish on the island will already display traits for a certain size. Dispersal-related filters (such as biological dispersal via animals) likely explain the bias of certain plant lineages on islands (Burns, 2005). Although the island species is expected to change morphology over evolutionary timescale, the mainland progenitor species is not expected to undergo significant morphological change due to unaltered selection pressures (Lomolino, 2005). It would be unexpected that large species become smaller, and vice versa, (without a significant time period).

However, plants may display similar traits between ‘species pairs’, as insular species may favour particular evolutionary pathways, resulting in repeated forms of evolution. For example, a particularly exposed and sunny island (relative to the mainland) may have many endemic plant species with small leaves. In this setting, small leaves may be evolutionarily advantageous in comparison to large leaves, as they are better suited to cope with temperature regulation, and sunlight over-exposure. In this sense environmental factors (and biological factors), almost certainly provide basis for size changes in particular morphological features. Such factors and selection pressures consistently occur in island settings, making island settings perfect experiments isolated by space and time.

Comparisons of Island and mainland plant traits offer insight into these ‘island laboratories’. This thesis deals with ten specific morphological features over two trait groupings. These trait groups were selected because 1.) seeds and replicative features have been considered already, 2.) to offer further quantitative support for tests involving vegetative features, and 3.) as a novel consideration, as to my knowledge, specific investigation of floral features in this context has not occurred before.

The first group is **Floral features**. This group was comprised of features specifically relating to flowers. Flower area (overall flower length x overall flower width), Inflorescence length, petal area (petal length x petal width), sepal area (sepal length x sepal width), filament length, anther length, and pedicel length. The second group was comprised of **Vegetative features**. Vegetative features included stature (total height of a plant), leaf area (lamina length

x lamina width), and petiole length. More specific details related to how these measurements were defined and measured are in their respective chapters. Reproductive features (such as seeds and fruits) were excluded from this thesis, as there are already adequate investigation in this area (Kavanagh & Burns, 2014), and there is limited opportunity to significantly improve the current sampling size.

Figure 1.2 Anagenesis occurs when new species form along a lineage without any branching in the line of descent. Cladogenesis occurs when a new clade (or group) of species arise by evolutionary divergence from an ancestral form. This thesis assumes that the mainland form is extant and that has undergone little or no evolutionary change.

Figure 1.3 The three evolutionary scenarios for trait size changes. Outcome 1: divergent group becomes larger in size. Outcome 2: divergent group becomes smaller in size. Outcome 3: divergent group stays the same in size, and displays non-size related change.

The Island Rule

History

Foster (1964) demonstrated that large mainland animals including lagomorphs, carnivores and artiodactyls displayed insular dwarfism, while small animals like rodents and marsupials displayed gigantism on islands compared to their closest mainland counterparts. Van Valen in (1973) termed this phenomenon the 'Island Rule'. Later, Heaney (1978) and Lomolino (1985) specified that the rule was better described as a gradual trend among species of different body size. However, the Island Rule is still often generalised to "big species get small, small species get big", (See Figures 1.4).

The Island Rule in a graphic form displays a 'shift' where the diversity of an island is greatly reduced compared to the diversity of the mainland. Scholars have interpreted these evolutionary shifts as communities coming back to a median or an optimal functional zone (Brown, Marquet & Taper, 1993; Damuth, 1993; Raia & Meiri, 2011). That is to say, if an island's small species increase in size and big species decrease in size, overall the total size range of this island 'moves away' from extreme values. Therefore, as variation in size decreases, the values themselves become closer towards a common average. Island variation is usually contained within the variation limits of the mainland, thereby being an optimisation zone.

While studies by Lomolino and other academics (see Lomolino, 2006) have demonstrated multiple examples of support for the Island Rule, there continue to be critiques. Meiri, Cooper & Purvis (2007), comment on the Island Rule's tendency to report clade-specific responses to insularity, and that the graded trend can be explained according to taxonomy. In fact, there have been multiple instances where the Island Rule has 'failed' to be the best explanatory principle (Welch, 2008; Itescu, Karraker, Raia, Pritchard & Meiri, 2014). Concern has been raised, especially for animal studies, that human propensity to move species and cause localised extinctions may 'blur' the true extent of insular patterns of evolution (Faurby & Svenning, 2016). Critiques of the Island Rule in animal species, continue to arise. In the last few months, Lokatis & Jeschke (2018) published a paper outlining how support for the Island Rule in literature may be connected to bias from authors. Gould (1997), in discussing Cope's rule of organism body-size evolution, stated that focusing on extremes tends to intrigue the mind more than the full range of variation. Along a line of reasoning, Meiri, Raia and Phillimore (2011) proposed that perceived insular body size pattern may simply reflect an ascertainment

bias. In order to have a full and legitimate investigation of the Island Rule, it is important to involve as many replicates as possible to eliminate this potential source of conflict. Lokatis and Jeschke (2018) state that with potential sources of bias in some papers, the Island Rule is well empirically supported in only half of the studies, although it tends to be better supported when restricted to mammals. Remarkably, the Island Rule as a concept has been greatly considered with respect to animals, without very much examination of the Rule in other areas such as plants.

Figure 1.4 An illustration of the Island Rule displayed in two ways.

A) Island represented as a function of Mainland, where the orange line is a suggestion of a data trend indicating Island Rule.

B) The Si Ratio (where $S_i = \text{Island size of measured trait} / \text{Mainland size of measured trait}$) compared to Mainland value.

The dashed blue line represents that Line of Isometry where Island values = closest Mainland relative values. The arrows indicate how the island species population have shifted away from the line of Isometry, demonstrating gigantism for smaller species, and dwarfism for larger species (relative to their closest mainland relative).

Patterns and processes

The pattern of Island Rule is a spectrum of insular gigantism to dwarfism resulting respectively from small to big mainland relatives. This means that there are also intermediate insular species that 'stay' intermediate in comparison to their closest mainland relative. The Island Rule pattern is inferred to reflect dissimilarities in selective pressures (Lomolino, 2006). However, this is a somewhat simplification of the nature of evolutionary forces acting upon island phenotypes. Differentiation of island traits is invariably dependant on a number of processes such as founder events, small population size and limited gene flow (Bosssdorf *et al.*, 2005). The nature of these processes means that different evolutionary forces (such as genetic drift) may be acting on the evolution of island plants. Such island evolutionary histories would likely differ at species and trait level. While it is simple to present these concepts as potential drivers of insular size evolution they can be difficult to research.

In order to understand differences in size morphology, the two distinct features in the Island Rule (dwarfism and gigantism) have been separated to focus literature and understanding specific to each distinction. In plants there are no delineation to classify a plant as a dwarf or giant. The closest defined term is dwarfing, through intentional or natural processes a cultivar of plants become significantly smaller than the standard (Milach & Federizzi, 2011). Therefore, to understand size changes on islands, a standard is required. The best standard to use in this instance is the closest mainland relative to an island endemic plant species. This process assumes mainland traits have a static phenotype, and that island species are not the result of evolutionary mechanisms such as phenotypic plasticity, local adaptation. This is a robust assumption, as describing a species in science is rigorous, meaning endemic island species are unlikely to be incorrectly described as a mainland species displaying phenotypic plasticity.

Evidence of Insular Dwarfism – Why might species get smaller?

Examples of dwarfism are less frequently noted in literature than examples of gigantism on islands (Lokatis & Jeschke, 2018). Of dwarfism examples available, there is more literature and understanding of processes for animals compared to plants. Hanken and Wake (1993) state that miniaturization is common in multiple living and extinct taxa, especially "foraminiferans, nemertines, annelids, brachiopods, molluscs, arachnids, crustaceans, insects, echinoderms, and ascidians", though it seems most common and more pronounced in fish, amphibians and reptiles. Some small bodied mainland species have been most closely related to even smaller

island species. Lawlor (1982) demonstrated how small seed-consuming rodents of the *Peromyscus* genus unexpectedly display dwarfism on islands. While on Jersey, the Channel Islands, Lister (1989) reported that teeth and limb bones of Red deer individuals (*Cervus elaphus*) were one-sixth of their size some 6000 years ago. In contrast, and somewhat more common are examples of large mainland species displaying island dwarfism. In particular, there are multiple cases of large mainland species such as elephant and hippopotamus species displaying dwarfism on islands (Roth, 1990; Poulakakis, Mylonas, Lymberakis, Fassoulas, 2002; Weston & Lister, 2009; van der Geer, Lyras, Mitteroecker & Macphee, 2018).

There is some empirical evidence in literature for insular dwarfism of plant species. Shinohara & Murakami (2006) studied *Blechnum* and *Lysimachia* species isolated on 'alpine islands'. Their findings showed that these 'island' species compared to their 'mainland' counterparts down the mountain were significantly smaller. This smallness extended into the cellular scale, as the small 'island' species had a smaller size of epidermal cells present on the leaf. Burns (2016a) found that *Alyxia ruscifolia* (Apocynaceae) on Lord Howe Island displayed dwarfism in stature relative to the Australian Noosa Head population. Sun *et al.* (2016) also published similar work supporting the presence of dwarfism in *Smilax biflora* (Smilacaceae). Hendriks & Burns (unpubl. data) considered all available endemic species on Cocos Island, Pacific Island (off the coast of Costa Rica) and found that they displayed dwarfism of both stature and leaf traits over all taxonomic groups compared to their closest mainland relatives. Studies of insular size changes tend to focus on plant vegetative features, and not necessarily link traits, meaning it can be difficult to identify what processes promote insular dwarfism.

Factors and processes that contribute to size changes difficult to disentangle. It is generally agreed that increased intraspecific competition, predation, and taxonomy are the major drivers of a vertebrate species' propensity to display island dwarfism (Palkovacs, 2003). However, our understanding of the mechanisms for vertebrate species does not necessarily translate to plant species.

On islands, there are multiple theories as to why dwarfism may occur in plant species. These can be generally split into two camps; Biotic and Abiotic factors. Biotic factors may include competition, co-evolved partners, and resource availability. Greater interspecific competition on a size restricted island, means that individuals that reproduce quicker could gain an evolutionary advantage. However, in reaching sexual maturity quicker, such species

tend to display long-term dwarfism (Palkovacs, 2003). It is known that pollinators act as selective agents on floral traits (Inoue, Maki & Masuda, 1996). Islands are known to have less available pollinators compared to the mainland in terms of sheer volume and also species diversity (Barrett, 1996), therefore floral features could respond to a reduced set of generalist pollinators by having smaller, less specialised flowers. In computer simulations, of island biomass-limitation, small body size was more likely to occur than gigantism (Wassersug, Yang, Sepkoski & Raup, 1979). Abiotic factors that might impact on insular size changes could include climatic factors (such as temperature or wind exposure), habitat or substrate quality as a reflection of island quality. There is some evidence that climatic factors (such as a warmer temperature) may result in decreased stature and leaf size, as Leger (2013) showed when comparing a list of the same species between 1900 and 2000. The island itself in terms of substrate availability or general habitat may also play a role in selecting for individuals resulting in speciation and potentially size modifications. The Lord Howe Island palms are an example of speciation that probably arose due to differences in soil substrates (Savolinen *et al.*, 2006).

In short, the given reasons available for why plant species may reduce in size when on an island include reduction in resources, potential pollinator effect, substrate quality, or habitat. These factors on their own, or as multiple parts of a system together with other unmentioned mechanisms, may result in the potential for island species to display dwarfism relative to their mainland counterparts. In these described instances dwarfism is favoured through natural selection. Such feedback systems could explain species' dwarfism over time, as smaller individuals would continue to be favoured.

Evidence of Insular Gigantism - Why might species get bigger?

Gigantism is most often reported for insular species (Lokatis & Jeschke, 2018). Reporting bias can be misleading, as gigantism seems to be less common or advantageous for insular species (Lomolino, 2005). This in part may be a reflection of people being intrigued by the odd and unusual (Lokatis & Jeschke, 2018). Of insular gigantism examples available, there is more literature and understanding of processes for animals compared to plants. The flagship lineage for animal insular gigantism is birds, especially in New Zealand. New Zealand has many large, flightless birds related to smaller flighted birds (Daugherty, Gibbs & Hitchmough, 1993; Clout & Craig, 1995; Lomolino, 2005). Flighted birds such as the Haast eagle and Eyles's harrier demonstrated gigantism and are most closely related to small Australian birds of prey (Bunce

et al, 2005 in Evans, 2018). Further examples of insular gigantism include testudinidae, both fossil, and extant species such as the Galapagos tortoises which outweigh and outsize mainland relatives (Jaffe, Slater & Alfaro, 2011). There are further peculiar examples of already large species displaying insular gigantism such as the Kodiak bear *Ursus middendorffi* (Meiri, 2004), and the extinct Crete deer *Cervus major* (Sondaar, 1977).

Island gigantism specifically pertaining to plants has been reported in literature. Böhle, Hilger and Martin (1996) used molecular data to infer the evolution and island colonization of *Echium* L. (Boraginaceae). This study showed that island plants displayed secondary woodiness or gigantism on oceanic islands compared to their closest mainland relatives, in line with a 'weeds-to-trees' phenomenon (Carlquist, 1974). Similar studies to Böhle *et al.* (1996) have been conducted and also found that gigantism in island species seemed to be more common for plant stature (Panero, Francisco-Ortega, Jansen, Santos-Guerra, 1999). In fact, studies by Carlquist (1974), Grant (1998), and Percy & Cronk (2002) all noted this observation in their research. There is still further research that finds evidence that secondary woodiness in herbaceous plant species is a repeated evolutionary pattern (Lens, Davin, Smets & del Arco, 2013; Crawford & Archibald, 2017; Whittaker, Fernández-Palacios, Matthews, Borregaard & Triantis, 2017). Contrary to expectations, research supporting gigantism in island plant leaves did not find any evidence of woodiness (Burns *et al.*, 2012). Research from Cox & Burns (2017) has shown that leaves on Chatham Island species showed stronger evidence for island gigantism than plant stature, which was also greater for the island species compared to their closest mainland relative. Kavanagh & Burns (2015) also found that leaves are significantly larger on islands. Other traits, such as seed size has also been demonstrated to increase on islands through inter-specific comparison (Kavanagh & Burns, 2014). These studies demonstrate the multiple specific features of plants that can display gigantism, with stature being the most frequently reported. Unfortunately, potential mechanisms driving this gigantism in vascular plant species remain elusively difficult to disentangle.

The most common mechanisms for gigantism are generally attributed to reduced resource interspecific competition, relaxed predation pressures, and higher quality resources (Lomolino, 2005). Palkovacs (2003) suggested that because large animals are generally more difficult to predate on, gigantism may offer reduced extrinsic mortality. However, for plants

(similar to plant dwarfism) there is limited understanding of the patterns and mechanisms resulting in insular gigantism.

Explanations for processes fostering insular gigantism (similar to dwarfism) can be grouped as biotic or abiotic in nature. Biotic explanations seem to solely rely on one explanation; absence of herbivory. In the absence of herbivory, plants no longer need to be adapted to being small, and inconspicuous to avoid predation (Bowen & Vuren, 1997). A relaxed predation pressure, may allow species to get bigger. Alternative explanations are abiotic in nature, and comprise of niche availability, island quality, climatic stimuli, or taxonomic predisposition (Williamson, 1983). In a new location with available niches, gigantism may be a reflection of the evolution of a species maximising available space, especially with reduced inter-specific competition, but increased intra-specific competition. Factors arising from island settings may influence plant sizes. Louw (2016), found that altitude seemed to influence the size of selago cushions, in such a way that the higher the altitude, the taller the selago cushion. It may be that climatic factors promote the evolution of gigantism in a lineage, although Burns *et al.* (2012) disagree citing release from predation and increased intra-specific competition as being more pertinent explanations. Insular gigantism on islands may reflect the unique island assemblages that form, and the evolutionary response that certain species have to these settings. It might be that certain lineages have a tendency towards either gigantism or dwarfism (Itescu *et al.*, 2014; Welch, 2008).

In short, the main reasons given for insular gigantism seem to be increased resources, potential relaxed predation and competition pressures. While other mechanisms and considerations may explain why gigantism of traits occurs, in the previously described instances, larger individuals may be favoured through natural selection. Such feedback systems could explain species' gigantism over time, as bigger individuals would continue to be favoured.

The Island Rule and Plants

Whilst somewhat general, the Island Rule eloquently explains the complex nature of islands and the evolutionary processes occurring on them. Descriptions go as far as suggesting it is the simplest ecotypic rule used to explain nature (Van Valen, 1973). For this reason, its quick adoption and also vigorous debate has led to multiple different scopes and perspectives, especially in insular animals. At its essence, the theory deals with understanding if islands (and

the evolutionary forces associated with them) 'select' for an optimum body size, or rather an optimisation of body size (Case, 1978). This is demonstrated with a reduction of size range on islands compared to the mainland.

Insular plant size changes have not been extensively investigated. In all truth, even just understanding the evolution of insular plants is generally required, with most studies focused on emblematic island animal taxa. Available plant literature has tended to focus on size changes to seeds and fruits, or arborescence (Hochberg, 1980; Kavanagh & Burns, 2014). Arborescence is the demonstration of the susceptibility of herbaceous mainland species to display gigantism and insular woodiness, which is frequently reported (Carlquist, 1980; Wagstaff *et al.*, 2010). However, species on satellite islands off New Zealand display a tendency for gigantism, notable for both leaves and stature irrespective of woodiness (Beever, 1989; Burns *et al.*, 2012; Cox and Burns, 2017).

There has also been study conducted considering insular seed size. Kavanagh & Burns (2014) found that insular seed size tended to display gigantism, and that this reflected the growth form of the plant species. Further investigations by Cox and Burns (2017), found support for Kavanagh & Burns' 2014 study, with a tendency for gigantism found in insular seeds. Additionally, the study also found that there was a trend for larger island seeds for species with larger taxonomic divergence times. Dispersive features such as seed and fruit were not considered in this study, because there was not a large availability of data, from new sources or species that would significantly enhance the literature currently available.

Studies have shown that insular dwarfism in plants occurs (Shinohara & Murakami, 2006; Burns, 2016a; Sun *et al.*, 2016). Gigantism in insular plant species has also been observed (Carlquist, 1974; Böhle *et al.*, 1996; Grant, 1998; Panero *et al.*, 1999; Percy & Cronk, 2002; Kavanagh & Burns, 2014; Kavanagh & Burns, 2015). However, studies that tie the two together to better understand the graded trend of the Island Rule are significantly less (Kavanagh & Burns, 2014; Cox & Burns, 2017; Hendriks & Burns, unpubl. data). Such observations focus on stature, leaf size, and seed size while other morphological features are generally overlooked; in particular floral components. Irrespective of the features observed, very few have examined the underlying mechanistic forces that act on evolution of insular plant size changes.

The aim of this thesis is to ascertain if the Island Rule is applicable to plants, considering multiple morphological characters. Further, for the first time, an insular floral size range

reduction will be investigated in light of the Island Rule. Understanding evolutionary patterns improves our knowledge of evolution. Investigation of the drivers of evolutionary size change improve scientific endeavours for modelling systems to better predict the future impact of climate change for plants.

Thesis overview

In this thesis, I explored evolutionary patterns in ten different plant traits on islands in the South Pacific region. The approach taken was a 'species pairs' (island-mainland) comparison, where insular taxa were directly compared to their mainland sister taxa. Data was collected from flora descriptions and herbaria measurements. As the format is similar for each data chapter there may be some repetition, particularly for methodology and introductions.

In chapter 2, I tested for differences in floral features, split into seven categories (flower, inflorescence, petal, sepal, filament, anther, and pedicel). Floral data was sourced from literature, and herbarium measurements to produce data sets for each individual category. After testing to see if there was an overall trend for evolutionary changes in the various traits of flower anatomy using simple regression models, I then tested if size variation could be explained by additional factors. Finally, I tested multiple random factors to understand if they were major influencing factors in insular size changes.

In chapter 3, I tested for differences in vegetative features, split into maximum stature, leaf area and petiole length. Vegetative data was sourced from literature and literature, to produce a comprehensive data set. As mentioned for chapter 3, 'species pairs' were created for insular taxa and their sister mainland taxa. After testing to see if there was an overall trend for evolutionary changes in the various traits of flower anatomy using simple regression models, I then tested if size variation could be explained by additional factors. Finally, I tested multiple random factors to understand if they were major influencing factors in insular size changes.

In chapter 4, I consolidate the findings of the thesis, and how each set of features compare against one another. Overall through exploring trait specific evolutionary changes in plants this thesis is able to broaden our understanding of insular evolutionary processes and outcomes.

Chapter 2: Floral features

Introduction

A popular observation on islands is the occurrence of small flowers. In referring to the Aru Islands in Indonesia Alfred Russel Wallace (1832) wrote that “tropical flowers are less abundant, on average less showy, and are far less effective in adding colour to the landscape, than in temperate climates”. Expressing a similar sentiment, the flora of the Galapagos Islands was described by Charles Darwin (1835) as having no large flowers. The common occurrence of small flowers was a notion that Alfred Wallace held dear for more than four decades, as the 1876 description of his travels through Asia reported that the flowers were essentially one type throughout. They have been further described as small and inconspicuous (Carlquist, 1974; Grant, 1998). Insular flower size continues to be reported in more recent literature. Investigations into the angiosperms of the Juan Fernández Islands (Chile), found that the majority of flower sizes (60%) were small ($\leq 26\text{mm}^2$) (Bernadello, Anderson, Stuessy & Crawford, 2001). While on the Izu Islands of Japan, plant species also display evidence of floral dwarfism (Kamijo & Hashiba, 2003). Such observations and studies only considered size change within a species (essentially testing for island plasticity). However, my research considers the evolutionary changes of flower size between closely related mainland and island species.

Island flowers are not all small and inconspicuous though, in fact some cases display gigantism. On the Izu Islands for example, while some species (did indeed) display dwarfism, others display gigantism (Kamijo & Hashiba, 2003). The megaherbs on the sub-Antarctic Islands south of New Zealand are a great example of flower gigantism. Hooker (1847 in Fell 2002, p. 53) was one of the first naturalists to record megaherbs on the sub-Antarctic islands. In his description of the plants he stated that the *Pleurophyllum* meadow produced “a floral display second to none outside the tropics”. Large flowers in the sub-Antarctics is a story of repeated evolutionary form occurring multiple times across a number of lineages (Mitchell-Oldie & Wagstaff, 1999), a fact which has drawn scientific attention toward megaherb study in more recent years (Lord, 2015; Little, Eidesen, Müller, Dickinson & Lord, 2016). Therefore, evidence of both gigantism and dwarfism of flower size exists on islands.

Not only did naturalists and scientists document instances of islands generally differing from the mainland, but they also commented on broad trends they believed were occurring

across latitude. A frequent historic view of floral sizing was that tropical regions display large showy flowers, with less tropical regions display more generalist flowers. A generalist flower as being typically denoted as drab (often green or white), small and inconspicuous (Ollerton, Killick, Lamborn, Watts & Whiston, 2007). In Indonesia Alfred Russel Wallace (1832) described his expectation of tropical climates to be abundant with showy coloured flowers. While on Chatham Island (Galapagos) Charles Darwin (1835 in Brown, 2010; p. 301) wrote that he had only come across a handful of flowers so ugly and insignificant, he felt that they were better suited to occurring in Arctic Circle rather than an equatorial island. These reports by Wallace and Darwin, indicating that flower size may differ as a function of latitude, were never followed up with quantitative empirical study. There is some evidence that latitude may influence size morphology in animals according to Bergmann's rule due to climatic or geological differences (McNab, 1971; Blackburn, Gaston & Loder, 1999); therefore, it is possible that flower size may differ according to geographic location (and/or) latitude.

The Pollinator Potential Paradigm is introduced as a novel potential explanation for insular size patterns of flowers. The hypothesis states that reduced island pollinator diversity results in reduced floral size variation. Considered 'subsets of the mainland' island biotas tend to support less species diversity, and consequently less pollinator diversity, compared to that of the continental landmasses (Olesen & Jordano, 2002; Bellemain & Ricklefs, 2008). Samples often do not reflect the full variation in a population. Therefore, a subset of pollinators from the mainland will most likely represent a reduced variation of pollinator body size. This means that the potential body size range of pollinators on islands is reduced comparative to the mainland. Plants and pollinators are highly co-evolved. Flower size is usually indicative of pollinator type and size (Jordano, 1987; Herrera, 1989; Barrett, 1996; Hu, Dilcher, Jarzen, & Taylor, 2008; Futuyma, 2009). Pollinators can act as selective agents on floral traits (Inoue, *et al.*, 1996). Wallace (1891) demonstrated that islands with low numbers of bee and butterflies also have a low number of big showy flowers. Therefore, reduced island pollinator communities may reduce flower size on islands.

It is possible to theoretically model the Pollinator Potential Paradigm. The foundation of the model is that a group of islands of the same size exists, each increasingly further from the mainland. Each island receives a certain number of potential immigrants from the mainland, with the island closest to the mainland receiving the most, and the furthest island

receiving the least. This could occur through stepping stone dispersal (Yamada, Kodama & Maki, 2014). The mainland population is assumed to have a normal distribution, and islands receive a random subset of this population. The closest island to the mainland receives a greater number of pollinator species and therefore a greater diversity in body size range, while the furthest island receives the least species and consequently, the least diversity in body size range (see Figure 2.1). The concepts and logic of this paradigm appear to be supported by basic mathematical modelling (Burns, pers. comm.)

The paradigm could be applicable to the dataset if the standard deviation of the size range of a given island floral feature is smaller than that of the mainland. There is greatest support for the Island Rule, when the body size range of island pollinators is smaller than the body size range of mainland pollinators. Islands with a smaller subset of the initial population are more likely to have reduced body size range diversity, meaning that potential patterns for the Island Rule are more pronounced. As the body size diversity of an island approaches the body size diversity of the mainland, the distribution of the size range becomes more equal on both axes. Resulting in outcomes that do not follow the Island Rule pattern.

The Pollinator Potential Paradigm has been recognised in part by previous works, in particular Inoue (1990) proposed that low pollinator availability may explain small flowers on the Izu Islands, Japan. Certainly, studies like Olesen & Jordano (2002) found that islands have less diversity of pollinators compared to the mainland. Rather than be explained by evolutionary processes, it is hypothesized here that reduced insular size diversity relative to the mainland may simply be explained by the nature of stochastic chance, and the probability that subsets invariably fail to represent the source population's full diversity.

In this chapter, following the unique opportunity to contribute towards an unsaturated topic I test for the patterns of size range reduction in floral features. The Pollinator Potential Paradigm (as explained here) is one hypothesis which may explain a reduction in size range of floral species. The presence (or absence) of a size change pattern were considered with additional climatic, biological or geographical information. To evaluate evolutionary insular size changes, the following predictions were tested using linear regressions: (1) Flowers of endemic island species will display reduced size diversity compared to their closest mainland relatives (2) Does a pattern occur irrespective of latitude, (3) other factors will not be statistically meaningful in understanding the Island Rule.

Figure 2.1 An illustration of the Pollinator Potential Paradigm.

A) Graphic interpretation of reduced pollinator size diversity on islands, compared to a larger size diversity of pollinators on the mainland

B) Distribution of pollinators from mainland to an island. A group of islands of the same size each increasingly further from the mainland. Each island receives a certain number of potential immigrants from the mainland, with the island closest to the mainland receiving the most, and the furthest island receiving the least.

C) Normal distribution of mainland pollinator body size. Islands receive a random subset of this population.

D) Curve showing the range of body size for a given subsample of mainland pollinators. The closest island to the mainland receives a greater number of pollinator species and therefore a greater body size range, while the furthest island receives the least. Insularity can be expressed as both isolation and geographic size. Large islands are statistically similar to close islands, just, as far islands are to small ones.

Methods

Study site

New Zealand was used as a central ‘mainland’ feature, and only islands within 1800km of the coast were included. The islands contained in this geographical area were identified as having species that most likely originated from New Zealand. New Zealand (and the islands around it) have a long history of geological isolation. New Zealand and its islands isolated from Gondwana about 80 million years ago. Lord Howe, Norfolk and Macquarie islands are 7 million, 2.5 million and 300,000 years old respectively, having arisen through undersea volcanic activity. Terrestrial taxa arriving to islands all had to disperse overwater. However, land bridges may have connected some of the smaller islands around New Zealand and aided in species dispersal (Diamond, 1984; Waters & Craw, 2006). The islands considered for this study included; Antipodes, Auckland, Bounty, Campbell, Chatham, Kermadec, Lord Howe, Macquarie, Norfolk, Snares, Stewart and the Three Kings (see Figure 2.2).

Species Selection

Determination of endemic Island plant species

A phylogenetic comparative method was undertaken in order to assess the evolutionary hypothesis of a reduction in insular size variation. In order to compare deep evolutionary time, extant island endemics were compared to their closest extant mainland relative. Checklists were compiled for all insular endemic plant species known to exist on the 12 Island groups. (See Table 2.1 below and appendices for lists, species pairs and references).

Determination of closest mainland relative

Closest mainland sister taxa were identified through molecular phylogenies where they were most closely related to a ‘checklist’ endemic species. Only information from phylogenies that gave rise to one closest mainland relative were used, creating ‘species pairs’, all other phylogenies were unusable (refer to Figure A1 (Appendix A) for examples of suitable and unsuitable phylogenies). Of a potential dataset of 274 endemic plant species, 148 were included in molecular phylogenies. However, of that only 65 of those studies (from 9 islands) produced results that allowed them to be included in the study (refer to table 2.1). For the purposes of this study, it is assumed that the relevant phylogenies collected do not display issues of non-independence between different species (i.e. the true patterns of relatedness are represented in the phylogeny). Further research undertaking phylogenetically independent contrast analysis, could account for any issues of non-independence in phylogenies.

Figure 2.2 Map of islands around New Zealand included in this study.

Table 2.1 The breakdown of species representation from identified islands of interest

Island Group	Number of endemic vascular plant taxa	Number of taxa with phylogeny (usable phylogenies resulting in 1 mainland relative)	Island taxa list reference(s)
Antipodes	5	1 (1)	Dosley (1989), New Zealand Plant Conservation Network (NZCPN) (2018), Rance (2018)
Auckland	10	5 (2)	NZCPN (2018), Phillips (2012), Rance (2018)
Bounty	1	1 (0)	Rance (2018)
Campbell	6	1 (1)	NZCPN (2018) Rance (2018)
Chatham	40	35 (17)	de Lange (2013), Heenan et al. (2012), NZCPN (2018)
Kermadec	25	14 (9)	Nathan (2012), NZPCN (2012)
Lord Howe	109	60 (21)	Department of Environment and Climate Change (NSW) (2007). NZCPN (2018)
Macquarie	4	3 (0)	de Lange et al. (2005), NZPCN (2018) Flora of Australia (1994)
Norfolk	41	16 (11)	NZCPN (2018), Rance (2018)
Snares	2	1 (0)	NZCPN (2018)
Stewart	14	3 (1)	NZCPN (2018)
Three Kings	17	8 (2)	NZCPN (2018), Wright (1982)
OVERALL	274	148 (65)	

Collection of morphological measurements

Data only included measurements from adult specimens, (i.e. mature reproductive individuals). Trait measurements primarily came from literature or herbaria specimen measurements (see list of sources in Appendix A). This was appropriate for most cases. For some species, relevant data was printed in non-English languages; if this was easily translatable, then this data was used. Morphological features considered for this study included floral features (average flower area, average petal area, average sepal area, maximum inflorescence length, maximum filament length, maximum anther length, and maximum pedicel length). Further detail on each morphological feature for how it is specifically defined and measured can be found under the ‘floral measurement’ heading, Box 2.1. These features were selected primarily as they were the floral traits most commonly reported on. Some traits (such as petal size) are obviously related to pollinator attraction and interaction. However, other features, such as sepal area or pedicel length can also impact pollination potential (big sepals or a small pedicel, may result in obscuring the flower). Testing of multiple traits ensures that results are not bias by one trait.

Where trait measurements were not published, herbaria presses were referred to. In particular, specimens were measured at Auckland War Memorial Museum (AK) and Te Papa (WELT) herbariums. In cases where access to digital herbarium specimens were required, dried measurements could be measured using the image software *Image J*. A minimum of five measurements for each morphological feature was required for each specimen that was measured from herbarium presses. Measurements came from all available structures on herbaria sheets, and as many independent individual plants as possible. There was a preference for physical measurements from herbaria specimens, rather than online (again refer to Appendix A to see which measurements these were).

Each of the trait data sets contained a mixture of herbarium measured and floristic literature derived species pairs. Species pairs themselves reflected only one measurement type. Datasets of both herbaria based and flora based measurements have been proven to not cause statistically significant issues (Kavanagh 2015; Cox & Burns 2017). Regardless, the source of measurement origin was considered as a random factor for linear mixed models (see Appendix B for source of measurement references). For some flora it is unclear if the measurements come from fresh or dried specimens, it is assumed that flora are compatible and follow similar rigorous standards in order to provide a true representation of the morphology of plants.

Floral measurements

All angiosperms were considered that had perfect hermaphroditic flowers, additionally species exhibiting imperfect flowers (i.e. monoecious or dioecious) were included where the measurements for both functional male and functional female flowers could be collectively averaged.

Floral measurement definitions

BOX2.1***Flower area***

Average flower area was measured as flower length (length from pedicel attachment to the tip of the petals) x flower width (maximum distance perpendicular to the length measurement at the widest point of the flower). The island-mainland species pair sample size for flower area was $n = 35$.

Inflorescence length

Maximum inflorescence length was measured as maximum length from point of attachment to the rest of the plant to the tip of the inflorescence. The sample size inflorescence length was $n = 24$.

Petal area

Average petal area was measured as the average length (length from attachment to the base of the flower unit to the tip of the petals) x average petal width (maximum distance perpendicular to the length measurement at the widest point of the petal). The sample size for petal area was $n = 34$.

Sepal area

Average sepal area was measured as average length (length from attachment to the plant to the tip of the sepal) x average sepal width (maximum distance perpendicular to the length measurement at the widest point of the sepal). The sample size for sepal area was $n = 34$.

Filament length

Maximum filament length was the total length of the filament from point of attachment to the flower unit, to the base of the filament. The sample size for filament length was $n = 25$.

Anther length

Maximum Anther length was measured as (total length from attachment to filament to the tip of the anther). The sample size for anther length was $n = 26$.

Pedicel length

Maximum pedicel length was the total length of the pedicel from point of attachment, to the point of attachment to the flower. The sample size pedicel length was $n = 35$.

Statistical Methodology

The sample size of a given plant trait (e.g. flower area) is a subset of the 65 available species depending on 1). If the species meets the given criteria for the measurement (as previously outlined and 2). If measurements for both the insular and mainland relative were obtainable. This means that the sample number of species in each analysis varies. All measurements were natural-logged before analysis (with the exception of latitude values – see below).

Analysis of the data generally followed the procedure of Lomolino (2005). Statistical comparisons between the island and mainland groups used the lme4, lmodel2 and car packages in the R environment (R Core Team 2013). Nine islands encompassing a ~16,000 kilometre area of the South Pacific are represented across ten datasets. Each of these differently sized islands have their own unique climatic and biological factors that could all potentially influence certain morphological features in plants. Such factors were integrated in different mixed model approaches.

Morphological size divergence (S_i) was expressed as the trait measurement of an insular species divided by that of its genetically closest mainland relative's corresponding trait value. Lomolino (2005) outlines that this is a useful measurement for visualisation of the data for gigantism and dwarfism. This 'ratio' data was analysed through model 1 linear regression. Further, insular and mainland species traits were analysed through model 2 linear regression. This method avoids the potential repercussions of the S_i ratio method, which may include "possible statistical problems and artefacts associated with regressions using ratios" (Lomolino 2005). Evidence supporting the presence of the Island Rule exists if the Model 2 regression trend for a trait results in an intercept >0 and a gradient <1 .

Linear Regressions

Model 1 linear regression was undertaken on S_i ratio data, with a general formula of:

$$lm(y \sim x)$$

This formula is the basis for further linear mixed models to come. Here x variable was always mainland values, while y value was either Island values or S_i ratio values. T values, P values and R^2 values were extracted using this method.

Model 2 regressions were conducted on the island vs. mainland data with a formula of:

$$lmodel2(y \sim x)$$

This model is suitable, because island species vary as a function of mainland species (islands represent a subset of the mainland). This formula computed OSL (Ordinary Least Squares values). The results of this test gives an R value as well as a slope and intercept value for the trend of the data, along with the 95% confidence intervals for these measurements. This allows the data trend to be statistically compared to the line of isometry (the line where island values = mainland values).

Testing of additional biological, climatic or geographical factors

Statistical analysis was also run to examine if latitude or additional factors influenced insular floral size variation. These factors are described below in table 2.2.

Table 2.2 Biological, Climatic and geographical factors considered in analysis

Factor	Description
latitude	Presented as a converted decimal degree value. Latitude measurements were taken from the centre of each island mass, as an 'average island value' (see table 2.3 for latitude reading and Figure 2.2 for a visual refresher).
island	The island of origin for an insular endemic species. Any large discrepancies as a result of island may indicate environmental differences.
measure	Where the measurements came from. Either herbaria or a floral description. In order to be statistically relevant each trait had to have at least six examples of factors where the outcome was binary (e.g. measurement type is either herbaria or flora based).
endemic	The total number of endemic plant species in total from the given island of occurrence
order	The total number of endemic plant species within the same taxonomic order from the same island of occurrence
type	The generic type of plant (e.g. shrub, tree, herb)
Orderz	The taxonomic order of a plant. This factor indicates if there are tendencies of the lineage to display certain characteristics, regardless of the plant positioning in the landscape
rainfall	Annual average rainfall of the island (measured in mm)
temp	Annual average temperature of the island (measured in Celsius)
wind	Annual average wind speed (km/hr)
size	Size of the island (measured in km ²)

Latitude readings are made up of three parts (degrees, minutes, seconds), with the latter two being broken into 60 piece segments. To ensure that the graphics and statistical operations would interpret these values correctly, the distance for minutes was converted into tenths ($[\text{minute value}/60] \times 10$), and seconds were omitted. E.g. for the Antipodes (49°41'11"), the degrees stay the same, the minutes are converted and the seconds are omitted, ($41/60 = 0.68$,

0.68 x 10 = 68), to a corresponding decimal degree of 49.68. Analyses used Model 1 linear regression, with a similar basic formula as for Si ratios with a formula of: $lm(Si\ ratio \sim factor)$.

Table 2.3 Island latitude values

Group	Latitude value	Decimal degrees
Antipodes	49°41'11"S	49.68
Auckland	50°42'05"S	50.70
Campbell	52°32'09"S	52.53
Chatham	43°55'42"S	43.92
Kermadecs	29°15'53"S	29.25
Lord Howe	31°32'26"S	32.53
Norfolk	29°02'12"S	29.03
Stewart	46°57'51"S	46.95
Three Kings	34°09'42"S	34.15

Results

Analysis of Island Rule trend in floral features

Table 2.4 Specific statistical results table for each of the 3 indicator methods of statistical significance in different floral features.

Morphological feature	Model 1				Model 2			
	t value	P value	slope	slope 95% confidence interval	t value	P value	slope	slope 95% confidence interval
Flower area	-3.42	1.7e ⁻³ *	-0.39	-0.63 to -0.16	5.02	8.8e ⁻⁶ *	0.58	0.36 to 0.82
Inflorescence length	-4.25	4e ⁻⁴ *	-0.69	-1.04 to -0.35	1.78	0.04*	0.29	-0.05 to 0.63
Petal area	-5.19	1.1e ⁻⁵ *	-0.53	-0.74 to -0.32	4.56	3.6e ⁻⁵ *	0.47	0.26 to 0.68
Sepal area	-5.65	3.4e ⁻⁶ *	-0.69	-0.94 to -0.49	2.49	0.009*	0.31	0.06 to 0.56
Filament length	-2.9	8.1e ⁻³ *	-0.31	-0.53 to -0.09	6.5	5.7e ⁻⁷ *	0.69	0.47 to 0.91
Anther length	-3.32	0.003*	-0.57	-0.93 to -0.22	2.47	0.01*	0.43	0.07 to 0.78
Pedicel length	-3.41	1.7e ⁻³ *	-0.40	-0.64 to -0.16	5.05	8.8e ⁻⁶ *	0.59	-0.44 to 0.22

Analyses of floral measurements in vascular plants yielded consistent results. Regression results indicate that regardless of the regression models used, trends for each trait tested are consistent with that predicted by the Island Rule; i.e. a pattern from insular gigantism toward dwarfism as the mainland species size increased (with all 7 floral traits being consistent with the rule, significant at the 0.05 level; table 2.4). All floral feature slopes differed from a gradient 1 for Model 0 analysis, when considering the 95% confidence level for the slope. While in a similar fashion, floral feature slopes differed from a gradient 1 for Model 2 analysis, when considering the 95% confidence level for the slope.

Analysis of Island Rule trend in plants across additional biological, climatic or geographical factors

No observable pattern was recorded for six of the eleven factors in any of the floral features at the 0.05 level (measure, endemic, order, type, Orderz and temp). For these factors the null hypothesis cannot be rejected, indicating that the size of insular floral features are not impacted by any of the five mentioned factors. Statistical correlation for some traits were observed against the five remaining factors; latitude, island, rainfall, wind and size. Statistical outcomes for the analysis of Island Rule in plants across all factors considered can be found in Appendix B.

Analysis comparing latitude generally described no observable pattern in any of the floral features, except for inflorescence length, which did. Six of the seven floral features were not significant at the 0.05 level. For these six features the pattern of the Island Rule occurring on the islands seems to be independent of island latitude. For these six remaining features the null hypothesis cannot be rejected, meaning that there is no indication that floral features are impacted by latitude (see Appendix B). This indicates that the pattern of reduced insular size may act independently of latitude. Statistical significance indicating a correlation between latitude and maximum Inflorescence length was present at the 0.05 level (p value, 0.02). Statistical outcomes for the analysis of Island Rule in plants across latitudes can be found in Appendix B. It is worth noting that Lomolino (2005), states that statistics with ratios should be done cautiously (specifically with this application), as they may produce results that can be difficult to disentangle, given their statistical nature.

Statistical significance (at the 0.05 level) indicated a correlation between the factor island and three of the floral traits. These features were petal area, Inflorescence length, and flower size (p values, 0.02, 0.03 and 0.01 respectively). Statistics were replicated with the removal of islands which only had 1 representative. The replicated statistics showed no statistical significance for any of the traits (at the 0.05 level).

Statistical significance (at the 0.05 level) indicated a correlation between the factor size and three of the floral traits. These features were petal area, pedicel length and inflorescence length (p values of 0.01, 0.02 and 0.01 respectively). This was a positive correlation, for petal size and inflorescence length, with the greater the size of the island of origin, the greater the

average size of the floral feature. There was a negative correlation, for pedicel length, with the greater the size of the island of origin, and smaller the maximum pedicel length.

Statistical significance (at the 0.05 level) indicated a correlation between the factor rainfall and maximum inflorescence length and average flower size (p values of 0.04 and 0.03 respectively). This was a negative correlation with the greater the average annual rainfall, the smaller the average size of the floral feature.

Statistical significance (at the 0.05 level) indicated a correlation between the factor wind and two of the floral traits. These features were petal area and flower size (p values of 0.01 and 0.003 respectively). This was a negative correlation with the greater the average annual wind speed, the smaller the average size of the floral feature.

Figure 2.3 Flower area comparison of Island versus mainland. A) Comparing Si against Mainland average flower area. $R^2 = 0.26$. B) Comparing Island against Mainland average flower area. $R = 0.66$. Dashed line (Line of Isometry) is the plane at which Island values equal mainland values. (Both axes are natural logged)

Figure 2.4 Inflorescence length comparison of Island versus mainland. A) Comparing Si against Mainland maximum inflorescence length. $R^2 = 0.44$. B) Comparing Island against Mainland maximum inflorescence length. $R = 0.35$. Dashed line (Line of Isometry) is the plane at which Island values equal mainland values. (Both axes are natural logged)

Figure 2.5 Petal area comparison of Island versus mainland. A) Comparing Si petal area against Mainland average petal area. $R^2 = 0.46$. B) Comparing Island against Mainland average petal area. $R^2 = 0.63$. Dashed line (Line of Isometry) is the plane at which Island values equal mainland values. (Both axes are natural logged)

Figure 2.6 Sepal area comparison of Island versus mainland. A) Comparing Si average sepal area against Mainland average sepal area. $R^2 = 0.49$. B) Comparing Island against Mainland average sepal area. $R = 0.40$. Dashed line (Line of Isometry) is the plane at which Island values equal mainland values. (Both axes are natural logged)

Figure 2.7 Filament length comparison of Island versus mainland. A) Comparing Si filament length against mainland maximum filament length. $R^2 = 0.27$. B) Comparing Si filament length against mainland maximum filament length. $R = 0.81$. Dashed line (Line of Isometry) is the plane at which Island values equal mainland values. (Both axes are natural logged)

Figure 2.8 Anther length comparison of Island versus mainland. A) Comparing Si anther length against mainland maximum anther length. $R^2 = 0.31$. B) Comparing Si anther length against mainland maximum anther length. $R = 0.45$. Dashed line (Line of Isometry) is the plane at which Island values equal mainland values. (Both axes are natural logged)

Figure 2.9 Pedicel length comparison of Island versus mainland. A) Comparing Si pedicel length against mainland maximum pedicel length. $R^2 = 0.26$. B) Comparing Si pedicel length against mainland maximum pedicel length. $R^2 = 0.66$. Dashed line (Line of Isometry) is the plane at which Island values equal mainland values. (Both axes are natural logged)

Discussion

The presence of the Island Rule in seven floral traits was observed (flower area, inflorescence length, petal area, sepal area, filament length, anther length and pedicel length). There was a pattern of island dwarfism (compared to large mainland counterparts) to gigantism (compared to small mainland counterparts). Evidence of insular size range reduction was clear, thereby supporting the Island Rule. Island trait size reduction occurred irrespective of latitude. Evidence for size range reduction in insular traits occurred across multiple trait analyses. This is the first empirical evidence for the pattern of size diversity reduction in floral features.

Processes acting to reduce floral trait size range

Flower size tends to vary as a function of pollinator type and size (Jordano, 1987; Herrera, 1989; Barrett, 1996; Hu *et al.*, 2008; Futuyma, 2009). Pollinators can act as selective agents on floral traits (Inoue *et al.*, 1996). Low numbers of large ‘showy’ flowers are correlated with low bee and butterfly numbers (Wallace, 1891). A small sample will never express the full variation of the mainland, due to statistical chance. Therefore, a reduction in floral size range may be explained by a reduction in the body size range of mainland pollinators to an island. This processes coined ‘the Pollinator Potential Paradigm’ provides a clear rational explanation, hypothesizing the link between reduced insular pollinator size and reduced insular floral size, and explaining floral size changes on islands.

Individuals migrating to an island still undergo natural selection, even before size trait differences between the mainland and the island are observable. The pattern of the Island Rule is inferred to reflect dissimilarities in selective pressures on islands (Lomolino, Sax, Riddle & Brown, 2006). Factors influencing natural selection can be either biological or climatic in nature. Insular animal species can be impacted by resource limitation, or relaxation from predations (Palkovacs, 2003; Lomolino, 2005). Evolutionary processes that directly impact animals do not necessarily directly impact plants. However, as flower size is intrinsically linked with insular pollinator body size, so factors impacting pollinators may indirectly impact plants. With this connection, factors that currently are considered ‘animal specific’, may be indirectly ‘plant specific’ too. Features such as predation from carnivores, or social animal interactions, which have not classically be linked with plants, may in fact offer new insight into plant evolutionary pathways.

Possibly confounding effects of trait allometry

All floral traits demonstrated similar graph morphologies as seen in Figures 2.3 to 2.9. If it is assumed that each species is responsible for a similar point in each graph morphology, then traits would appear linked. Plant features have displayed a tendency to have features that are correlated with one another (Corner, 1949; Niklas, 1994; Westoby & Wright, 2003; Sun *et al.*, 2006; Enquist, Tiffney & Niklas 2007). In particular, these studies have focused on the connectedness of traits such as plant stature, twig and leaf size, and stature. Further evidence suggests that seed size is correlated with stature (Kavanagh & Burns, 2014; Cox & Burns, 2017). This is relevant to size changes of floral features as it raises questions for future research into the allometry of insular plant reproductive traits. Flowers are the structures that form seeds. A noticeable tendency for insular seeds to display gigantism (Kavanagh & Burns, 2014 and Cox & Burns, 2017), should be logically correlated to a tendency for larger floral features. Further research on the topic may explain if floral features (including additional traits such as ovary size, or number of ovules) display allometric relationships with other traits like seed size. However, studies have indicated that in some instances allometry has failed to be supported among different traits (Kavanagh & Burns, 2014; Burns, 2016a; Cox & Burns, 2017). Therefore while traits would be expected to demonstrate allometric correlations, this is not necessarily the case. Further research into this area will provide a better understanding of evolutionary size changes, and the intricacies of trait interaction.

The impact of additional factors

Of the seven floral traits, latitude only marginally impacts inflorescence length. This indicates that for these six remaining traits, the patterns are robust and exist irrespective of locality. While latitude seems to correlate with inflorescence length, a similar correlation exists for the island of origin. However, there was overlap between island standard error, and island groups were poorly represented, island of origin does not explain the size ratio of Inflorescence length. This indicates that the size change pattern which seems to exist for inflorescence length occurs due to a latitudinal gradient, more so than archipelago specific changes. When inflorescence length was considered against latitude, species on islands closer to Antarctica displayed bigger maximum inflorescence length, and species closer to the tropics displayed smaller maximum inflorescence length. These findings are consistent with Bergman's Rule (the animal based theory that latitude influences body size, with smaller species being found in warm tropical regions, and larger bodied species occurring in colder, polar areas (Niering, Whittaker & Lowe,

1963; Drezner, 2003). A previous study by Niering *et al.* (1963) found that *Carnegiea gigantea* seemed to display this “botanical Bergmann trend”. However, critics of this study specify that this pattern depended more on rainfall (winter precipitation) over latitude associated temperature (Drezner, 2003). There are multiple additional factors closely correlated with latitude which may explain size variation across the landscape (Mosquin, 1971; Shahjahan *et al.*, 1987; Fitter, Fitter, Harris & Williamson, 1995; Yu, Luedeling & Xu, 2010; Schleuning *et al.*, 2012). While this study has provided evidence of a pattern, further research is required in order to better understand the processes acting to reduce island size diversity.

Of the seven floral traits, the size of the island of origin was correlated to three of the seven floral traits (maximum Inflorescence length, maximum pedicel size and average petal size). This indicates that for the remaining four traits, the patterns are robust and exist irrespective of locality. It is well known that bigger islands can support a greater abundance of species (Kohn & Walsh, 1994). In addition, a larger island allows for species to be bigger (relative to smaller islands). A larger island (with more pollinators) may impact average petal size and maximum inflorescence length, as larger visual cues may result in higher rates of pollination. Larger visual cues may be selected by animal pollinators, as they stand out against other smaller individuals. Remarkably, the size pattern attributed to maximum pedicel length is the opposite of the other two traits mentioned above. The length of the pedicel dictates the distance at which the flower is held from the rest of the plant, and may indicate the plants preferred pollination pathway. Pedicel length may reflect instances of low pollinator frequency (such as smaller sized islands). Previous studies have found that a statistical significant difference in the length of pedicel in female compared to hermaphroditic flowers (Weller, Sakai, Culley, Campbell & Dunbar-Wallis, 2006). A long pedicel would be advantageous for wind pollination, either through self-pollination or cross-pollination. In addition, a smaller pedicel with a larger flower, may reduce any damage to the pedicel during animal pollination compared to a large flower with a large pedicel.

The average annual wind speed was correlated to two of the seven floral traits (average petal size, and average flower size). This indicates that for the remaining five traits, the patterns exist irrespective of wind speed. Wind pollination is important in pollinator limited environments (Culley, Weller & Sakai, 2002). Plant reliance on pollinators may decrease, as wind increases, as plants may be aided in wind-facilitated selfing, or variable outcrossing via

wind pollination. The impact of wind on a plant can range from microscopic damage to regional-level successional change (Gardiner, Berry & Moulia, 2016). Therefore, it is possible that the negative correlation of size of floral traits to annual average wind speed, may be attributed to the rate of physical damage. With windier places resulting in higher rates of damage, meaning smaller floral traits (such as petal size and inflorescence length) are selectively represented in future generations.

Annual average rainfall was correlated to two of the seven floral traits (maximum Inflorescence length, and average flower size). This indicates that for the remaining five traits, patterns exist irrespective of precipitation. There was no indication that the annual average temperature of an island impacted the size of endemic floral features relative to their closest mainland relative. This finding is consistent with Drezner (2003), who found that size patterns of plants seem to relate more closely to rainfall than to temperature. High rainfall leads to increased erosion, and nutrient loss. Flowers can be energetically expensive for plants (Vasconcelos & Proenca, 2015). A negative correlation to high rainfall, may reflect this energetic relationship, indicating that smaller flowers and inflorescences are selected for in higher rainfall environments. Rainfall related damage to crops is increasing with climate change (Rosenzweig, Tubrello, Goldberg, Mills & Bloomfield, 2002). Physical damage from rainfall events would be reduced for smaller flowers and inflorescences (compared to larger flowers and inflorescences). Which may explain the negative correlation between flower and inflorescence size versus annual average rainfall. It is possible that smaller flowers last longer than larger flowers, although, further research is required to prove this. Rainfall could limit insect pollinator availability, meaning that smaller flowers result in a higher chance of pollination, especially during long rainfall events.

Closing remarks

Understanding evolution is topical, as a changing environment will mean changing climatic processes. If plants do respond to climatic processes in the ways I have found, then it may be useful information for understanding how plants will respond in the future. These findings, and research in this area, may expose how plant lineages behave, and may be useful for future development in the horticulture, or agricultural trades.

Chapter 3: Vegetative features

Introduction

There are a number of studies irrespective of the Island Rule that consider insular size changes in vegetative features. An aspect of the theory that seems to captivate naturalists and scientists alike is the ‘the weeds to tree phenomenon’, otherwise referred to as secondary insular woodiness or arborescence. Charles Darwin (1859) postulated that due to the competitive nature of island settings, an insular herb (when competing with herbaceous plants alone) might gain an advantage by growing taller. Further study by Carlquist 1974 suggested that secondary woodiness may be the result of relaxed herbivory (relative to the mainland). Alternative explanations for insular woodiness include adaptation for drought resistance (Lens *et al.* 2013).

However, size changes on islands are not solely linked to insular woodiness. Further research found evidence of insular size changes occurring in the absence of woodiness (Dawson 1988; Carlquist 1980; Burns 2016a; Cox & Burns 2017). Specific examples include larger insular leaf size and stature (Cox and Burns 2017). In a similar fashion ‘Megaherbs’ (large herbaceous plants) can be repeatedly found on many of the sub-Antarctic Islands (Wagstaff, Breitwieser & Ito, 2011). Such patterns were found to vary depending on the growth form of the species pair, with graminoids tending towards dwarfism, woody plants showing slight gigantism and herbaceous plants showing significant gigantism (Cox and Burns 2017). Meanwhile, Bowen & Vuren (1997) found that island endemic plants displayed increased leaf size, but not increased woodiness compared to mainland plants. While a consistent pattern, it is unclear why gigantism may be advantageous to insular plants who do not exhibit woodiness (Dawson 1988).

Another common topic of insular size investigation is changes in leaf size. Tsukaya *et al.* (2007) found that island plants may exhibit significant variation in leaf shape. There is strong evidence for insular leaf gigantism (Cox and Burns, 2017), in particular insular populations of New Zealand’s North Coast have demonstrated larger leaves than their relative mainland populations (Beever 1989; Burns *et al.* 2012). Morphological changes to plants may also result in dwarfism, in particular smaller leaf size is known to minimize herbivory (Hanley, Lamont, Fairbanks & Rafferty, 2007). Insular species displaying larger leaves may reflect relaxed herbivory selection (Burns 2016a; Burns 2016b), while alternately, smaller leaves may reflect

recent immigration events to islands (Cox and Burns, 2017). Leaf size may also reflect other climatic factors associated with island. Louw (2016) found that leaf area was larger at lower altitudes, a similar finding to Huntley (1971, as cited in Bakker *et al.* 1971). While Westoby & Wright (2003) found that areas with higher rainfall tended to have larger leaves, while areas with less rainfall had smaller leaves.

In this chapter, following the unique opportunity to contribute towards a largely unsaturated field, I test for patterns of the Island Rule in vegetative features. The purpose is to better understand the applicability of the Island Rule across different plant taxa, especially as historically studies have neglected such theory application on plants. Further objectives were to understand if the presence (or absence) of a size change pattern could be attributed to latitude, or climatic, biological or geographic factors. To evaluate evolutionary insular size changes, the following predictions were tested using linear regressions and mixed models: (1) if there is a common size change trend among insular species, (2) that any pattern occurs irrespective of latitude, (3) other factors will not be statistically meaningful in understanding the Island Rule.

Methods

Study site

New Zealand was used as a central feature, and only islands within 1800km of the coast were included. The islands contained in this geographical area were identified as having species that most likely originated from New Zealand. New Zealand (and the islands around it) have a long history of geological isolation. New Zealand and its islands isolated from Gondwana about 80 million years ago. Lord Howe, Norfolk and Macquarie islands are 7 million, 2.5 million and 300,000 years old respectively, having arisen through undersea volcanic activity. Terrestrial taxa arriving to islands all had to disperse overwater. However, land bridges may have connected some of the smaller islands around New Zealand and aided in species dispersal abilities (Diamond, 1984; Waters & Craw, 2006). The islands considered for this study included; Antipodes, Auckland, Bounty, Campbell, Chatham, Kermadec, Lord Howe, Macquarie, Norfolk, Snares, Stewart and the Three Kings (see Figure 2.2).

Species Selection

Determination of endemic Island plant species

A phylogenetic comparative method was undertaken in order to assess the evolutionary hypothesis of a reduction in insular size variation. In order to compare deep evolutionary time, extant island endemics were compared to their closest extant mainland relative. Checklists were compiled for all insular endemic plant species known to exist on the 12 Island groups. (See Table 2.1 below and appendices for lists, species pairs and references).

Determination of closest mainland relative

Closest mainland sister taxa were identified through molecular phylogenies where they were most closely related to a 'checklist' endemic species. Only information from phylogenies that gave rise to one closest mainland relative were used, creating 'species pairs', all other phylogenies were unusable (refer to Figure A1 (Appendix A) for examples of suitable and unsuitable phylogenies). Of a potential 275 endemic plant species, 145 were included in molecular phylogenies, however of that only 65 of those studies (from 9 islands) produced results that allowed them to be included in the study (refer to table 2.1). For the purposes of this study, it is assumed that the relevant phylogenies collected do not display issues of non-independence between different species. To overcome this, further research should undertake phylogenetically independent contrast analysis.

Collection of morphological measurements

Data only included measurements from adult specimens, (i.e. mature reproductive individuals). Trait measurements primarily came from scientific field notes, field guidebooks or literature (see list of sources in Appendix A). This was appropriate for most cases. For some species relevant data was printed in non-English languages; if this was easily translatable, then this data was used. Morphological features considered for this study included vegetative features (Maximum plant stature, average leaf blade area and maximum petiole length). Further detail on each morphological feature for how it is specifically defined and measured can be found under the 'vegetative measurement' heading, Box 3.1.

Where trait measurements were not published, herbaria presses were referred to. In particular, specimens were measured at Auckland War Memorial Museum and Te Papa herbariums. In cases where access to digital herbarium specimens were required, dried measurements could be measured using the image software *Image J*. A minimum of five

measurements for each morphological feature was required for each specimen that was measured from herbarium presses. Measurements came from all available structures on herbaria sheets, and as many independent individual plants as possible. There was a preference for physical measurements from herbaria specimens, rather than online (again refer to Appendix A to see which measurements these were).

Each of the trait data sets contained a mixture of herbarium measured and flora or literature derived species pairs. Species pairs themselves reflected only one measurement type. Datasets of both herbaria based and flora based measurements have been proven to not cause statistically significant issues (Kavanagh 2015; Cox & Burns 2017). Regardless, the source of measurement origin was considered as a random factor for linear mixed models (see Appendix B for source of measurement references). For some flora it is unclear if the measurements come from fresh or dried specimens, it is assumed that flora are compatible and follow similar rigorous standards in order to provide a true representation of the morphology of plants.

Vegetative measurements

Vegetative feature data was collected from floral descriptions, online and physical herbarium specimens and included three morphological traits. They were categorised into three distinct groups (1) Maximum plant stature, (2) average leaf blade area and (3) maximum petiole length. (See Appendix C for list of species included in each). They were defined and measured as seen in Box 3.1

Vegetation measurement definitions

BOX3.1

Stature

Maximum plant stature is the total height in meters of the specimen measurement differed depending on plant types. For ferns this was measured as the length between ground and the tip of the longest frond. For orchids it was measured as the length between the base of the individual and the uppermost extension of leaves. For other plants such as herbs, shrubs or trees this was measured as the length from ground level to the highest point of the uppermost leaf. Stature Sample size was n= 54

Leaf area

Leaf area was used as a term that included lamina, and blade measurements from angiosperms, ferns, palms and grasses. Average leaf area is equal to leaf blade length x leaf width. Leaf blade length is measured from the tip of the blade down to where the petiole and blade meet. Leaf blade width is defined as the widest measurement across the blade. Leaf blade Sample size was n= 56

Petiole length

Maximum petiole length was used as a term that included petiole measurements from angiosperms and palms, as well as rachis measurements in ferns. Both the petiole and rachis are analogous structures, as they dictate the distance that the leaf blade is form the main body of the plant. Maximum petiole length is the total length of the petiole from point of attachment, to the start of the leaf blade. Petiole Sample size was n= 32.

Statistical Methodology

The sample size of a given plant trait (e.g. leaf size) is a subset of the 65 available species depending on 1). If the species meets the given criteria for the measurement (as previously outlined and 2). If measurements for both the insular and mainland relative were obtainable. This means that the sample number of species in each analysis varies. All measurements were natural-logged before analysis (aside from latitude values – see below).

Analysis of the data generally followed procedure of Lomolino (2005). Any indication of visual outliers were tested using Cook's distance. Any point with a distance >0.3 from the mean was removed from the data (this only occurred for one data point in the Stature data set) Tests with

outlier can be viewed in Appendix C. Statistical comparisons between the island and mainland groups used the lme4, lmodel2 and car packages in the R environment (R Core Team 2013). Nine islands encompassing a ~16,000 kilometre area of the South Pacific are represented across ten datasets. Each of these differently sized islands have their own unique climatic and biological factors that could all potentially influence certain morphological features in plants. Such factors were integrated in different mixed model approaches.

Morphological size divergence (S_i) was expressed the trait measurement of an insular species divided by that of its genetically closest mainland relative's corresponding trait value. Lomolino (2005) outlines that this is a useful measurement for visualisation of the data for gigantism and dwarfism. This 'ratio' data was analysed through model 1 linear regression. Further, insular and mainland species traits were analysed through model 2 linear regression. This method avoids the potential repercussions of the S_i ratio method, which may include "possible statistical problems and artefacts associated with regressions using ratios" (Lomolino 2005). Evidence supporting the presence of the Island Rule exists if the Model 2 regression trend for a trait results in an intercept >0 and a gradient <1 .

Linear Regressions

Model 1 linear regression was undertaken on S_i ratio data, with a general formula of: $lm(y \sim x)$. This formula is the basis for further linear mixed models to come. Here x variable was always mainland values, while y value was either Island values or S_i ratio values. T values, P values and R^2 values were extracted using this method.

Model 2 regressions were conducted on the island vs. mainland data with a formula of: $lmodel2(y \sim x)$. This model is suitable, because island species vary as a function of mainland species (islands represent a subset of the mainland). This formula computed OLS (Ordinary Least Squares values). The results of this test gives an R value as well as a slope and intercept value for the trend of the data, along with the 95% confidence intervals for these measurements. This allows the data trend to be statistically compared to the line of isometry (the line where island values = mainland values).

Testing of additional biological, climatic and geographical factors

Statistical analysis was also run to see if an island's latitude or additional factors influenced plant size variation. These factors are described in Table 2.2. In addition Chapter 2 explains how latitude 'decimal degrees' work worked out, and Table 2.3 presented these adjusted values.

Results

Analysis of Island Rule trend in vegetative features

Analyses of vegetative measurements in vascular plants yielded results that were consistent with floral features. Regression results indicate that regardless of the models used, trends are consistently in line with the Island Rule; i.e. a graded trade from gigantism toward dwarfism as the mainland species size increased, with all 3 vegetative traits being consistent with the rule significant at the 0.05 level regardless of the statistical regression model table 3.1]. All vegetative features do not have an intercept of zero. The majority of the 95% confidence intervals for intercept do not include 0, however 1 (petiole length) does. Of the 3 features, only 1 (petiole length) contains a negative value within the 95% confidence interval for intercept, this may be a reflection of more instances of dwarfism or a no change in smaller species relative to the gigantism or no change in larger species

Analysis of Island Rule trend in plants across multiple factors

No correlations between any of the vegetative traits were found when compared to eight of the additional factors (latitude, island, measure, endemic, order, type, Orderz or temp). For these instances where correlation is not found to be significant, the Island Rule clearly occurs irrespective of factors. In these instances, the null hypothesis cannot be rejected, meaning that there is no indication that vegetative features are impacted by these factors (see Appendix C for test statistics). There was no statistics support (at the 0.05 level) for correlation of the remaining three factors and the insular size change of either leaf area or petiole length. However, significant correlation (at the 0.05 level) was found for three factors (rainfall, wind and size) against the island ratio of maximum stature (p values of $5.35e^{-6}$, 0.0008 and 0.02 respectively). There was a negative size correlation of stature with average annual rainfall and average annual wind speed. There was a positive correlation between the size correlation of stature and the size of the island of origin.

Table 3.1. Specific statistical results table for each of the 3 indicator methods of statistical significance in different vegetative features.

	Model 1				Model 2			
	t value	p value	Slope	Slope 95% confidence level	t value	p value	Slope	Slope 95% confidence level
Maximum stature	-4.52	$3.70e^{-5} *$	-0.24	-0.35 to -0.12	12.48	$2.01e^{-17} *$	0.73	0.62 to 0.85
Leaf area	-4.34	$6.60e^{-5} *$	-0.35	-0.52 to -0.19	7.84	$7.84e^{-11} *$	0.76	0.65 to 0.88
Petiole length	-3.17	$3.30e^{-3} *$	-0.33	-0.54 to -0.12	6.43	$2.4e^{-7} *$	0.67	0.46 to 0.88

Figure 3.1 Maximum stature length comparison of Island versus mainland. A) Comparing Si against Mainland maximum stature. $R^2 = 0.29$. B) Comparing Island against Mainland maximum stature. $R = 0.87$. Dashed line (Line of Isometry) is the plane at which island values equal mainland values. (Both axes are natural logged)

Figure 3.2 Leaf area comparison of Island versus mainland. A) Comparing Si against Mainland average leaf area. $R^2 = 0.25$. B) Comparing Island against Mainland average leaf area. $R = 0.73$. Dashed line (Line of Isometry) is the plane at which island values equal mainland values. (Both axes are natural logged)

Figure 3.3 Petiole length comparison of Island versus mainland. A) Comparing Si against Mainland maximum petiole length. $R^2 = 0.23$. B) Comparing Island against mainland maximum petiole length. $R = 0.74$. Dashed line (Line of Isometry) is the plane at which island values equal mainland values. (Both axes are natural logged)

Figure 3.4 The statistical significant graphic results of stature against different factors: Size of island (A), Average annual rainfall (B), and Annual average wind speed (C). All measurement data is natural logged. The dashed lined represented the line of isometry, where Island values = mainland values. See Appendix C for test statistic values.

Discussion

My findings investigated the presence of the Island Rule in three vegetative traits (stature, leaf area and petiole length). There was a pattern of dwarfism (in large mainland counterparts) to gigantism (in small mainland counterparts). Evidence of insular size range reduction was clear, thereby supporting the Island Rule. The range of Island trait size reduced across multiple traits, irrespective of latitude.

Processes acting to reduce vegetative trait size range

Islands contain less species than the mainland, resulting in overall less diversity relative to the mainland (Olesen & Jordano 2002; Bellemain & Ricklefs 2008). The 'shift' of island species to display a reduced size range can be viewed as a return to a median or an optimal functional zone (Raia & Meiri 2011; Brown, Marquet & Taper, 1993; Damuth 1993). Island weather differs significantly from continents in that continents exhibit more stable climates; i.e. less variation (Boomert & Bright, 2007). Variation in insular climatic factors, could provide a significant selective force for evolution of traits (Bond & Midgley 2001). This stability fosters wider specialisation and diversity in plants, while in contrast the turbulent conditions found on islands favours generalists.

Vulnerable plants displaying significant variation in fragile environments are better able to persist due to stable environmental conditions (Bond & Midgley 2001). Strong selective circumstances force species into extinction, or to undergo evolutionary selection for beneficial

traits (MacArthur & Wilson, 2001). Therefore, a mainland progenitor species displaying notable extreme variation, would be required to demonstrate a trait 'shift' in order for the lineage to persist on an island. Therefore, island plants may undergo changes towards an optimal functional zone due to less pronounced mainland selection pressures. Common occurrences of size range reduction indicates that optimal functional zones seem to occur across many vegetative traits.

Possible confounding effects of trait allometry

Plant features have been proven to be intrinsically linked (Niklas 1994; Corner 1949; Enquist *et al.* 2007; Westoby & Wright, 2003; Sun, Jin & Shi, 2006). Through the development constraint hypothesis (Harvey & Pagel 1991), one feature can only demonstrate change in morphology within the constraints of supporting traits. All three of the vegetative traits displayed similar results. The pattern of the data was similar between traits (Figures 3.1 to 3.3). While my results did not follow trends within a species, similar patterns between traits may indicate that they are intrinsically linked. Corner (1949) demonstrated previously that seed size is correlated with traits such as stem size and plant height. Kavanagh & Burns (2015) and Cox & Burns (2017) also found evidence that insular seed size tended to display gigantism, and correlate with plant stature. However, the same studies found that not all traits correlate, and that some, such as leaf size, display size independently of other traits. If traits are linked, it will be difficult to disentangle whether evolutionary processes act on one trait at one time, all traits at the same time, or only some traits at any given time. Finding answers to such questions will improve our understanding of evolutionary size changes in vegetative traits, especially for terrestrial plant species.

The Possible confounding effects of location

Concern has been raised, especially for animal studies, that human propensity to move species and cause localised extinctions may 'blur' the true extent of insular patterns of evolution (Faurby & Svenning, 2016). Plants are specifically collected and moved outside of their natural geographical location by botanists, and garden enthusiasts. Generally, plant origin is more confidently located than animal origins, as plants outside of natural geographic locations often breed more poorly, and are usually geographically bound (Nathan, 2006). Plant dispersal via anthropogenic means is also a more recent occurrence, dependant in part, on technological advances allowing for successful transportation (Nathan, 2006). Therefore, the concern of

historic anthropogenic interference in species dispersal, is probably more pronounced in animal taxa, compared to plant taxa. Further study could aim to understand if factors associated with anthropogenic interference, or taxonomic propensity pose an impact on observing evolutionary size changes in plant.

The impact of latitude and island factors

A plant's stature is arguably one of its most important features, as the height of a plant can dictate its success to be pollinated, withstand meteorological events, or accomplish photosynthesis (Anten, 2004). Increasingly, studies are finding that latitude is often not the factor responsible for driving evolutionary change (Schleuning *et al.* 2012; Fitter *et al.* 1995; Mosquin 1971; Yu, Luedeling, Xu 2010; Shahjahan, Duve & Bonman 1987). Abiotic factors (in particular rainfall) have been reported as accountable for 'latitudinal trends' (Louw, 2016). Drezner (2003) found that different climatic factors across latitude (such as rainfall) were better explanations for differences in stature of insular plant species compared to other factors, such as temperature. The results from my research support this literature. High rainfall may lead increased erosion, and nutrient loss. A negative correlation between annual average rainfall and insular plant maximum stature may reflect this relationship, and indicates that smaller species are selected for in higher rainfall environments. In addition, Rosenzweig *et al.*, (2002) found that rainfall related damage to crops is increasing with climate change. Physical damage from rainfall events would be reduced for plants with smaller stature (compared to larger stature plants). Which may explain the negative correlation between plant stature size ratios versus annual average rainfall.

It is well known that bigger islands can support a greater abundance of species (Kohn & Walsh, 1994; Panitsa, Tzanoudakis, Triantis & Sfenthourakis, 2006). In addition, a larger island would allow for species to be bigger (relative to smaller islands). The finding that insular plant patterns are positively correlated with bigger island size, may therefore reflect high levels of intra-specific competition environments.

Gardiner *et al.* (2016) discuss how the impact of wind on a plant can range from microscopic damage to regional-level successional change. Therefore, it is possible that the negative correlation of plant stature to annual average wind speed, may be attributed to the rate of physical damage. With windier places resulting in higher rates of damage, meaning smaller plants are selectively represented in future generations.

It is possible that the correlations seen for annual average wind speed, and size of the island of origin are related. Because small islands are more exposed (Panitsa *et al.*, 2006), they would tend to be windier than bigger islands. This means it is difficult to say if the size of the island, or the level of average wind exposure, or some combination of the two factors best explains size patterns seen for insular plant stature. Further research will be required to disentangle these factors.

Closing remarks

Vegetative traits exhibited patterns consistent with the island rule across multiple statistical tests and factors. No additional factors correlated with insular size change patterns seen for leaf area or petiole length. The results of this study support previous research, which has considered island size change patterns on islands, particularly around the patterns and explanations for patterns seen with insular maximum stature. The Island Rule is presented here as a robust theorem for plant features. Such evidence provides insight into the further application of the rule, and a better understanding of the extent to which it can be applied across multiple geographical areas.

Chapter 4: General Discussion

Insular size changes in plants

As part of this thesis, investigation occurred to understand insular plant size variation in the South Pacific. The findings of Chapter 2 (floral features) are entirely novel, and provide consistent evidence of reduced island size diversity. This pattern was observed regardless of the statistical models used. Secondly, vegetative traits (Chapter 3) also demonstrated a tendency for reduced size variation, thereby providing evidence for the Island Rule. These findings were consistent with recent studies indicating that insular species display significant morphological differences relative to their mainland counterparts (Kavanagh & Burns 2015; Cox and Burns 2017).

Processes and mechanisms of insular plant size change

Flowers are arguably one of the most important features for a plant. Without pollination, subsequent fertilisation and dispersal of genes cannot occur (for sexual flowers relying on sexual reproduction). In Chapter 2, the first empirical testing demonstrated a reduction in the size range of island plant floral features. Additionally, for the first time, academic claims that latitude seemed to have an effect on flower size were investigated (Darwin 1835; Wallace 1832 and Carlquist 1974). According to my results there is strong evidence that reduction of floral size range on islands, occurs irrespective of latitude.

The Pollinator Potential Paradigm provided a clear rationale why floral features may reflect evidence for size range reduction. Flowers co-evolve with pollinators. For example, there are cases where flowers display incredibly complex morphology, and in a like-wise manner the pollinator does too (Kritsky 1991). Modelling of mainland compared to island body size range (through the Pollinator Potential Paradigm) indicates that flower size may be driven by stochastic chance of pollinator dispersal. Reduced body size range of insular pollinators (compared to the mainland), effectively seems to account for why islands have a reduced floral size range compared to the mainland. Changes in morphology are known to be driven by both biotic and abiotic factors. Insular evolution therefore not only relies on the conditions of the Island, but also the composition of other species on the island as well, in particular species that

provide a supporting ecosystem service. It may be that other island bound species play a larger role in dictating the evolutionary trajectory of a specific species than currently acknowledged.

Evolutionary trends in vegetative features, seem better understood than floral features. For Chapter 3, evidence of the Island Rule was found across all vegetative traits. Stature changes (generally associated with insular woodiness) have been studied extensively (Darwin 1835; Carlquist 1974; Hochberg 1980; Beever 1989; Givnish 1998; Hanley *et al.* 2007; Burns *et al.* 2012; Wagstaff *et al.* 2011; Burns 2014; Kavanagh 2015). Compared to these papers, my results differed, in that clear evidence for support of the island rule was demonstrated. It seems that reduced size range in insular vegetative traits are best explained as optimal functional zone 'shifts' (Brown, Marquet & Taper, 1993; Damuth 1993; Raia, Meiri 2011). That is to say, if an island's small species increase in size and big species decrease in size, overall the total size range of this island 'moves away' from extreme values. Therefore, as variation in size decreases, the values themselves become closer towards a common average. Island variation is usually contained within the variation limits of the mainland, thereby being an optimisation zone. Previous to this study reporting on insular size changes were generally directional (either trending toward gigantism or dwarfism). The findings of this thesis demonstrated the first empirical testing of a reduction of size variation in endemic island plant petioles (compared to petioles of their closest mainland relative). In addition, other vegetative traits displayed the expected trend of the Island Rule. Such information demonstrates the persistence of this pattern across multiple vegetative traits.

Possible confounding effects of trait allometry

The reoccurring theme that plant features all display a similar pattern of a graded trend from dwarfism to gigantism could be explained by Havey & Pagel's 1991 Theory of Development Constraint. One trait can only demonstrate change to the constraint of supporting traits. This could mean for example; potential for leaf size to increase is dependent on the petiole, which in turn is dependent on the plant's structure. Plant features have displayed a tendency to have features that are correlated with one another (Corner 1949; Niklas 1994; Westoby & Wright, 2003; Enquist *et al.* 2007; Sun, Jin & Shi, 2006). The patterns exhibited by plant features considered in this thesis may reflect the relatedness of features within a species. However, studies have shown that some insular plants do not support the Development

Constraint Theory. For these examples traits demonstrate change independent of other traits (Kavanagh & Burns 2014; Cox & Burns 2017). Further research is required in order to better understand the processes and tendencies of evolutionary insular size change.

The effect of latitude and archipelago

Empirical evidence suggested that latitude had minimal impact on the size of insular traits. Of the ten traits considered in this thesis (flower area, inflorescence length, petal area, sepal area, filament length, anther length, pedicel length, stature, leaf area and petiole length) only one feature indicated that latitude may play a role in insular sizing (maximum inflorescence length). Such findings are in contrast with previous studies such as Niering *et al.* (1963) who demonstrated that *Carnegiea gigantea* seemed to display a “botanical Bergmann trend”, where differences were attributable across a latitudinal gradient. It should be noted that latitude gradients differ from one another especially in regards to area. This means that true comparisons of latitude variation are not necessarily comparable. My findings support previous studies which failed to find support for common trends along latitudinal gradients (Schleuning *et al.* 2012; Fitter *et al.* 1995; Mosquin 1971; Yu, Luedeling, Xu 2010; Shahjahan, Duve & Bonman 1987). Instead alternative abiotic forces, such as altitude may be a better explanation for plant size variation (Louw, 2016). This demonstrates that the Island Rule is a robust concept that occurs irrespective of the geographical location or archipelago.

The effect of climate and Island size

Three additional factors were found to show some level of impact on floral and vegetative features, these were annual average wind speed, average annual rainfall, and the size of the island of origin. My findings support previous studies that find rainfall and stature is correlated (Givnish, Wong, Stuart-Williams, Holloway-Phillips & Farquhar, 2014). However no previous study seems to have previously researched the correlation between annual average rainfall and inflorescence length or flower size.

The findings that species display larger insular size on larger islands, is a basic tenant of biology, big species can only survive in large areas with access to resources. Therefore it is not surprising to find that the size of the island of origin is positively correlated to stature, and inflorescence length. Remarkably the finding that pedicel length is negatively correlated to island size indicates that there is a selection process occurring that demands further study.

My findings of annual average wind speed, seem to be novel. While there does not seem to be research investigating the impact that wind speed can have on insular plant size, there is evidence that wind can have a serious impact on plants (Gardiner *et al.*, 2016). This is yet another topic uncovered by this research that requires further investigation.

It seems likely that there are correlations between different factors. The size of an island, can reflect how exposed it is, and therefore how windy (Panitsa *et al.*, 2006). Further research in the nature of the interactions between different factors and the true impact they have on plant features will be required to better understand the evolution of endemic insular plant species.

Critical analysis and potential limitations of the methodology

There is no perfect way in which to conduct science, and all methods are inherently biased, and assumptions should be acknowledged and if possible, controlled so that confidence can be placed in a study (Marczyk, DeMatteo & Festinger, 2005). The use of both herbarium specimen literature and measurements could have introduced bias into the research. However, this was controlled for by testing if the origin of measurement impacted the results. There was no statistical evidence that this occurred, in addition findings from Cox and Burns (2017) indicate that this data treatment is robust, and suitable. In this thesis the main assumptions come from phylogenies from which this whole research project has been underpinned by. Caution over the use of phylogenetic methods is frequently cited as a cause for concern (Huelsenbeck & Kirkpatrick, 1996). The identification of species pairs has been exclusively based on the topological congruence of phylogenetic reconstructions. This means that even though inferred relationships have been created through the use of bootstrapping and baseian support it might not truly reflect the evolutionary history of species seen on an island. Populations are dynamic, and can change dramatically over very short time periods. The transient nature of organism means that current distributions do not necessarily represent historic distributions (Hallström & Janke, 2010). From the phylogenies it is impossible to know (without extensive research) if there was limited sampling of species, or if the creation of the phylogeny was impacted by extinction events. The nature of organisms is also difficult to represent in a phylogeny, in that near-shore island floras may be the result of multiple colonisation events within a given lineage. Such suspicions could only be known from repeating a comprehensive replication of both island and mainland populations, which even then may

result in an inconclusive outcome. Finally, this methodology assumes that the DNA recovered from cells is comparable, in that it has been correctly sampled, from the correct species, without contamination, and that sequences have been lodged without glitches or miss-labelling, and that they were included as part of the phylogenetic work.

Conclusions and Future directions

While the Island Rule has consistently framed thinking for insular animal species, it has rarely been utilized as a framework for insular plant studies. In this thesis, not only has novel investigation occurred through the first empirical study of reduced insular floral size diversity, but I have also presented a holistic understanding of support for the Island Rule across vegetative features. It is clear that such patterns tend to exist irrespective of the plant trait. Further research is required to better understand why this might be the case.

Going forward this research sets the standard for future research in the area, and also provides a platform from which a greater understanding on insular species can come from. Future research might consider morphology changes at individual population levels. Do certain tendencies to display dwarfism of one trait result in other traits 'following suit'? Is there an interaction between some geographic factors and biological factors that influence certain traits in light of the Island Rule? Subsequent investigation following the basis that this thesis has set out, will continue to unravel the intricacies of insular plant evolution.

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Image credit

Figure 2.2

Map of study islands surrounding New Zealand.

Jaz Hamilton, Hamilton Geospatial Solutions Ltd, 2018. Made with Natural Earth. Free vector and raster map data @ naturalearthdata.com.

List of Herbarium voucher specimens

Table R1: List of Herbarium voucher specimens and their location

Herbarium	Plant species and voucher codes
Allan Herbarium of Landcare Research New Zealand Limited (CHR)	<i>Brachyglottis repanda</i>
	• CHR 216104 C
	• CHR 216104 B
	<i>Lepidium oblitum</i>
	• CHR 552303 B
	<i>Metrosideros excelsa</i>
	• CHR296099
	<i>Myrsine aquilonia</i>
Auckland War Memorial Museum Herbarium (AK)	• CHR551684
	<i>Senecio hawaii</i>
	• CHR 201160 A
	<i>Alectryon excelsus excelsus</i>
	• AK337298
	• AK163401
	• AK105236
	<i>Alectryon excelsus grandis</i>
	• AK5125
	• AK210756
	<i>Brachyglottis arborescens</i>
	• AK22882
	• AK218336
	<i>Brachyglottis repanda</i>
	• AK10522
	• AK362469
	• AK22882
	<i>Carex chathamica</i>
	• AK314668
	<i>Carex kermadecensis</i>
	• AK366570,
	• AK29529
	<i>Corokia macrocarpa</i>
	• AK6736
	• AK6735
	<i>Festuca coxii</i>
	• AK2009
	<i>Festuca luciarum</i>
	• AK20090
	<i>Korthalsella disticha</i>
	• AK23262
	<i>Lepidium oblitum</i>
	• CHR 5523033
	<i>Melicytus novae-zelandiae subsp. centurionis</i>
	• AK5325
	<i>Melicytus novae-zelandiae subsp. novae-zelandiae</i>
	• AK369727
	• AK5327
	<i>Metrosideros excelsa</i>
	• AK358098
	<i>Myrsine aquilonia</i>
	• AK226841

	<i>Myrsine chathamica</i> <ul style="list-style-type: none"> • AK358264 • AK355715 <i>Pennantia baylisiana</i> <ul style="list-style-type: none"> • AK22872 • AK22875 <i>Pittosporum umbellatum</i> <ul style="list-style-type: none"> • AK4683 • AK102344, <i>Pseudopanax chathamicus</i> <ul style="list-style-type: none"> • AK6209 <i>Pseudopanax crassifolius</i> <ul style="list-style-type: none"> • AK6183 <i>Raoulia buchananii</i> <ul style="list-style-type: none"> • AK121993 <i>Senecio minimus</i> <ul style="list-style-type: none"> • AK347668 <i>Sonchus novae-zelandiae</i> <ul style="list-style-type: none"> • AK304834 <i>Sonchus oleraceus</i> <ul style="list-style-type: none"> • AK304834 <i>Veronica insularis</i> <ul style="list-style-type: none"> • AK217304, • AK183138
Botanic Garden and Botanical Museum Berlin-Dahlem, Freie Universität Berlin (B)	<i>Melaleuca ericifolia</i> <ul style="list-style-type: none"> • B -W 14365 -01 0 • B -W 14365 -02 0 <i>Veronica orchidea</i> <ul style="list-style-type: none"> • B-W 00163-01-0
Botanische Staatssammlung München (M)	<i>Brachyglottis repanda</i> <ul style="list-style-type: none"> • M0030359
De Candolle Herbarium (GDC),	<i>Senecio australis</i> <ul style="list-style-type: none"> • G00468791 • G00468809,
Exsiccata Europaeae Herbarium	<i>Veronica orchidea</i> <ul style="list-style-type: none"> • 3308
Herbarium, Trinity College, Dublin (TCD)	<i>Pittosporum umbellatum</i> <ul style="list-style-type: none"> • TCD0010024 • TCD0009989
Herbarium of the Arnold Arboretum (A),	<i>Myrsine faberi</i> <ul style="list-style-type: none"> • A00062246
Herbier Museum Paris	<i>Coprosma pilosa</i> <ul style="list-style-type: none"> • P03819109 <i>Korthalsella dichotoma</i> <ul style="list-style-type: none"> • P00078675 • P04697482 • P05066328 • P05097223 • P05066329 <i>Melicope polybotrya</i> <ul style="list-style-type: none"> • P05184454 <i>Negria rhabdothamusides</i> <ul style="list-style-type: none"> • P03851834 <i>Pittosporum umbellatum</i> <ul style="list-style-type: none"> • P02502872

	<i>Sacromelicope simplicifolia</i> <ul style="list-style-type: none"> • P00222344 • P05214419 <i>Veronica orchidea</i> <ul style="list-style-type: none"> • P03516880 • P02502869 <i>Xylosma vincentii</i> <ul style="list-style-type: none"> • P0064888 • P00648881 • 2468816 • 15173 • P04647112 • P00648882
Linnean Society of London Herbarium (LINN), Missouri Botanical gardens	<i>Korthalsella dichotoma</i> <ul style="list-style-type: none"> • 2927190 <i>Melaleuca ericifolia</i> <ul style="list-style-type: none"> • LINN-HS1243-13 <i>Myrsine aquilonia</i> <ul style="list-style-type: none"> • 2246496 <i>Veronica orchidea</i> <ul style="list-style-type: none"> • 102778 • 102776
Martin-Luther-Universität (HAL),	<i>Cynoglossum paniculatum</i> <ul style="list-style-type: none"> • HAL0115079
Muse'um National d'Histoire Naturella	<i>Olearia argophylla</i> <ul style="list-style-type: none"> • P00711258
National Botanic gardens of Belgium	<i>Corokia cotoneaster</i> <ul style="list-style-type: none"> • P01900002 • BR0000005948567 • BR0000005948246 <i>Myrsine platystigma</i> <ul style="list-style-type: none"> • BR0000005225002 <i>Pseudopanax crassifolius</i> <ul style="list-style-type: none"> • BR0000005785070 <i>Sarcomelicope simplicifolia</i> <ul style="list-style-type: none"> • P00543913 • P00543914
National Herbarium of New South Wales (NSW)	<i>Cryptocarya gregsonii</i> <ul style="list-style-type: none"> • NSW524068 • NSW524032 <i>Dendrobium kingianum</i> <ul style="list-style-type: none"> • NSW87427 <i>Melaleuca howeana</i> <ul style="list-style-type: none"> • NSW365338 <i>Negria rhabdothamusides</i> <ul style="list-style-type: none"> • NSW402620 <i>Sonchus kirkii</i> <ul style="list-style-type: none"> • NSW135787
National Herbarium of Victoria (MEL),	<i>Alyxia squamulosa</i> <ul style="list-style-type: none"> • MEL223111 • MEL223108 <i>Carmichaelia exsul</i> <ul style="list-style-type: none"> • MEL2120317 <i>Carex tasmanica</i>

	<ul style="list-style-type: none"> • MEL1620511 <i>Leptinella featherstonii</i> <ul style="list-style-type: none"> • MEL42209 <i>Myrsine platystigma</i> <ul style="list-style-type: none"> • MEL622061 <i>Xylosma parviflorum</i> <ul style="list-style-type: none"> • MEL582309 • MEL100642 • MEL582308 • MEL52311 • MEL582310 • MEL100641 <i>Plectorrhiza tridentata</i> <ul style="list-style-type: none"> • MEL1540868
Natural History Museum (BM), BM000810473	<i>Brachyglottis repanda</i> <ul style="list-style-type: none"> • BM000810473 <i>Pennantia corymbosa</i> <ul style="list-style-type: none"> • BM000839739
Naturalis Biodiversity Centre, formerly Leiden University	<i>Cryptocarya densiflora</i> <ul style="list-style-type: none"> • L0036112 <i>Korthalsella dichotoma</i> <ul style="list-style-type: none"> • L3923569 <i>Lenbrassia australiana</i> <ul style="list-style-type: none"> • L2819235 • L3793925 • L2819233 <i>Melicope polybotrya</i> <ul style="list-style-type: none"> • L2124202 • L2124201 • L2124203 <i>Pennantia endlicheri</i> <ul style="list-style-type: none"> • L0014946 <i>Xylosma vincentii</i> <ul style="list-style-type: none"> • L0011394
Naturhistorisches Museum Wien Botanische Abteilung	<i>Pittosporum bracteolatum</i> <ul style="list-style-type: none"> • W0046205 • W0046206
Royal Botanic Gardens of Edinburgh	<i>Negria rhabdothermusides</i> <ul style="list-style-type: none"> • E00642060
Royal Botanic Gardens, Kew (K)	<i>Abrotanella spathulata</i> <ul style="list-style-type: none"> • K000796675 <i>Alyxia reinwardtii</i> <ul style="list-style-type: none"> • H570/97 50 <i>Carmichaelia exsul</i> <ul style="list-style-type: none"> • K000950835 <i>Carmichaelia williamsii</i> <ul style="list-style-type: none"> • K000950929 <i>Corokia macrocarpa</i> <ul style="list-style-type: none"> • K000739753 <i>Cynoglossum paniculatum</i> <ul style="list-style-type: none"> • K000573727 <i>Dendrobium kingianum</i> <ul style="list-style-type: none"> • K001089618 <i>Dendrobium moorei</i> <ul style="list-style-type: none"> • K001085450

	<ul style="list-style-type: none"> • K001085449
	<i>Korthalsella dichotoma</i>
	<ul style="list-style-type: none"> • K000912677
	<i>Korthalsella disticha</i>
	<ul style="list-style-type: none"> • K000912682
	<i>Lepidium obtusatum</i>
	<ul style="list-style-type: none"> • K000642772
	<i>Melicope polybotrya</i>
	<ul style="list-style-type: none"> • K000717407
	<i>Melicytus novae-zelandiae</i> subsp. <i>centurionis</i>
	<ul style="list-style-type: none"> • K000370077
	<i>Myrsine platystigma</i>
	<ul style="list-style-type: none"> • K000756398
	<i>Negria rhabdothamusides</i>
	<ul style="list-style-type: none"> • K000831478
	<i>Olearia mooneyi</i>
	<ul style="list-style-type: none"> • K000838921
	<i>Plantago aucklandica</i>
	<ul style="list-style-type: none"> • K000438784
	<i>Pittosporum bracteolatum</i>
	<ul style="list-style-type: none"> • K000591735
	<i>Pittosporum umbellatum</i>
	<ul style="list-style-type: none"> • K000591694
	<i>Pseudopanax chathamicus</i>
	<ul style="list-style-type: none"> • K000810129
	<i>Pseudopanax kermadecensis</i>
	<ul style="list-style-type: none"> • K000810341
	<i>Senecio australis</i>
	<ul style="list-style-type: none"> • K000250508
	<i>Senecio minimus</i>
	<ul style="list-style-type: none"> • K000852323
	<ul style="list-style-type: none"> • K000852325
	<i>Sonchus grandifolius</i>
	<ul style="list-style-type: none"> • K000808042
	<i>Sonchus novae-zelandiae</i>
	<ul style="list-style-type: none"> • K000323043
	<i>Sonchus oleraceus</i>
	<ul style="list-style-type: none"> • K001118926
	<ul style="list-style-type: none"> • K001118922
	<i>Veronica insularis</i>
	<ul style="list-style-type: none"> • K001070461
Swedish Museum of Natural History Department of Botany	<i>Alyxia reinwardtii</i>
	<ul style="list-style-type: none"> • (S), S-G-10786
Te Papa Herbarium, Wellington (TP)	<i>Abrotanella rosulata</i>
	<ul style="list-style-type: none"> • SP102466
	<i>Abrotanella spathulata</i>
	<ul style="list-style-type: none"> • SP57761
	<i>Brachyglottis arborescens</i>
	<ul style="list-style-type: none"> • SP78892
	<ul style="list-style-type: none"> • SP14393
	<i>Brachyglottis huntii</i>
	<ul style="list-style-type: none"> • SP77964
	<i>Brachyglottis repanda</i>
	<ul style="list-style-type: none"> • SP58743
	<i>Brachyglottis stewartiae</i>

-
- SP40512
 - Coprosma chathamica*
 - SP097813
 - SP56390
 - Coprosma repens*
 - SP094169,
 - SP101281
 - Gentianella chathamica* subsp. *Chathamica*
 - SP003354
 - SP091523 (A)
 - Gentianella saxosa*
 - SP47560
 - SP47517
 - Leptinella serrulata*
 - SP091212
 - Melicytus novae-zelandiae* subsp. *centurionis*
 - SP029562
 - SP029543
 - SP029550
 - SP067867
 - SP085716
 - Metrosideros excelsa*
 - SP023044
 - Metrosideros kermadecensis*
 - SP095393
 - SP088606
 - Myosotidia hortensium*
 - K001067060
 - Pennantia endlicheri*
 - SP086322
 - SP08611
 - SP083238
 - Pittosporum bracteolatum*
 - SP084276
 - Plantago lanigera*
 - SP104833/A
 - SP089135
 - Pseudopanax arboreus*
 - SP54311
 - Pseudopanax chathamicus*
 - SP25031
 - SP3307
 - SP3351
 - SP25068
 - Pseudopanax crassifolius*
 - SP022836
 - SP099142
 - SP078845
 - Pseudopanax kermadecensis*
 - SP05341
 - Senecio australis*
 - SP82400
 - Senecio kermadecensis*
 - SP90180,
 - SP31463
-

References

	<i>Sonchus grandifolius</i> <ul style="list-style-type: none"> • SP27962, • SP27948
The Gray Herbarium (GH)	<i>Cryptocarya densiflora</i> <ul style="list-style-type: none"> • GH00041368
United States National Museum	<i>Lenbrassia australiana</i> <ul style="list-style-type: none"> • 00453906 <i>Myosotidium hortensia</i> <ul style="list-style-type: none"> • 00947912
Universität Göttingen (GOET),	<i>Pseudopanax arboreus</i> <ul style="list-style-type: none"> • GOET012768

Appendices

Appendix A: Generalised supplementary material

Island species checklists

TableA1 Antipodes Island species checklist

Antipodes endemic taxa	Available phylogeny	Closest extant mainland relative
<i>Puccinellia antipoda</i>	no phylogeny available	-
<i>Epilobium sp. aff. alsinoides</i>	no phylogeny available	-
<i>Gentianella antipoda</i>	Heenan, Mitchell, De Lange, Keeling & Paterson, 2010	<i>Gentianella cerina</i>
<i>Senecio radiolatus subsp. antipodus</i>	no phylogeny available	-
<i>Stellaria decipiens var. angustata</i>	no phylogeny available	-

TableA2 Auckland Island species checklist

Auckland endemic taxa	Available phylogeny	Closest extant mainland relative
<i>Abrotanella spathulata</i>	Wagstaff, Breitwieser & Swenson 2006	<i>Abrotanella spathulata</i> acts as the mainland species to <i>Abrotanella rosulata</i>
<i>Callitriche aucklandica</i>	no phylogeny available	-
<i>Cardamine depressa var. depressa</i>	no phylogeny available	-
<i>Cardamine latior</i>	no phylogeny available	-
<i>Gentianella cerina</i>	von Hagen & Kadereit 2001	-
<i>Gentianella concinna</i>	Glenny 2013	-
<i>Geum albiflorum</i>	no phylogeny available	-
<i>Plantago aucklandica</i>	Tay, Meudt, Garnock-Jones & Ritchie, 2010	<i>Plantago lanigera</i>
<i>Plantago triantha</i>	Tay <i>et al.</i> 2010	-
<i>Poa aucklandica subsp. aucklandica</i>	no phylogeny available	-

TableA3 Bounty Island species checklist

Bounty endemic taxa	Available phylogeny	Closest extant mainland relative
<i>Lepidium seditiosum</i>	de Lange, Heenan, Houlston, Rolfe & Mitchell, 2013	-

TableA4 Campbell Island species checklist

Campbell endemic taxa	Available phylogeny	Closest extant mainland relative
<i>Abrotanella rosulata</i>	Wagstaff <i>et al.</i> , 2006	<i>Abrotanella spathulata</i>
<i>Chionogentias antarctica</i>	no phylogeny available	-
<i>Cardamine depressa var. stellata</i>	no phylogeny available	-
<i>Cardamine subcarnosa</i>	no phylogeny available	-
<i>Gentianella antarctica</i>	no phylogeny available	-
<i>Poa aucklandica subsp. Campbellensis</i>	no phylogeny available	-

TableA5 Chatham Island species checklist

Chatham endemic taxa	Available phylogeny	Closest extant mainland relative
<i>Aciphylla dieffenbachii</i>	Heenan <i>et al.</i> 2010	-
<i>Aciphylla traversii</i>	Heenan <i>et al.</i> 2010	-
<i>Asplenium chathamense</i>	Perrie <i>et al.</i> 2014	-
<i>Austroderia turbaria</i>	no phylogeny found	-
<i>Brachyglottis huntii</i>	Heenan <i>et al.</i> 2010	<i>Brachyglottis stewartiae</i>
<i>Carex auceps</i>	no phylogeny found	-
<i>Carex chathamica</i>	Heenan <i>et al.</i> 2010	<i>Carex kermadecensis</i>
<i>Carex ventosa</i>	Heenan <i>et al.</i> 2010	<i>Carex trifida</i>
<i>Coprosma chathamica</i>	Heenan <i>et al.</i> 2010	<i>Coprosma repens</i> - excluded from the study, as it seemed unlikely that dispersal occurred from the Chathams to Norfolk Island, especially with the North Island in the middle of this dispersal path. More likely that <i>Coprosma repens</i> (sister taxa to both <i>C. baueri</i> & <i>C. chathamica</i>) dispersed separately to both Chatham islands and Norfolk Island. However, introducing <i>C. repens</i> as mainland relative deviates from methods, and causes issues of non independence.
<i>Coprosma propinqua</i> var. <i>martinii</i>	Heenan <i>et al.</i> 2010	<i>Coprosma propinqua</i> var. <i>propinqua</i>
<i>Corokia macrocarpa</i>	Heenan <i>et al.</i> 2010	<i>Corokia cotoneaster</i>
<i>Disphyma papillatum</i>	Heenan <i>et al.</i> 2010	-
<i>Dracophyllum arboreum</i>	Heenan <i>et al.</i> 2010	-
<i>Festuca coxii</i>	Heenan <i>et al.</i> 2010	<i>Festuca luciarum</i>
<i>Gentianella chathamica</i> subsp. <i>chathamica</i>	Heenan <i>et al.</i> 2010	<i>Gentianella saxosa</i>
<i>Geranium traversii</i>	Heenan <i>et al.</i> 2010	-
<i>Lepidium oblitum</i>	de Lange <i>et al.</i> 2013	<i>Lepidium obtusatum</i>
<i>Lepidium panniforme</i>	de Lange <i>et al.</i> 2013	-
<i>Lepidium rekohuense</i>	de Lange <i>et al.</i> 2013	-
<i>Leptecophylla robusta</i>	Heenan <i>et al.</i> 2010	<i>Leptecophylla juniperina</i>
<i>Leptinella featherstonii</i>	Heenan <i>et al.</i> 2010	<i>Leptinella serrulata</i>
<i>Linum monogynum</i> var. <i>chathamicum</i>	Heenan <i>et al.</i> 2010	<i>Linum monogynum</i> var. <i>monogynum</i>
<i>Melicytus chathamicus</i>	Heenan <i>et al.</i> 2010	-
<i>Myosotidium hortensia</i>	Weigend <i>et al.</i> 2013	<i>Cynoglossum paniculatum</i>
<i>Myrsine coxii</i>	Heenan <i>et al.</i> 2010	<i>Myrsine aquilonia</i>
<i>Olearia chathamica</i>	Heenan <i>et al.</i> 2010	-
<i>Olearia semidentata</i>	Heenan <i>et al.</i> 2010	-
<i>Olearia telmatica</i>	Heenan <i>et al.</i> 2010	-
<i>Olearia traversiorum</i>	Heenan <i>et al.</i> 2010	-

<i>Plagianthus regius</i> subsp. <i>chathamicus</i>	no phylogeny found	-
<i>Poa chathamica</i>	Heenan <i>et al.</i> 2010	<i>Poa cita</i>
<i>Pseudopanax chathamicus</i>	Heenan <i>et al.</i> 2010	<i>Pseudopanax crassifolius</i>
<i>Pterostylis silvicultrix</i>	no phylogeny found	-
<i>Rapanea chathamica</i>	Heenan <i>et al.</i> 2010	-
<i>Senecio radiolatus</i> subsp. <i>radiolatus</i>	no phylogeny found	-
<i>Sonchus grandifolius</i>	Heenan <i>et al.</i> 2010	<i>Sonchus novae-zelandiae</i>
<i>Sporadanthus traversii</i>	Heenan <i>et al.</i> 2010	<i>Sporadanthus ferrugineus</i>
<i>Veronica barkeri</i>	Heenan <i>et al.</i> 2010	-
<i>Veronica chathamica</i>	Heenan <i>et al.</i> 2010	-
<i>Veronica dieffenbachii</i>	Heenan <i>et al.</i> 2010	-

TableA6 Kermadec Island species checklist

Kermadec endemic taxa	Available phylogeny	Closest extant mainland relative
<i>Ascarina lucida</i> var. <i>lanceolata</i>	No phylogeny found	-
<i>Carex kermadecensis</i>	Papadopoulos <i>et al.</i> 2011	<i>Carex chathamica</i> (<i>C. kermadecensis</i> acts as the mainland in this pairing).
<i>Coprosma acutifolia</i>	Papadopoulos <i>et al.</i> 2011	<i>Coprosma propinqua</i>
<i>Coprosma petiolata</i>	Papadopoulos <i>et al.</i> 2011	-
<i>Coriaria arborea</i> var. <i>kermadecensis</i>	No phylogeny found	-
<i>Cyathea kermadecensis</i>	No phylogeny found	-
<i>Cyathea milnei</i>	Lewis 2001	<i>Cyathea dealbata</i>
<i>Cyperus insularis</i>	Reid, Carter & Urbatsch, 2014	<i>Cyperus ustulatus</i>
<i>Disphyma australe</i> subsp. <i>stricticaule</i>	No phylogeny found	-
<i>Homalanthus polyandrous</i>	No phylogeny found	-
<i>Hypolepis dicksonioides</i>	Perrie <i>et al.</i> 2015	<i>Hypolepis rugosula</i>
<i>Imperata cheesemanii</i>	No phylogeny found	-
<i>Lepidium castellanum</i>	de Lange <i>et al.</i> 2013	-
<i>Metrosideros kermadecensis</i>	Papadopoulos <i>et al.</i> 2011	<i>Metrosideros excelsa</i>
<i>Myoporum rapense</i> subsp. <i>Kermadecense</i>	No phylogeny found	-
<i>Parapolystichum kermadecense</i>	Perrie & Brownsey 2012	-
<i>Poa polyphylla</i>	No phylogeny found	-
<i>Pouzolzia australis</i>	No phylogeny found	-
<i>Pseudopanax kermadecensis</i>	Perrie & Shepherd 2009	<i>Pseudopanax arboreus</i>
<i>Rhopalostylis baueri</i> var. <i>cheesemanii</i>	No phylogeny found	-
<i>Scaevola gracilis</i>	Howarth, Gustafsson, Baum & Motley, 2003	-
<i>Senecio kermadecensis</i>	Liew, Memory, Ortiz-Barrientos, De Lange & Pelsner, 2018	<i>Senecio hauwai</i>
<i>Sonchus kirkii</i>	Kim, Chunghee & Mejías, 2007	<i>Sonchus oleraceus</i>
<i>Myrsine kermadecensis</i>	Papadopoulos <i>et al.</i> 2011	-
<i>Veronica brevifracemosa</i>	No phylogeny found	-

TableA7 Lord Howe Island species checklist

Lord Howe endemic taxa	Available phylogeny	Closest extant mainland relative
<i>Alyxia squamulosa</i>	Papadopoulos <i>et al.</i> 2011	<i>Alyxia reinwardtii</i>
<i>Apium prostratum</i> subsp. <i>howense</i>	no phylogeny found	-
<i>Asplenium goudeyi</i>	Ohlsen, Perrie, Shepherd, Brownsey & Bayly, 2015	-
<i>Asplenium milnei</i>	Ohlsen <i>et al.</i> 2015	-
<i>Asplenium pteridoides</i>	Ohlsen <i>et al.</i> 2015	-
<i>Asplenium surrogatum</i>	Ohlsen <i>et al.</i> 2015	-
<i>Atractocarpus stipularis</i>	no phylogeny found	-
<i>Blechnum contiguum</i>	Perrie <i>et al.</i> 2014, Papdopoulos <i>et al.</i> 2011	-
<i>Blechnum fullagarii</i>	Perrie <i>et al.</i> 2014, Papdopoulos <i>et al.</i> 2011	<i>Blechnum nigrum</i>
<i>Blechnum geniculatum</i>	no phylogeny found	-
<i>Blechnum howeanum</i>	Perrie <i>et al.</i> 2014, Papdopoulos <i>et al.</i> 2011	<i>Blechnum triangularifolium</i>
<i>Boehmeria calophleba</i>	no phylogeny found	-
<i>Brachyscome segmentosa</i>	no phylogeny found	-
<i>Carmichaelia exsul</i>	Heenan 1998	<i>Carmichaelia williamsii</i>
<i>Cassinia tenuifolia</i>	no phylogeny found	-
<i>Celtis conferta</i> ssp. <i>amblyphylla</i>	no phylogeny found	-
<i>Cephalomanes bauerianum</i>	no phylogeny found	-
<i>Chionanthus quadristamineus</i>	no phylogeny found	-
<i>Chionochloa howensis</i>	no phylogeny found	-
<i>Coprosma huttoniana</i>	Papadopoulos <i>et al.</i> 2011	-
<i>Coprosma inopinata</i>	Papadopoulos <i>et al.</i> 2011	-
<i>Coprosma lanceolaris</i>	Papadopoulos <i>et al.</i> 2011	-
<i>Coprosma prisca</i>	Papadopoulos <i>et al.</i> 2011	<i>Coprosma petiolate</i>
<i>Coprosma putida</i>	Papadopoulos <i>et al.</i> 2011	-
<i>Coprosma</i> sp. Nov	Papadopoulos <i>et al.</i> 2011	-
<i>Corokia carpodetoides</i>	no phylogeny found	-
<i>Cryptocarya gregsonii</i>	Papadopoulos <i>et al.</i> 2011	<i>Cryptocarya densiflora</i>
<i>Cyathea brevipinna</i>	Papadopoulos <i>et al.</i> 2011	-
<i>Cyathea howeana</i>	Korall <i>et al.</i> 2007 Papadopoulos <i>et al.</i> 2011	<i>Cyathea robertsiana</i>
<i>Cyathea macarthurii</i>	Papadopoulos <i>et al.</i> 2011	-
<i>Cyathea robusta</i>	Papadopoulos <i>et al.</i> 2011	-
<i>Dendrobium macropus</i> ssp. <i>howeanum</i>	no phylogeny found	-
<i>Dendrobium moorei</i>	Papadopoulos <i>et al.</i> 2011, Burke, Bayly, Adams & Ladiges, 2008	<i>Dendrobium kingianum</i>
<i>Dietes robinsoniana</i>	Wilson & Morrison 2000,	-
<i>Diplazium melanochlamys</i>	no phylogeny found	-
<i>Dracophyllum fitzgeraldii</i>	Wagstaff <i>et al.</i> 2010	-
<i>Drypetes deplanchei</i> ssp. <i>affinis</i>	no phylogeny found	-
<i>Dysoxylum pachyphyllum</i>	no phylogeny found	-
<i>Elaeocarpus costatus</i>	Baba 2013	-

<i>Elatostema grande</i>	no phylogeny found	-
<i>Exocarpus homalocladus</i>	no phylogeny found	-
<i>Ficus macrophylla</i> ssp. <i>columnaris</i>	no phylogeny found	-
<i>Gahnia howeana</i>	no phylogeny found	-
<i>Geniostoma huttonii</i>	Papadopulos <i>et al.</i> 2011	-
<i>Geniostoma petiolosum</i>	Papadopulos <i>et al.</i> 2011	-
<i>Gonocarpus</i> sp	no phylogeny found	-
<i>Grammitis diminuta</i>	Papadopulos <i>et al.</i> 2011	-
<i>Grammitis nudicarpa</i>	Papadopulos <i>et al.</i> 2011	-
<i>Grammitis wattsii</i>	Papadopulos <i>et al.</i> 2011	-
<i>Guoia coriacea</i>	no phylogeny found	-
<i>Hedyscepe canterburyana</i>	Papadopulos <i>et al.</i> 2011	<i>Basselinia glabrata</i>
<i>Howea belmoreana</i>	Papadopulos <i>et al.</i> 2011	-
<i>Howea forsteriana</i>	Papadopulos <i>et al.</i> 2011	-
<i>Hymenophyllum howense</i>	Papadopulos <i>et al.</i> 2011	-
<i>Hymenophyllum moorei</i>	Papadopulos <i>et al.</i> 2011	<i>Hymenophyllum baileyianum</i>
<i>Korthalsella emersa</i>	Papadopulos <i>et al.</i> 2011	<i>Korthalsella rubra</i>
<i>Lastreopsis nephrodioides</i>	no phylogeny found	-
<i>Lepidium howei-insulae</i>	no phylogeny found	-
<i>Lepidium nesophilum</i>	de Lange <i>et al.</i> 2013	-
<i>Lepidorrhachis mooreana</i>	no phylogeny found	-
<i>Leptopteris moorei</i>	no phylogeny found	-
<i>Leptospermum polygalifolium</i> ssp. <i>howense</i>	no phylogeny found	-
<i>Lordhowea insularis</i>	no phylogeny found	-
<i>Luzula longiflora</i>	no phylogeny found	-
<i>Machaerina insularis</i>	no phylogeny found	-
<i>Marattia howeana</i>	Murdock 2008	-
<i>Marsdenia tubulosa</i> (possibly extinct)	no phylogeny found	-
<i>Melaleuca howeana</i>	Brown <i>et al.</i> 2001	<i>Melaleuca ericifolia</i>
<i>Melicope contermina</i>	Papadopulos <i>et al.</i> 2011	-
<i>Melicope polybotrya</i>	Papadopulos <i>et al.</i> 2011	<i>Sarcomelicope simplicifolia</i>
<i>Melicytus novae-zelandiae</i> ssp. <i>centurionis</i>	Mitchell, Heenan, Murray, Molloy & De Lange, 2009	<i>Melicytus novae-zelandiae</i> subsp. <i>novae-zelandiae</i>
<i>Metrosideros nervulosa</i>	Papadopulos <i>et al.</i> 2011	-
<i>Metrosideros sclerocarpa</i>	Papadopulos <i>et al.</i> 2011	-
<i>Myrsine mcomishii</i>	Papadopulos <i>et al.</i> 2011	-
<i>Myrsine myrtillina</i>	Papadopulos <i>et al.</i> 2011	-
<i>Myrsine platystigma</i>	Papadopulos <i>et al.</i> 2011	<i>Myrsine faberi</i>
<i>Negria rhabdothamnoides</i>	Woo, Funke, Smith, Lockhart & Garnock-Jones, 2011	<i>Lenbrassia australiana</i>
<i>Olearia ballii</i>	Papadopulos <i>et al.</i> 2011	-
<i>Olearia elliptica</i> ssp. <i>praetermissa</i>	Papadopulos <i>et al.</i> 2011	-
<i>Olearia mooneyi</i>	Papadopulos <i>et al.</i> 2011	<i>Olearia argophylla</i>
<i>Pandanus forsteri</i>	Gallaher, Callmender, Buerki & Keeley, 2015	<i>Pandanus kanehirae</i>

<i>Pandorea pandorana</i> ssp. <i>austrocaledonia</i>	no phylogeny found	-
<i>Parsonsia howeana</i>	no phylogeny found	-
<i>Passiflora herbertiana</i> ssp. <i>insulae-howeii</i>	no phylogeny found	-
<i>Phymatosorus pustulatus</i> ssp. <i>Howensis</i>	no phylogeny found	-
<i>Pimelea congesta</i>	no phylogeny found	-
<i>Piper hooglandii</i>	Papadopulos <i>et al.</i> 2011	-
<i>Pittosporum erioloma</i>	no phylogeny found	-
<i>Plantago hedleyi</i>	no phylogeny found	-
<i>Plectorrhiza erecta</i>	Hidayat, Weston, Yukawa, Ito & Rice, 2012	<i>Plectorrhiza tridentata</i>
<i>Polystichum moorei</i>	Papadopulos <i>et al.</i> 2011	-
<i>Polystichum whiteleggei</i>	Papadopulos <i>et al.</i> 2011	-
<i>Psychotria carronis</i>	no phylogeny found	-
<i>Pteris microptera</i>	Papadopulos <i>et al.</i> 2011	<i>Pteris comans</i>
<i>Scaevola taccada</i>	no phylogeny found	-
<i>Senecio howeanus</i>	no phylogeny found	-
<i>Senecio pauciradiatus</i>	no phylogeny found	-
<i>Sophora howinsula</i>	Mitchell & Heenan 2002	-
<i>Stephania japonica</i> var <i>timoriensis</i>	no phylogeny found	-
<i>Symplocos candelabrum</i>	no phylogeny found	-
<i>Syzygium fullargarii</i> (syn. <i>Cleistocalyx fullargarii</i>)	no phylogeny found	-
<i>Tetragonia implexicoma</i> (possibly extinct)	Klak, Hanáček & Bruyns, 2017	-
<i>Trophis scandens</i> ssp. <i>megacarpa</i>	no phylogeny found	-
<i>Uncinia debilior</i>	no phylogeny found	-
<i>Wahlenbergia insulae-howeii</i>	no phylogeny found	-
<i>Westringia viminalis</i>	no phylogeny found	-
<i>Xylosma maidenii</i>	Papadopulos <i>et al.</i> 2011	-
<i>Xylosma parvifolium</i>	Papadopulos <i>et al.</i> 2011	<i>Xylosma vincentii</i>
<i>Zygogynum howeanum</i> (syn. <i>Bubbia howeanum</i>)	no phylogeny found	-

TableA8 Macquarie Island species checklist

Macquarie endemic taxa	Available phylogeny	Closest extant mainland relative
<i>Azorella macquariensis</i>	Nicolas & Plunkett 2012	-
<i>Corybas dienemus</i>	Lehnebach, Zeller, Frericks & Ritchie, 2016	-
<i>Corybas sulcatus</i>	Lehnebach <i>et al.</i> 2016	-
<i>Puccinellia macquariensis</i>	no phylogeny available	-

TableA9 Norfolk Island species checklist

Norfolk endemic taxa	Available phylogeny	Closest extant mainland relative
<i>Abutilon julianae</i>	no phylogeny found	-
<i>Achyranthes arborescens</i>	McCauley & Havran, 2013	-

<i>Achyranthes margaretarum</i>	no phylogeny found	-
<i>Araucaria heterophylla</i>	Stefanorić <i>et al.</i> 1998, Ruhsam <i>et al.</i> 2015, Graham, Henry, Godwin & Nikles, 1996	<i>Araucaria cunninghamii</i>
<i>Asplenium dimorphum</i>	Ohlsen <i>et al.</i> 2015	<i>Asplenium difforme</i>
<i>Boehmeria australis subsp. australis</i>	no phylogeny found	-
<i>Carex neesiana</i>	no phylogeny found	-
<i>Clematis dubia</i>	no phylogeny found	-
<i>Coprosma baueri</i>	Papadopoulos <i>et al.</i> 2011	<i>Coprosma chathamica</i> – excluded from the study see <i>Coprosma chathamica</i> (Table A5).
<i>Coprosma pilosa</i>	Papadopoulos <i>et al.</i> 2011	<i>Coprosma fowerakeri</i>
<i>Cyathea australis subsp. norfolkensis</i>	no phylogeny found	-
<i>Cyathea brownii</i>	Papadopoulos <i>et al.</i> 2011	<i>Cyathea robinsonii</i>
<i>Dendrobium brachypus</i>	no phylogeny found	-
<i>Dendrobium macropus subsp. macropus</i>	no phylogeny found	-
<i>Elatostema montanum</i>	no phylogeny found	-
<i>Elymus multiflorus var. kingianus</i>	no phylogeny found	-
<i>Euphorbia norfolkiana</i>	no phylogeny found	-
<i>Hibiscus insularis</i>	Ruan, Chen, Li & da Silva, 2011	-
<i>Korthalsella disticha</i>	Sultan 2014	<i>Korthalsella dichotoma</i>
<i>Lastreopsis calantha</i>	Gardner, Perrie, Shepherd & Nagalingum 2017	-
<i>Melicope littoralis</i>	no phylogeny found	-
<i>Melicytus latifolius</i>	Stajsic, Walsh, Douglas, Messina & Molloy, 2015	<i>Melicytus novae-zelandiae subsp. novae-zelandiae</i>
<i>Melicytus ramiflorus subsp. oblongifolius</i>	Stajsic <i>et al.</i> 2015	-
<i>Meryta angustifolia</i>	no phylogeny found	-
<i>Meryta latifolia</i>	Perrie & Shepherd 2009	<i>Meryta denhamii</i>
<i>Myoporum obscurum</i>	no phylogeny found	-
<i>Myrsine ralstoniae</i>	no phylogeny found	-
<i>Pennantia endlicheri</i>	Keeling, Gardner & de Lange 2004	<i>Pennantia corymbosa</i>
<i>Phreatia limenophylax</i>	no phylogeny found	-
<i>Pittosporum bracteolatum</i>	Carrodus 2009	<i>Pittosporum umbellatum</i>
<i>Pteris kingiana</i>	Chao, Moore & Ladle, 2014	<i>Pteris tremula</i>
<i>Pteris zahlbruckneriana</i>	no phylogeny found	-
<i>Senecio australis</i>	Liew <i>et al.</i> 2018	<i>Senecio minimus</i>
<i>Senecio evansianus</i>	no phylogeny found	-
<i>Senecio hooglandia</i>	Liew <i>et al.</i> 2018	-
<i>Streblorrhiza speciosa</i>	no phylogeny found	-
<i>Taeniophyllum norfolianum</i>	no phylogeny found	-
<i>Thelychiton brachypus</i>	no phylogeny found	-
<i>Tmesipteris norfolkensis</i>	no phylogeny found	-

<i>Ungeria floribunda</i>	no phylogeny found	-
<i>Wikstroemia australis</i>	no phylogeny found	-

TableA10 Snares Island species checklist

Snares endemic taxa	Available phylogeny	Closest extant mainland relative
<i>Anisotoma acutifolia</i>	no phylogeny available	-
<i>Stilbocarpa robusta</i>	Mitchell <i>et al.</i> 1999	-

TableA11 Stewart Island species checklist

Stewart endemic taxa	Available phylogeny	Closest extant mainland relative
<i>Aciphylla cartilaginea</i>	no phylogeny found	-
<i>Aciphylla stannensis</i>	no phylogeny found	-
<i>Aciphylla traillii</i>	Radford, Watson & Preston 2001	-
<i>Bulbinella gibbsii</i> var. <i>gibbsii</i>	no phylogeny found	-
<i>Celmisia clavata</i>	no phylogeny found	-
<i>Chionochoa lanea</i>	no phylogeny found	-
<i>Gentianella gibbsii</i>	no phylogeny found	-
<i>Gingidia flabellate</i>	no phylogeny found	-
<i>Leptinella traillii</i> subsp. <i>traillii</i>	no phylogeny found	-
<i>Poa aucklandica</i> subsp. <i>rakiura</i>	no phylogeny found	-
<i>Ranunculus kirkii</i>	no phylogeny found	-
<i>Ranunculus stylosus</i>	no phylogeny found	-
<i>Ranunculus viridis</i>	Lehnebach 2008	-
<i>Raoulia goyenii</i>	Smitsen, Breitwieser, Ward, McLenachan & Lockhart, 2010	<i>Raoulia buchananii</i>

TableA12 Three Kings Island species checklist

Three Kings endemic taxa	Available phylogeny	Closest extant mainland relative
<i>Alectryon excelsus</i> subsp. <i>grandis</i>	Edwards & Gadek 2000	<i>Alectryon excelsus</i>
<i>Brachyglottis arborescens</i>	Wagstaff & Breiwyser 2004	<i>Brachyglottis repanda</i>
<i>Carex elingamita</i>	Heenan <i>et al.</i> 2010	-
<i>Coprosma macrocarpa</i>	Papadopoulos <i>et al.</i> 2011	-
<i>Cordyline obtecta</i>	no phylogeny found	-
<i>Davallia tasmanii</i> subsp. <i>tasmanii</i>	no phylogeny found	-
<i>Elingamita johnsonii</i>	Stöckler 2001	-
<i>Kunzea triregensis</i>	no phylogeny found	-
<i>Meryta sinclairii</i>	no phylogeny found	-
<i>Myrsine oliveri</i>	Papadopoulos <i>et al.</i> 2011	-
<i>Pennantia baylisiana</i>	Keeling <i>et al.</i> 2004	-
<i>Pimelea telura</i>	no phylogeny found	-
<i>Piper melchior</i>	no phylogeny found	-
<i>Pittosporum fairchil</i>	no phylogeny found	-
<i>Streblus smithii</i>	no phylogeny found	-
<i>Tecomanthe speciose</i>	no phylogeny found	-
<i>Veronica insularis</i>	Dirk <i>et al.</i> 2004	-

Suitable versus unsuitable phylogenies

Figure A1 Suitable versus unsuitable phylogenies

In Phylogeny Example A, the Island species of interest (d) is in a position where there is only one mainland relative. In this example. This demonstrates a suitable phylogeny that could be used for this thesis. This methodology relies heavily on fundamental assumptions, see discussion for more on this topic. In Phylogeny Example X the Island species of interest is not clearly in a clade with one mainland species. Here it is equally related to all 7 members of the clade it is in. With each of those members having a locality bigger than the Island species. In this instance it is not possible to ascertain which of the phylogenetic relationships are most likely, therefore without 1 clear extant mainland relative, this island species is not able to be used in the study. In Phylogeny Example Y, similar to Phylogeny Example X it is not possible to ascertain which of the mainland species are more closely related to the island species, therefore a 'species pair' is unable to be made, and this Island species too is unable to be a part of the study. Phylogeny Example B shows a similar reasoning to Phylogeny Example A, in that Island species a and b (both from the same island) are related to 1 mainland relative. However, for the purposes of this thesis, it is not possible to disentangle interspecific changes in the island species versus the island/ mainland change if both island species were kept. Averaging the island species also might not give a true representation of the original island founder population before it spilt into two island species. In this instance this phylogeny is also unsuitable for the study and cannot be used.

Taxomic order breakdown per island of all endemic species

TableA13 Endemic species frequency grouped by taxonomic order and island

	AN	AU	BO	CP	CH	KD	LH	MQ	NO	SN	SW	TK	Total
Apiales	-	-	-	-	3	1	2	1	4	1	4	3	19
Arecales	-	-	-	-	-	1	4	-	-	-	-	-	5
Asparagales	-	-	-	-	1	-	4	2	5	-	1	1	14
Asterales	1	1	-	1	9	3	11	-	3	-	3	1	33
Boraginales	-	-	-	-	1	-	-	-	-	-	-	-	1
Brassicales	-	2	1	2	3	1	2	-	-	-	-	-	11
Canellales	-	-	-	-	-	-	1	-	-	-	-	-	1
Caryophyllales	1	-	-	-	1	1	1	-	2	-	-	-	6
Chloranthales	-	-	-	-	-	1	-	-	-	-	-	-	1
Cucurbitales	-	-	-	-	-	1	-	-	-	-	-	-	1
Cyatheales	-	-	-	-	-	2	4	-	2	-	-	-	8
Ericales	-	-	-	-	4	1	5	-	1	-	-	2	13
Fabales	-	-	-	-	-	-	2	-	1	-	-	-	3
Gentianales	1	2	-	2	3	2	13	-	2	1	1	1	28
Geraniales	-	-	-	-	1	-	-	-	-	-	-	-	1
Hymenophyllales	-	-	-	-	-	-	3	-	-	-	-	-	3
Lamiales	-	3	-	-	3	2	6	-	1	-	-	2	17
Laurales	-	-	-	-	-	-	1	-	-	-	-	-	1
Malpighiales	-	-	-	-	2	1	5	-	3	-	-	-	11
Malvales	-	-	-	-	1	-	1	-	4	-	-	1	7
Marattiales	-	-	-	-	-	-	1	-	-	-	-	-	1
Myrtales	1	-	-	-	-	1	5	-	-	-	-	1	8
Osmundales	-	-	-	-	-	-	1	-	-	-	-	-	1
Oxalidales	-	-	-	-	-	-	1	-	-	-	-	-	1
Pandanales	-	-	-	-	-	-	1	-	-	-	-	-	1
Pinales	-	-	-	-	-	-	-	-	1	-	-	-	1
Piperales	-	-	-	-	-	-	1	-	-	-	-	1	2
Poales	1	1	-	1	7	4	4	1	2	-	2	1	24
Polypodiales	-	-	-	-	1	2	17	-	4	-	-	1	25
Psilotales	-	-	-	-	-	-	-	-	1	-	-	-	1
Ranunculales	-	-	-	-	-	-	1	-	1	-	3	-	5
Rosales	-	1	-	-	-	1	5	-	2	-	-	1	10
Santalales	-	-	-	-	-	-	2	-	1	-	-	-	3
Sapindales	-	-	-	-	-	-	4	-	1	-	-	1	6
Saxifragales	-	-	-	-	-	-	1	-	-	-	-	-	1
Species Total	5	10	1	6	40	25	109	4	41	2	14	17	274

AN =Antipodes, AU = Auckland, BO= Bounty, CH= Chathams, KD = Kermadec, LH = Lord Howe, MQ = Macquarie, NO= Norfolk, SN = Snares, SW = Stewart, TK = Three Kings

TableA14 Island Group Frequency per morphological feature

Island group frequency												
Measurement type	Antipodes	Auckland	Bounty	Campbell	Chatham	Kermadecs	Lord Howe	Macquarie	Norfolk	Snares	Stewart	Three Kings
Flower area	1	1	-	1	10	4	11	-	3	-	1	3
Inflorescence length	-	1	-	1	6	2	8	-	3	-	-	3
Sepal area	1	1	-	1	11	4	10	-	3	-	-	3
Petal area	1	1	-	1	10	4	10	-	3	-	1	3
filament length	1	1	-	-	6	3	9	-	2	-	-	3
anther length	1	1	-	-	9	2	7	-	3	-	-	3
pedicel length	1	1	-	1	11	4	11	-	3	-	-	3
Stature	1	1	-	1	16	8	16	-	9	-	1	3
leaf area	1	1	-	1	16	8	17	-	9	-	1	3
Petiole length	-	-	-	-	8	5	11	-	6	-	-	2
Overall												

Appendix B: Chapter 2 Supplementary material

Analysis of different factors

Table B1 Analysis of Island Rule in floral features across Latitude

Morphological feature	t value	p value	R squared	F statistic
Flower area	-0.06	0.95	0.004	3.9e ⁻³ on 1 & 33 DF
Inflorescence length	2.47	0.02 *	0.22	6.12 on 1 & 22 DF
Petal area	0.49	0.63	0.008	0.24 on 1 & 32 DF
Sepal area	0.18	0.86	0.001	0.03 on 1 & 30 DF
Filament length	0.64	0.53	0.02	0.41 on 1 & 23 DF
Anther length	0.64	0.53	0.02	0.40 on 1 & 24 DF
Pedicle length	-1.27	0.95	0.05	3.4e ⁻³ on 1 & 33 DF

Different analysis factors

Factor	Description
island	The island of origin for an insular endemic species. Any large discrepancies as a result of island may indicate environmental differences.
measure	Where the measurements came from. Either herbaria or a floral description
endemic	The total number of endemic plant species in total from the given island of occurrence
order	The total number of endemic plant species within the same taxonomic order from the same island of occurrence
type	The generic type of plant (e.g. shrub, tree, herb)
Orderz	The taxonomic order of a plant. This factor indicates if there are tendencies of the lineage to display certain characteristics, regardless of the plant position in the landscape
rainfall	Annual average rainfall of the island (measured in mm)
temp	Annual average temperature of the island (measured in Celsius)
wind	Annual average windspeed (km/hr)
size	Size of the island (measured in km ²)

Table B2 Analysis of Island Rule in Filament length against different factors

	T value	P value	F stat	R squared
island	1.49	0.37	1.16 on 6 & 18 DF	0.28 (Adjusted 0.04)
measure	0.55	0.59	0.29 on 1 & 23 DF	0.01 (Adjusted -0.03)
endemic	-0.64	0.53	0.41 on 1 & 23 Df	0.02 (Adjusted -0.03)
order	1.53	0.14	2.35 on 1 & 23 DF	0.7 (Adjusted 0.5)
type	-2.99	0.89	0.33 on 5 & 19 DF	0.08 (Adjusted -0.16)
Orderz	0.21	0.77	0.63 on 10 & 14 DF	0.31 (Adjusted -0.18)
rainfall	-0.89	0.38	0.79 1 & 23 DF	0.03 (Adjusted-0.008)
temp	-0.77	0.45	0.60 on 1 & 23 DF	0.03 (Adjusted -0.02)
wind	0.23	0.82	0.05 on 1 & 23 DF	0.002 (Adjusted -0.04)
size	1.31	0.20	1.71 on 1 & 23 DF	0.07 (adjusted 0.03)

Table B3 Analysis of Island Rule in Petal area against different factors

	T value	P value	F stat	R squared
island	16.65	0.02*	2.77 on 8 & 25 DF	0.47 (Adjusted 0.29)
measure	1.73	0.09	2.99 on 1 & 32 DF	0.09 (Adjusted 0.06)
endemic	-1.81	0.08	3.29 on 1 & 32 DF	0.09 (Adjusted 0.06)
order	-0.12	0.90	0.02 on 1 & 32 DF	4.7xe ⁻⁴ (Adjusted -0.03)
type	-0.89	0.74	0.55 on 5 & 28 DF	0.09 (Adjusted -0.07)
Orderz	-4.14	0.19	1.54 on 11 & 22 DF	0.44 (Adjusted 0.15)
rainfall	-0.74	0.46	0.55 on 1 & 32 DF	0.02 (Adjusted -0.01)
temp	-0.83	0.41	0.69 on 1 & 32 DF	0.02 (Adjusted -0.01)
wind	-2.73	0.01 *	7.44 on 1 & 32 DF	0.19 (Adjusted 0.16)
size	2.86	0.01 *	8.20 on 1 & 32 DF	0.20 (adjusted 0.18)

Table B4 Analysis of Island Rule in Sepal area against different factors

	T value	P value	F stat	R squared
island	4.78	0.49	0.92 on 6 & 26 DF	0.17 (Adjusted -0.02)
measure	0.82	0.42	0.68 on 1 & 31 DF	0.02 (Adjusted -0.01)
endemic	-1.53	0.14	2.32 on 1 & 31 DF	0.07 (Adjusted 0.04)
order	0.69	0.49	0.47 on 1 & 31 DF	0.01 (Adjusted -0.02)
type	-5.31	0.29	1.32 on 5 & 27 DF	0.19 (Adjusted 0.05)
Orderz	-5.25	0.10	1.91 on 11 & 21 DF	0.5 (Adjusted 0.24)
rainfall	-1.57	0.13	2.47 on 1 & 31 DF	0.07 (Adjusted 0.04)
temp	-0.69	0.49	0.48 on 1 & 31 DF	0.02 (Adjusted -0.02)
wind	-2.04	0.05	4.18 on 1 & 31 DF	0.12 (Adjusted 0.09)
size	0.96	0.35	0.92 on 1 & 31 DF	0.03 (Adjusted -0.003)

Table B5 Analysis of Island Rule in Anther length against different factors

	T value	P value	F stat	R squared
island	1.79	0.20	1.59 on 6 & 19 DF	0.33 (Adjusted 0.12)
measure	-0.85	0.41	0.72 on 1 & 24 DF	0.03 (Adjusted -0.01)
endemic	-0.23	0.82	0.05 on 1 & 24 DF	2.2xe ⁻³ (Adjusted -0.04)
order	0.52	0.61	0.26 on 1 & 24 DF	0.01 (Adjusted -0.03)
type	2.66	0.79	0.51 on 6 & 19 DF	0.14 (Adjusted -0.13)
Orderz	12.14	0.07	2.31 on 11 & 14 DF	0.65 (Adjusted 0.07)
rainfall	-0.94	0.36	0.88 on 1 & 24 DF	0.04 (Adjusted -0.005)
temp	-0.38	0.71	0.14 on 1 & 24 DF	0.006 (Adjusted -0.04)
wind	-0.93	0.36	0.86 on 1 & 24 DF	0.03 (Adjusted -0.006)
size	0.65	0.95	0.004 on 1 & 24 DF	0.0002 (Adjusted -0.04)

Table B6 Analysis of Island Rule in Inflorescence length against different factors

	T value	P value	F stat	R squared
island	-16.67	0.03 *	3.06 on 6 & 17 DF	0.52 (Adjusted 0.35)
measure	1.52	0.14	2.31 on 1 & 22 DF	0.09 (Adjusted 0.05)
endemic	-1.47	0.16	2.16 on 1 & 22 DF	0.09 (Adjusted 0.05)
order	0.1	0.92	0.01 on 1 & 22 DF	4.2 xe ⁻⁴ (Adjusted -0.05)
type	-0.7	0.95	0.21 on 5 & 18 DF	0.06 (Adjusted -0.21)
Orderz	-4.88	0.41	1.13 on 9 & 14 DF	0.42 (Adjusted 0.05)
rainfall	-2.17	0.04 *	4.71 on 1 & 22 DF	0.18 (Adjusted 0.14)
temp	-1.42	0.17	2.02 on 1 & 22 DF	0.08 (Adjusted 0.04)
wind	-0.11	0.91	0.01 on 1 & 22 DF	0.0006 (Adjusted -0.004)
size	2.75	0.01 *	7.59 on 1 & 22 DF	0.26 (Adjusted 0.22)

Table B7 Analysis of Island Rule in Flower size against different factors

	T value	P value	F stat	R squared
island	5.6	0.01 *	3.19 on 8 & 26 DF	0.49 (Adjusted 0.34)
measure	-0.67	0.51	0.45 on 1 & 33 DF	0.01 (Adjusted -0.02)
endemic	-0.95	0.35	0.89 on 1 & 33 DF	0.03 (Adjusted 3.0xe ⁻³)
order	0.69	0.49	0.49 on 1 & 33 DF	0.01 (Adjusted -0.02)
type	-0.73	0.74	0.54 on 5 & 29 DF	0.09 (Adjusted -0.07)
Orderz	-2.36	0.29	1.29 on 13 & 21 DF	0.45 (Adjusted 0.1)
rainfall	-2.26	0.03 *	5.12 on 1 & 33 DF	0.13 (Adjusted 0.11)
temp	-0.49	0.63	0.24 on 1 & 33 DF	0.007 (Adjusted -0.02)
wind	-3.15	0.003 *	9.91 on 1 & 33 DF	0.23 (Adjusted 0.21)
size	1.81	0.08	3.28 on 1 & 33 DF	0.09 (Adjusted 0.06)

Table B8 Analysis of Island Rule in Pedicel length against different factors

	T value	P value	F stat	R squared
island	1.48	0.17	1.64 on 7 & 27 DF	0.29 (Adjusted 0.12)
measure	1.49	0.14	2.24 on 1 & 33 DF	0.06 (Adjusted 0.04)
endemic	0.65	0.52	0.42 on 1 & 33 DF	0.01 (Adjusted -0.02)
order	-0.96	0.45	0.91 on 1 & 33 DF	0.03 (Adjusted -2.6xe ⁻³)
type	2.67	0.44	0.99 on 5 & 25 DF	0.15 (Adjusted -1.9xe ⁻³)
Orderz	0.56	0.48	0.99 on 12 & 22 DF	0.35 (Adjusted 9.1xe ⁻⁴)
rainfall	0.02	0.98	0.0006 on 1 & 33 DF	1.7e ⁻⁵ (Adjusted -0.03)
temp	1.73	0.09	2.99 on 1 & 33 DF	0.08 (Adjusted 0.06)
wind	-0.34	0.73	0.12 on 1 & 33 DF	0.004 (Adjusted -0.03)
size	-2.37	0.02 *	5.63 on 1 & 33 DF	0.15 (Adjusted 0.12)

Supplementary graphs

Figure B1 Non-significant graphic results of latitude for floral features: (flower area (A), petal area (B), sepal area (C), filament length (D), anther length (E), and pedicel length (F)). All measurement data is natural logged. The dashed lined represented the line of isometry, where Island values = mainland values. See Appendix B for test statistic values. Latitude is measured in 'Decimal degrees'.

Species composition and measurement type and reference for floral features

Table B9 Flower area dataset measurements and measurement references

measurement type	island species	island flower area (cm ²)	Reference(s)	Mainland relative	mainland flower area (cm ²)	Reference(s)
herbarium	<i>Abrotanella rosulata</i>	0.067	SP102466	<i>Abrotanella spathulata</i>	0.38	SP57761
herbarium	<i>Alectryon excelsus grandis</i>	0.63	deLange, Cameron, & Murray, 1999	<i>Alectryon excelsus</i>	0.03	AK163401
herbarium	<i>Alyxia squamulosa</i>	0.48	Mel223111, MEL223108	<i>Alyxia reinwardtii</i>	0.39	H570/97 50
herbarium	<i>Brachyglottis arborescens</i>	0.17	SP78892 SP14292	<i>Brachyglottis repanda</i>	0.14	SP58743
flora	<i>Brachyglottis huntii</i>	1.34	NZFLORA	<i>Brachyglottis stewartiae</i>	0.97	NZFLORA
herbarium	<i>Carmichaelia exsul</i>	0.19	MEL2120317	<i>Carmichaelia williamsii</i>	3.49	K000950929
herbarium	<i>Corokia macrocarpa</i>	0.23	AK6736	<i>Corokia cotoneaster</i>	0.12	P01900002, BR0000005948567
herbarium	<i>Cryptocarya gregsonii</i>	0.25	NSW524068, NSW524032 confirmed with Hutton, 2002, and Australian Flora book vol 49	<i>Cryptocarya densiflora</i>	0.23	GH00041368
herbarium	<i>Dendrobium moorei</i>	0.85	K001085451 K001085449	<i>Dendrobium kingianum</i>	2.02	K001085439
flora	<i>Gentianella antipoda</i>	0.32	NZFLORA	<i>Gentianella cerina</i>	1.37	NZFLORA
herbarium	<i>Gentianella chathamica</i> subsp. <i>Chathamica</i>	1.56	SP003354, SP091523 (A)	<i>Gentianella saxosa</i>	1.72	SP47560, SP47517
herbarium	<i>Lepidium oblitum</i>	0.02	CHR 5523033	<i>Lepidium obtusatum</i>	0.03	K000642772
herbarium	<i>Leptecophylla robusta</i>	0.07	SP055221, SP018176	<i>Leptecophylla juniperina</i>	0.06	SP55449
herbarium	<i>Leptinella featherstonii</i>	0.51	MEL42209	<i>Leptinella serrulata</i>	0.22	SP091212
herbarium	<i>Melaleuca howeana</i>	0.06	NSW365338	<i>Melaleuca ericifolia</i>	0.04	B-W 14365-020
herbarium	<i>Melicope polybotrya</i>	0.15	L2124202, L2124201, L2124203, P05184454, K000717407	<i>Sacromelicope simplicifolia</i>	0.12	P00222344, P05214419
herbarium	<i>Melicytus novae-zelandiae</i> subsp. <i>centurionis</i>	0.19	SP029562 SP029543 SP029550 SP067867 SP085716	<i>Melicytus novae-zelandiae</i> subsp. <i>novae-zelandiae</i>	0.42	SP092870
herbarium	<i>Metrosideros kermadecensis</i>	0.84	SP095393, SP088606	<i>Metrosideros excelsa</i>	3.23	SP023044
herbarium	<i>Myosotidium hortensia</i>	0.23	K001067060	<i>Cynoglossum paniculatum</i>	0.08	K000573727
flora	<i>Myrsine chathamica</i>	0.07	nzcnp, nzflora	<i>Myrsine aquilonia</i>	0.13	nzcnp
herbarium	<i>Negria rhabdothamusides</i>	7.25	K000831478, NSW402620,	<i>Lenbrassia australiana</i>	2.16	L2819235, 00453906,

			E00642060, P03851834			L3793925, L2819233
herbarium	<i>Olearia mooneyi</i>	0.16	K000838921	<i>Olearia argophylla</i>	0.63	P00711258
herbarium	<i>Pennantia endlicheri</i>	0.15	L0014946	<i>Pennantia corymbosa</i>	0.063	SP086322, SP08611, SP083238
herbarium	<i>Pittosporum bracteolatum</i>	1.32	SP084276	<i>Pittosporum umbellatum</i>	0.63	TCD0010024
herbarium	<i>Plantago aucklandica</i>	0.033	K000438784	<i>Plantago lanigera</i>	0.19	SP104833/A, SP089135
flora	<i>Plectorrhiza erecta</i>	0.1	Hutton 2002, Dockrill 1967	<i>Plectorrhiza tridentata</i>	0.39	Australian Tropical Rainforest Orchids
herbarium	<i>Pseudopanax chathamicus</i>	0.26	SP3307, SP25031	<i>Pseudopanax crassifolius</i>	0.09	AK6183, SP022836, SP099142, SP078845, BR0000005785070
herbarium	<i>Pseudopanax kermadecensis</i>	0.13	SP05341	<i>Pseudopanax arboreus</i>	0.49	SP54311
herbarium	<i>Raoulia goyenii</i>	0.1	AK247246	<i>Raoulia buehneri</i>	0.03	AK121993
herbarium	<i>Senecio australis</i>	0.41	SP82400	<i>Senecio minimus</i>	0.48	AK347668
herbarium	<i>Senecio kermadecensis</i>	0.25	SP90180, SP31463	<i>Senecio hauwai</i>	0.42	CHR 201160 A
herbarium	<i>Sonchus grandifolius</i>	3	SP27962, SP27948	<i>Sonchus novae-zelandiae</i>	6	K000323043
herbarium	<i>Sonchus kirkii</i>	2.02	NSW135787, confirmed by Allan 1982	<i>Sonchus oleraceus</i>	1.26	AK304834
herbarium	<i>Veronica insularis</i>	0.63	AK217304, AK183138	<i>Veronica orchidea</i>	0.19	P03516880
herbarium	<i>Xylosma parvifolium</i>	0.14	MEL582311, MEL582308, MEL582310, MEL100641	<i>Xylosma vincentii</i>	0.24	P00648881, P002468816, P0015173, P04647112, P00648882

Table B10 Inflorescence length dataset measurements and measurement references

measurement type	island species	Inflorescence Length Average Island cm	Reference(s)	Mainland relative	Inflorescence Length Average mainland cm	Reference(s)
herbarium	<i>Abrotanella rosulata</i>	0.4	TP SP102466	<i>Abrotanella spathulata</i>	0.75	TP SP57761
herbarium	<i>Alectryon excelsus grandis</i>	12	de Lange 2012	<i>Alectryon excelsus excelsus</i>	14.5	AK337298
herbarium	<i>Alyxia squamulosa</i>	1.75	Mel223111, MEL223108	<i>Alyxia reinwardtii</i>	1.75	H570/97 50
herbarium	<i>Brachyglottis arborescens</i>	9.55	TP SP78892, SP14393	<i>Brachyglottis repanda</i>	17.27	TP SP58743
herbarium	<i>Brachyglottis huntii</i>	8.34	TP SP77964	<i>Brachyglottis stewartiae</i>	15.19	TP SP40512
herbarium	<i>Corokia macrocarpa</i>	5.5	AK6736	<i>Corokia cotoneaster</i>	0.6	P01900002
flora	<i>Dendrobium moorei</i>	7.5	aussie flora book, volume 49	<i>Dendrobium kingianum</i>	11	plantnet
flora	<i>Lepidium oblitum</i>	5.3	NZCPN	<i>Lepidium obtusatum</i>	3.3	NZCPN
herbarium	<i>Leptinella featherstonii</i>	0.6	MEL42209	<i>Leptinella serrulata</i>	0.5	Lloyd 1972

flora	<i>Melaleuca howeana</i>	1.5	aussie flora book, volume 49	<i>Melaleuca ericifolia</i>	1.35	vicflora
herbarium	Melicope polybotrya	6.5	L2124202, L2124201, L2124203, P05184454, K000717407	Sacromelicope simpliciaefolia	7	P00222344, P05214419
herbarium	<i>Melicytus novae-zelandiae subsp. centurionis</i>	0.45	AK5325	<i>Melicytus novae-zelandiae subsp. novae-zelandiae</i>	12	AK369727
herbarium	<i>Metrosideros kermadecensis</i>	2.46	TP SP095393, SP088606	<i>Metrosideros excelsa</i>	7.09	TP SP023044
herbarium	Myrsine chathamica	6	AK355715, AK358264	Myrsine aquilonia	1.5	MO2246496, CHR551684, AK226841
herbarium	Negria rhabdothermusides	5.2	K000831478, NSW402620, E00642060, P03851834	Lenbrassia australiana	9.5	L2819235, 00453906, L3793925, L2819233
herbarium	<i>Olearia mooneyi</i>	4.2	K000838921	<i>Olearia argophylla</i>	10	P00711258
herbarium	Pennantia endlicheri	10	L0014946	Pennantia corymbosa	5	SP086322, SP08611, SP083238
herbarium	<i>Pittosporum bracteolatum</i>	4	W0046205, W0046206	<i>Pittosporum umbellatum</i>	3.7	TCD0010024
herbarium	<i>Plantago aucklandica</i>	10	K000438784	<i>Plantago lanigera</i>	0.6	TP SP104833/A, SP089135
flora	<i>Plectorrhiza erecta</i>	3	aussie flora book, volume 49	<i>Plectorrhiza tridentata</i>	6.5	plantnet
herbarium	<i>Pseudopanax chathamicus</i>	3.26	TP SP25031, SP3307, SP3351, SP25068	<i>Pseudopanax crassifolius</i>	2.35	TP SP022836, SP099142, SP078845
herbarium	<i>Pseudopanax kermadecensis</i>	3.18	TP SP05341	<i>Pseudopanax arboreus</i>	3.36	TP SP54311
herbarium	<i>Senecio australis</i>	4.5	G00468791	<i>Senecio minimus</i>	12.2	K000852323
herbarium	<i>Veronica insularis</i>	3	K001070461	<i>Veronica orchidea</i>	15	P03516880, 3308

Table B11 Petal area dataset measurements and measurement references

measurement type	island species	island petal area	Reference(s)	Mainland relative	mainland petal area	Reference(s)
herbarium	<i>Abrotanella rosulata</i>	0.02	SP102466	<i>Abrotanella spathulata</i>	0.05	SP57761
herbarium	<i>Alectryon excelsus grandis</i>	0.06	deLange et al. 1999	<i>Alectryon excelsus excelsus</i>	0.01	AK163401
herbarium	<i>Alyxia squamulosa</i>	0.08	Mel223111, MEL223108	<i>Alyxia reinwardtii</i>	0.08	H570/97 50
herbarium	<i>Brachyglottis arborescens</i>	0.01	AK22882	<i>Brachyglottis repanda</i>	0.02	AK362469
herbarium	<i>Brachyglottis huntii</i>	0.31	SP77964	<i>Brachyglottis stewartiae</i>	0.38	SP40512

herbarium	<i>Carmichaelia exsul</i>	0.14	MEL2120317	<i>Carmichaelia williamsii</i>	2.45	K000950929, confirmed with Nzflora
herbarium	<i>Corokia macrocarpa</i>	0.05	AK6736	<i>Corokia cotoneaster</i>	0.05	BR0000005948246
herbarium	<i>Dendrobium moorei</i>	0.24	K001085451, K001085449	<i>Dendrobium kingianum</i>	0.3	NSW87427
flora	<i>Gentianella antipoda</i>	0.06	nzflora	<i>Gentianella cerina</i>	0.66	nzflora
herbarium	<i>Gentianella chathamica</i> subsp. <i>Chathamica</i>	0.41	SP003354, SP091523 (A)	<i>Gentianella saxosa</i>	0.57	SP47560, SP47517
herbarium	<i>Lepidium oblitum</i>	0.01	CHR 552303 B	<i>Lepidium obtusatum</i>	0.01	K000642772
herbarium	<i>Leptecophylla robusta</i>	0.01	SP055221, SP018176	<i>Leptecophylla juniperina</i>	0.01	SP55449
herbarium	<i>Leptinella featherstonii</i>	0.02	MEL42209	<i>Leptinella serrulata</i>	0.04	SP091212, confirmed by NZCPN
herbarium	<i>Melaleuca howeana</i>	0.02	NSW365338	<i>Melaleuca ericifolia</i>	0.01	B-W 14365-020
herbarium	<i>Melicope polybotrya</i>	0.04	L2124202, L2124201, L2124203, P05184454, K000717407	<i>Sacromelicope simplicifolia</i>	0.06	P00222344, P05214419
herbarium	<i>Melicytus novae-zelandiae</i> subsp. <i>centurionis</i>	0.01	SP029562, SP029543, SP029550, SP067867, SP085716	<i>Melicytus novae-zelandiae</i> subsp. <i>novae-zelandiae</i>	0.03	SP092870
herbarium	<i>Metrosideros kermadecensis</i>	0.12	SP095393, SP088606	<i>Metrosideros excelsa</i>	0.06	SP023044
herbarium	<i>Myosotidia hortensium</i>	0.48	K001067060	<i>Cynoglossum paniculatum</i>	0.048	K000573727
flora	<i>Myrsine chathamica</i>	0.05	nzcnp, nzflora	<i>Myrsine aquilonia</i>	0.027	nzcnp
herbarium	<i>Negria rhabdanthusoides</i>	0.12	K000831478, NSW402620, E00642060, P03851834	<i>Lenbrassia australiana</i>	0.09	L2819235, 00453906, L3793925, L2819233
herbarium	<i>Olearia mooneyi</i>	0.03	K000838921	<i>Olearia argophylla</i>	0.42	P00711258
herbarium	<i>Pennantia endlicheri</i>	0.05	L0014946	<i>Pennantia corymbosa</i>	0.03	SP086322, SP08611, SP083238
herbarium	<i>Pittosporum bracteolatum</i>	0.45	SP084276	<i>Pittosporum umbellatum</i>	0.42	TCD0009989
flora	<i>Plantago aucklandica</i>	0.01	nzflora	<i>Plantago lanigera</i>	0.01	nzflora
flora	<i>Plectorrhiza erecta</i>	0.04	Australian flora book, vol 49	<i>Plectorrhiza tridentata</i>	0.06	Australian Tropical Rainforest Orchids
herbarium	<i>Pseudopanax chathamicus</i>	0.06	SP3307, SP25031	<i>Pseudopanax crassifolius</i>	0.02	AK6183, SP022836, SP099142, SP078845,
herbarium	<i>Pseudopanax kermadecensis</i>	0.04	SP05341	<i>Pseudopanax arboreus</i>	0.05	SP54311
herbarium	<i>Raoulia goyenii</i>	0.02	AK247246	<i>Raoulia buehnerii</i>	0.001	AK121993
herbarium	<i>Senecio australis</i>	0.02	SP82400	<i>Senecio minimus</i>	0.03	AK347668
herbarium	<i>Senecio kermadecensis</i>	0.05	SP90180, SP31463	<i>Senecio hauwai</i>	0.03	CHR 201160 A

herbarium	<i>Sonchus grandifolius</i>	0.42	SP27962, SP27948	<i>Sonchus novae-zelandiae</i>	0.25	AK304834
herbarium	<i>Sonchus kirkii</i>	0.06	NSW135787	<i>Sonchus oleraceus</i>	0.05	AK304834
herbarium	<i>Veronica insularis</i>	0.15	AK217304, AK183138	<i>Veronica orchidea</i>	0.13	P03516880
herbarium	<i>Xylosma parvifolium</i>	0.03	MEL582311, MEL582308, MEL582310, MEL100641	<i>Xylosma vincentii</i>	0.06	P00648881, P002468816, P0015173, P04647112, P00648882

Table B12 Sepal area dataset measurements and measurement references

measurement type	island species	island sepal area	Reference(s)	Mainland relative	island sepal area	Reference(s)
herbarium	<i>Abrotanella rosulata</i>	0.01	SP102466	<i>Abrotanella spathulata</i>	0.03	SP57761
herbarium	<i>Alectryon excelsus grandis</i>	0.05	AK5125, confirmed by NZFLORA	<i>Alectryon excelsus excelsus</i>	0.002	AK163401
herbarium	<i>Alyxia squamulosa</i>	0.02	Mel223111, MEL223108	<i>Alyxia reinwardtii</i>	0.005	H570/97 50
herbarium	<i>Brachyglottis arborescens</i>	0.07	SP78892 SP14292	<i>Brachyglottis repanda</i>	0.04	SP58743
herbarium	<i>Brachyglottis huntii</i>	0.16	SP77964	<i>Brachyglottis stewartiae</i>	0.12	SP40512
herbarium	<i>Carmichaelia exsul</i>	0.01	MEL2120317	<i>Carmichaelia williamsii</i>	0.43	K000950929, confirmed with Nzflora
herbarium	<i>Corokia macrocarpa</i>	0.03	AK6736	<i>Corokia cotoneaster</i>	0.15	BR0000005948246
flora	<i>Dendrobium moorei</i>	0.02	Australian flora book, vol 49	<i>Dendrobium kingianum</i>	1.18	PlantNET
flora	<i>Gentianella antipoda</i>	0.058	nzflora	<i>Gentianella cerina</i>	0.25	nzflora
herbarium	<i>Gentianella chathamica</i> subsp. <i>Chathamica</i>	0.05	SP003354, SP091523 (A)	<i>Gentianella saxosa</i>	0.15	SP47560, SP47517
herbarium	<i>Lepidium oblitum</i>	0.01	CHR 552303 B	<i>Lepidium obtusatum</i>	0.01	K000642772
herbarium	<i>Leptecophylla robusta</i>	0.01	SP055221, SP018176	<i>Leptecophylla juniperina</i>	0.02	SP55449
herbarium	<i>Leptinella featherstonii</i>	0.04	MEL42209	<i>Leptinella serrulata</i>	0.01	SP091212, confirmed by NZCPN
herbarium	<i>Melaleuca howeana</i>	0.01	NSW365338	<i>Melaleuca ericifolia</i>	0.01	B-W 14365-020
herbarium	<i>Melicope polybotrya</i>	0.01	L2124202, L2124201, L2124203, P05184454, K000717407	<i>Sacromelicope simplicifolia</i>	0.02	P00222344, P05214419
herbarium	<i>Melicytus novae-zelandiae</i> subsp. <i>centurionis</i>	0.05	SP029562 SP029543 SP029550 SP067867 SP085716	<i>Melicytus novae-zelandiae</i> subsp. <i>novae-zelandiae</i>	0.004	SP092870
herbarium	<i>Metrosideros kermadecensis</i>	0.15	SP095393, SP088606	<i>Metrosideros excelsa</i>	0.06	SP023044
herbarium	<i>Myosotidia hortensium</i>	0.08	K001067060	<i>Cynoglossum paniculatum</i>	0.01	K000573727
herbarium	<i>Myrsine chathamica</i>	0.01	AK358264	<i>Myrsine aquilonia</i>	0.01	AK226841
flora	<i>Myrsine chathamica</i>	0.08	nzcnp, nzflora	<i>Myrsine aquilonia</i>	0.01	nzcnp

herbarium	Negria rhabdothermusides	0.12	K000831478, NSW402620, E00642060, P03851834	Lenbrassia australiana	0.08	L2819235, 00453906, L3793925, L2819233
herbarium	Olearia mooneyi	0.01	K000838921	Olearia argophylla	0.01	P00711258
herbarium	Pennantia endlicheri	0.01	L0014946	Pennantia corymbosa	0.01	SP086322, SP08611, SP083238
herbarium	Pittosporum bracteolatum	0.12	SP084276	Pittosporum umbellatum	0.15	TCD0009989
flora	Plantago aucklandica	0.02	nzflora	Plantago lanigera	0.05	nzflora
flora	Plectorrhiza erecta	0.03	Australian flora book, vol 49	Plectorrhiza tridentata	0.09	Australian Tropical Rainforest Orchids
herbarium	Pseudopanax chathamensis	0.03	AK6209	Pseudopanax crassifolius	0.01	AK6183
herbarium	Pseudopanax kermadecensis	0.01	K000810341	Pseudopanax arboreus	0.01	GOET012768
herbarium	Senecio australis	0.03	SP82400	Senecio minimus	0.04	G00301796
herbarium	Senecio kermadecensis	0.003	SP90180, SP31463	Senecio hauwai	0.02	CHR 201160 A
herbarium	Sonchus grandifolius	0.74	SP27962, SP27948	Sonchus novae-zelandiae	0.18	K000323043
herbarium	Sonchus kirkii	0.17	NSW135787	Sonchus oleraceus	0.11	AK304834
herbarium	Veronica insularis	0.03	K001070461	Veronica orchidea	0.05	B-W 00163-01-0
herbarium	Xylosma parvifolium	0.01	MEL582311, MEL582308, MEL582310, MEL100641	Xylosma vincentii	0.08	P00648881, P002468816, P0015173, P04647112, P00648882

Table B13 Filament length dataset measurements and measurement references

measurement type	island species	Filament length island mm	Reference(s)	Mainland relative	Filament length mainland mm	Reference(s)
herbarium	Alectryon excelsus grandis	0.75	deLange Cameron & Murray 1999	Alectryon excelsus excelsus	1	AK163401
herbarium	Alyxia squamulosa	8	MEL223111	Alyxia reinwardtii	5	S-G-10786
herbarium	Brachyglottis arborescens	2	AK218336	Brachyglottis repanda	2	AK362469
herbarium	Carmichaelia exsul	4.9	MEL2120317	Carmichaelia williamsii	8.5	K000950929
flora	Coprosma pilosa	3	aussie flora book	Coprosma fowerakeri	5.5	nzflora
herbarium	Corokia macrocarpa	4	AK6735	Corokia cotoneaster	2	BR0000005948567
herbarium	Dendrobium moorei	8	K001085450	Dendrobium kingianum	6	K001089618
flora	Gentianella antipoda	4.55	nzflora	Gentianella cerina	5.9	nzflora
flora	Gentianella chathamica subsp. chathamica	2.41	nzflora	Gentianella saxosa	7.85	nzflora
herbarium	Lepidium oblitum	1	CHR 552303 B	Lepidium obtusatum	1	K000642772
flora	Leptecophylla robusta	0.55	nzcnp	Leptecophylla juniperina	0.35	nzcnp
herbarium	Melaleuca howeana	2.8	NSW365338	Melaleuca ericifolia	4.5	B-W 14365-020
herbarium	Melicactus novae-zelandiae subsp. centurionis	0.67	SP029562, SP029543, SP029550,	Melicactus novae-zelandiae subsp. novae-zelandiae	2	AK5327

			SP067867, SP085716			
herbarium	<i>Metrosideros kermadecensis</i>	16	SP095393, SP088606	<i>Metrosideros excelsa</i>	23.89	AK358098, SP023044
herbarium	<i>Negria rhabdothermusides</i>	1.1	K000831478, NSW402620, E00642060, P03851834	<i>Lenbrassia australiana</i>	1.6	L2819235, 00453906, L3793925, L2819233
herbarium	<i>Olearia mooneyi</i>	3.5	K000838921	<i>Olearia argophylla</i>	4	P00711258
flora	<i>Plantago aucklandica</i>	0.34	nzflora	<i>Plantago lanigera</i>	0.43	nzflora
herbarium	<i>Plectorrhiza erecta</i>	3	Dockrill 1967	<i>Plectorrhiza tridentata</i>	4	MEL1540868
herbarium	<i>Pseudopanax chathamensis</i>	5	AK6209	<i>Pseudopanax crassifolius</i>	2.2	AK6183
herbarium	<i>Pseudopanax kermadecensis</i>	1.33	SP05341	<i>Pseudopanax arboreus</i>	4.19	SP54311
herbarium	<i>Senecio australis</i>	3.7	G00468791	<i>Senecio minimus</i>	0.4	K000852323
herbarium	<i>Sonchus grandifolius</i>	1.8	K000808042	<i>Sonchus novae-zelandiae</i>	0.8	K000323043
herbarium	<i>Sonchus kirkii</i>	10	NSW135787	<i>Sonchus oleraceus</i>	15	K001118926
herbarium	<i>Veronica insularis</i>	4	K001070461	<i>Veronica orchidea</i>	6.39	P03516880
herbarium	<i>Xylosma parvifolium</i>	0.25	MEL582311, MEL582308, MEL582310, MEL100641	<i>Xylosma vincentii</i>	0.3	P00648881, P002468816, P0015173, P04647112, P00648882

Table B14 Anther length dataset measurements and measurement references

measurement type	island species	Anther length island cm	Reference(s)	Mainland relative	Anther length mainland cm	Reference(s)
herbarium	<i>Alectryon excelsus grandis</i>	0.2	deLange Cameron & Murray 1999	<i>Alectryon excelsus excelsus</i>	0.03	AK163401
herbarium	<i>Alyxia squamulosa</i>	0.03	MEL223111	<i>Alyxia reinwardtii</i>	0.05	(S), S-G-10786
herbarium	<i>Brachyglottis arborescens</i>	0.25	AK22882	<i>Brachyglottis repanda</i>	0.08	AK10522
flora	<i>Coprosma pilosa</i>	0.02	aussie flora book, vol 49	<i>Coprosma fowerakeri</i>	0.27	nzflora
herbarium	<i>Corokia macrocarpa</i>	0.1	AK6735	<i>Corokia cotoneaster</i>	0.03	BR0000005948567
herbarium	<i>Dendrobium moorei</i>	0.07	K001085450	<i>Dendrobium kingianum</i>	0.05	K001089618
flora	<i>Festuca coxii</i>	0.39	floraseries	<i>Festuca luciarum</i>	0.26	nzflora
flora	<i>Gentianella antipoda</i>	0.08	nzflora	<i>Gentianella cerina</i>	0.13	nzflora
flora	<i>Gentianella chathamica</i> subsp. <i>Chathamica</i>	0.09	nzflora	<i>Gentianella saxosa</i>	0.2	nzflora
herbarium	<i>Lepidium oblitum</i>	0.01	CHR 552303 B	<i>Lepidium obtusatum</i>	0.05	K000642772
flora	<i>Leptecophylla robusta</i>	0.13	nzcnp	<i>Leptecophylla juniperina</i>	0.15	nzcnp
herbarium	<i>Melaleuca howeana</i>	0.03	NSW365338	<i>Melaleuca ericifolia</i>	0.02	B-W 14365-020

herbarium	<i>Melicytus novae-zelandiae</i> subsp. <i>centurionis</i>	0.09	AK5325	<i>Melicytus novae-zelandiae</i> subsp. <i>novae-zelandiae</i>	0.08	AK5327
herbarium	<i>Metrosideros kermadecensis</i>	0.1	SP095393, SP088606	<i>Metrosideros excelsa</i>	0.1	SP023044
herbarium	<i>Myosotidia hortensium</i>	0.11	K001067060	<i>Cynoglossum paniculatum</i>	0.2	K000573727
flora	<i>Myrsine chathamica</i>	0.2	nzcnp, nzflora	<i>Myrsine aquilonia</i>	0.15	nzcnp
herbarium	<i>Negria rhabdothermusides</i>	0.2	K000831478, NSW402620, E00642060, P03851834	<i>Lenbrassia australiana</i>	0.1	L2819235, 00453906, L3793925, L2819233
herbarium	<i>Pittosporum bracteolatum</i>	0.3	SP084276	<i>Pittosporum umbellatum</i>	2	P02502872, P02502869, AK4683
flora	<i>Plantago aucklandica</i>	0.12	nzflora	<i>Plantago lanigera</i>	0.1	nzflora
herbarium	<i>Plectorrhiza erecta</i>	0.04	Dockrill 1967	<i>Plectorrhiza tridentata</i>	0.05	MEL1540868
flora	<i>Poa chathamica</i>	0.27	nzflora	<i>Poa cita</i>	0.2	nzflora
herbarium	<i>Pseudopanax chathamicus</i>	0.05	AK6209	<i>Pseudopanax crassifolius</i>	0.1	AK6183
herbarium	<i>Pseudopanax kermadecensis</i>	0.11	SP05341	<i>Pseudopanax arboreus</i>	0.12	SP54311
herbarium	<i>Senecio australis</i>	0.02	G00468791	<i>Senecio minimus</i>	0.02	K000852323
herbarium	<i>Veronica insularis</i>	0.09	AK217304, AK183138	<i>Veronica orchidea</i>	0.19	P03516880
herbarium	<i>Xylosma parvifolium</i>	0.05	MEL582311, MEL582308, MEL582310, MEL100641	<i>Xylosma vincentii</i>	0.02	P00648881, P002468816, P0015173, P04647112, P00648882

Table B15 Pedicel length dataset measurements and measurement references

measurement type	island taxonomy	pedicel length island cm	Reference(s)	Mainland relative	Pedicel length mainland cm	Reference(s)
herbarium	<i>Abrotanella rosulata</i>	0.9	P00852291	<i>Abrotanella spathulata</i>	1.05	SP57761
herbarium	<i>Alectryon excelsus grandis</i>	0.23	De Lange et al. 2010	<i>Alectryon excelsus excelsus</i>	0.3	AK163401
herbarium	<i>Alyxia squamulosa</i>	0.42	Mel223111, MEL223108	<i>Alyxia reinwardtii</i>	0.5	H570/97 50
herbarium	<i>Brachyglottis arborescens</i>	1	SP78892, SP14292	<i>Brachyglottis repanda</i>	0.27	SP58743
herbarium	<i>Brachyglottis huntii</i>	1.16	SP77964	<i>Brachyglottis stewartiae</i>	0.75	SP40512
herbarium	<i>Carmichaelia exsul</i>	0.32	MEL2120317	<i>Carmichaelia williamsii</i>	0.6	K000950929
herbarium	<i>Corokia macrocarpa</i>	0.5	K000739753	<i>Corokia cotoneaster</i>	0.2	BR0000005948246
herbarium	<i>Cryptocarya gregsonii</i>	1.5	NSW524068, NSW524032	<i>Cryptocarya densiflora</i>	0.35	GH00041368
herbarium	<i>Dendrobium moorei</i>	1.8	K001085451, K001085449	<i>Dendrobium kingianum</i>	1.4	NSW87427
flora	<i>Gentianella antipoda</i>	0.14	nzflora	<i>Gentianella cerina</i>	0.12	nzflora
flora	<i>Gentianella chathamica</i> subsp. <i>Chathamica</i>	0.13	nzflora	<i>Gentianella saxosa</i>	0.15	nzflora

flora	<i>Lepidium oblitum</i>	0.07	NZCPN	<i>Lepidium obtusatum</i>	0.4	NZCPN
flora	<i>Leptecophylla robusta</i>	0.32	NZCPN	<i>Leptecophylla juniperina</i>	0.28	NZCPN
herbarium	<i>Leptinella featherstonii</i>	0.8	MEL42209	<i>Leptinella serrulata</i>	2	SP091212
herbarium	<i>Melaleuca howeana</i>	0.03	NSW365338	<i>Melaleuca ericifolia</i>	0.05	B-W 14365-020
herbarium	Melicope polybotrya	0.5	L2124202, L2124201, L2124203, P05184454, K000717407	Sacromelicope simplicifolia	0.1	P00222344, P05214419
herbarium	<i>Melicytus novae-zelandiae subsp. centurionis</i>	0.92	SP029562, SP029543, SP029550, SP067867, SP085716	<i>Melicytus novae-zelandiae subsp. novae-zelandiae</i>	0.29	SP092870
herbarium	<i>Metrosideros kermadecensis</i>	0.75	SP095393, SP088606	<i>Metrosideros excelsa</i>	0.42	CHR296099
herbarium	<i>Myosotidia hortensium</i>	1	K001067060	<i>Cynoglossum paniculatum</i>	2.5	K000573727
herbarium	<i>Myrsine chathamica</i>	0.12	AK358264	<i>Myrsine aquilonia</i>	0.13	AK226841
herbarium	Myrsine chathamica	0.2	AK355715, AK358264	Myrsine aquilonia	0.1	MO2246496, CHR551684, AK226841
herbarium	Negria rhabdothamusides	1.8	K000831478, NSW402620, E00642060, P03851834	Lenbrassia australiana	2.3	L2819235, 00453906, L3793925, L2819233
herbarium	<i>Olearia mooneyi</i>	1.1	K000838921	<i>Olearia argophylla</i>	0.9	P00711258
herbarium	Pennantia endlicheri	1	L0014946	Pennantia corymbosa	0.5	SP086322, SP08611, SP083238
herbarium	<i>Pittosporum bracteolatum</i>	1	K000591735	<i>Pittosporum umbellatum</i>	1.45	K000591694
herbarium	<i>Plantago aucklandica</i>	8	K000438784	<i>Plantago lanigera</i>	1.5	SP104833/A, SP089135
herbarium	<i>Plectorrhiza erecta</i>	1.12	Dockrill 1967	<i>Plectorrhiza tridentata</i>	0.3	MEL1540868
herbarium	<i>Pseudopanax chathamicus</i>	0.7	K000810129	<i>Pseudopanax crassifolius</i>	0.5	BR0000005785070
herbarium	<i>Pseudopanax kermadecensis</i>	0.4	K000810341	<i>Pseudopanax arboreus</i>	0.5	GOET012768
herbarium	<i>Senecio australis</i>	1.62	SP82400	<i>Senecio minimus</i>	0.27	AK347668
herbarium	<i>Senecio kermadecensis</i>	0.72	SP90180, SP31463	<i>Senecio hawaii</i>	1.35	CHR 201160 A
herbarium	<i>Sonchus grandifolius</i>	2.06	NSW135787	<i>Sonchus novae-zelandiae</i>	28	AK304834
herbarium	<i>Sonchus kirkii</i>	1.92	NSW135787	<i>Sonchus oleraceus</i>	2.57	AK304834
herbarium	<i>Veronica insularis</i>	0.6	K001070461	<i>Veronica orchidea</i>	0.15	B-W 00163-01-0
herbarium	Xylosma parvifolium	0.7	MEL582311, MEL582308, MEL582310, MEL100641	Xylosma vincentii	0.6	P00648881, P002468816, P0015173, P04647112, P00648882

Appendix C: Chapter 3 supplementary material

Analysis of different factors

Table C1 Analysis of Island Rule in vegetative features across Latitude

Morphological feature	t value	p values	R squared	F statistic
Stature	1.784	0.7934	0.004961	3.184 on 1 and 61 df
leaf area	0.988	0.327	0.016	0.9753 on 1 and 60 df
petiole length	0.481	0.6333	0.00067	0.2318 on 1 and 34 df

Table C2 Analysis of Island Rule in Stature with outlier

	T value	P value	F stat	R squared	Slope (95% CI)
Model 1	-3.34	0.01	11.13 on 1 and 52 df	0.17	-
Model 2	8.39	3.09e ⁻¹¹	-	-	0.72 (0.54 to 0.89)
Latitude	-0.41	0.68	0.18 on 1 and 52 df	0.01	-

Different Analysis factors

Factor	Description
island	The island of origin for an insular endemic species. Any large discrepancies as a result of island may indicate environmental differences.
measure	Where the measurements came from. Either herbaria or a floral description
endemic	The total number of endemic plant species in total from the given island of occurrence
order	The total number of endemic plant species within the same taxonomic order from the same island of occurrence
type	The generic type of plant (e.g. shrub, tree, herb)
Orderz	The taxonomic order of a plant. This factor indicates if there are tendencies of the lineage to display certain characteristics, regardless of the plant positioning in the landscape

Table C3 Analysis of Island Rule in Stature against different factors

	T value	P value	F stat	R squared
island	3.13	0.14	1.68 on 7 and 45 df	0.21
measure	0.154	0.88	0.023 on 1 and 51 df	0.0004
endemic	-2.66	0.44	4.269 on 1 and 51 df	0.08
order	-1.11	0.27	1.226 on 1 and 51 df	0.27
type	-1.12	0.6	0.841 on 11 and 41 df	0.6
Orderz	1.21	0.71	0.785 on 19 and 33 df	0.31
rainfall	-5.07	5.35e ⁻⁶ *	25.72 on 1 & 52 DF	0.33 (Adjusted 0.32)
temp	0.45	0.65	0.20 on 1 & 52 DF	0.004 (Adjusted -0.02)
wind	-3.55	0.0008 *	12.63 1 & 52 DF	0.19 (Adjusted 0.18)
size	2.46	0.02 *	6.06 on 1 & 52 DF	0.10 (Adjusted 0.09)

Table C4 Analysis of Island Rule in Leaf area against different factors

	T value	P value	F stat	R squared
island	4.22	0.15	1.586 on 8 & 48 DF	0.21
measure	-1.33	0.89	1.77 on 1 & 55 DF	0,3
endemic	-2.31	0.25	5.319 on 1 & 55 DF	0.01
order	-0.66	0.51	0.4353 on 1 & 55 DF	0.01
type	2.7	0.66	0.7789 on 11 & 45 DF	0.16
Orderz	-5.83	0.81	0.678 on 18 & 38 DF	0.24
rainfall	-1.48	0.14	2.21 on 1 & 55 DF	0.04 (Adjusted 0.02)
temp	-1.55	0.13	2.40 on 1 & 55 DF	0.04 (Adjusted 0.02)
wind	-0.62	0.54	0.38 on 1 & 55 DF	0.006 (Adjusted -0.01)
size	1.94	0.06	3.75 on 1 & 55 DF	0.06 (Adjusted 0.05)

Table C5 Analysis of Island Rule in petiole length against different factors

	T value	P value	F stat	R squared
island	-0.12	0.7	0.55 on 4 & 31 DF	0.07
measure	0.395	0.69	0.156 on 1 & 34 DF	0.004
endemic	-0.795	0.43	0.63 on 1 & 34 DF	0.02
order	-0.56	0.58	0.32 on 1 & 34 DF	0.01
type	1.727	0.65	0.69 on 6 & 29 DF	0.13
Orderz	3.036	0.16	1.58 on 13 & 22 DF	0.48
rainfall	-1.22	0.23	1.49 on 1 & 34 DF	0.04 (Adjusted 0.01)
temp	-0.73	0.47	0.53 on 1 & 34 DF	0.02 (Adjusted -0.01)
wind	-0.73	0.47	0.53 on 1 & 34 DF	0.02 (Adjusted -0.01)
size	0.43	0.67	0.19 on 1 & 34 DF	0.005 (Adjusted -0.02)

Supplementary graphs

Figure C1 Maximum stature length comparison of Island versus mainland. A) Comparing Si against Mainland maximum stature. $R^2 = 0.2141$. B) Comparing Island against Mainland maximum stature. $R = 0.8154$. (Both axes are natural logged)

Figure C2 Non-significant graphic results of presence of the Island Rule across latitude for stature (including outlier). Y axis is natural logged.

Figure C3 Cook's distance result demonstrating that *Arbotanella* is indeed a significant outlier.

Figure C4 Non-significant graphic results of presence of the Island Rule across latitude for vegetative features: (maximum stature (A), average leaf area (B), and Maximum petiole length (C)). The dashed lined represented the line of isometry, where Island values = mainland values. See appendices for test statistics values. Y axis is natural logged, and latitude is measured in 'Decimal degrees'.

Species composition and measurement type and reference for vegetative features

Table C6 Maximum stature dataset measurements and measurement references

measurement type	island species	Stature max Island m	Island Stature reference	Mainland relative	Stature max Mainland m	Mainland Stature reference
herbarium	<i>Abrotanella rosulata</i>	0.01	SP102466	<i>Abrotanella spathulata</i>	3.66	K000796675, SP57761
flora	<i>Alectryon excelsus grandis</i>	7	nzflora	<i>Alectryon excelsus excelsus</i>	20	nzcprn
herbarium	<i>Alyxia squamulosa</i>	2.5	Mel223111, MEL223108 descriptions	<i>Alyxia reinwardtii</i>	3	H570/97 50, confirmed by eflora
flora	<i>Araucaria heterophylla</i>	70	Australian Flora book vol 49	<i>Araucaria cunninghamii</i>	70	eflora
flora	<i>Asplenium dimorphum</i>	0.4	Australian Flora book vol 49	<i>Asplenium difforme</i>	0.45	Australian Flora book vol 49
flora	<i>Brachyglottis arborescens</i>	6	Oliver 1948	<i>Brachyglottis repanda</i>	6	nzflora
flora	<i>Brachyglottis huntii</i>	6	nzflora	<i>Brachyglottis stewartiae</i>	6	nzflora
herbarium	<i>Carex chathamica</i>	0.45	AK314668, confirmed by nzflora	<i>Carex kermadecensis</i>	1.1	AK366570, AK29529
flora	<i>Carex ventosa</i>	0.6	nzflora	<i>Carex trifida</i>	1	nzflora
flora	<i>Carmichaelia exsul</i>	3	Australian Flora book vol 49	<i>Carmichaelia williamsii</i>	4	Nz flora
flora	<i>Coprosma acutifolia</i>	10	nzflora	<i>Coprosma propinqua</i>	6	nzflora
flora	<i>Coprosma pilosa</i>	6	Australian Flora book vol 49	<i>Coprosma fowerakeri</i>	0.6	nzflora
flora	<i>Coprosma propinqua</i> var. <i>martinii</i>	6	Allan 1982	<i>Coprosma propinqua</i> var. <i>propinqua</i>	6	Allan 1982
flora	<i>Corokia macrocarpa</i>	6	nzflora	<i>Corokia cotoneaster</i>	3	nzflora
flora	<i>Cryptocarya gregsonii</i>	12	Australian Flora book vol 49	<i>Cryptocarya densiflora</i>	20	eflora
flora	<i>Cyathea milnei</i>	8	nzflora	<i>Cyathea dealbata</i>	12	nzflora
flora	<i>Cyperus insularis</i>	2	nzflora	<i>Cyperus ustulatus</i>	2	nzflora
flora	<i>Dendrobium moorei</i>	0.25	Australian Flora book vol 49	<i>Dendrobium kingianum</i>	0.3	PlantNET
herbarium	<i>Festuca coxii</i>	0.48	AK2009	<i>Festuca luciarum</i>	0.47	AK20090
flora	<i>Gentianella antipoda</i>	0.1	nzflora	<i>Gentianella cerina</i>	0.16	nzflora
flora	<i>Gentianella chathamica</i> subsp. <i>Chathamica</i>	0.16	nzflora	<i>Gentianella saxosa</i>	0.11	nzflora

flora	<i>Hedyscepe canterburyana</i>	15	Australian Flora book vol 49	<i>Basselinia glabrata</i>	15	palmpedia
herbarium	<i>Korthalsella disticha</i>	0.19	K000912682, AK23262	<i>Korthalsella dichotoma</i>	0.20	K000912677, L3923569, 2927190, P00078675, P04697482, P05066328, P05097223, P05066329
flora	<i>Korthalsella emersa</i>	0.15	Australian Flora book vol 49	<i>Korthalsella rubra</i>	0.16	vic flora
flora	<i>Lepidium oblitum</i>	0.95	nzcpcn	<i>Lepidium obtusatum</i>	0.3	nzflora
flora	<i>Leptecophylla robusta</i>	5	nzflora	<i>Leptecophylla juniperina</i>	2	nzcpcn
flora	<i>Leptinella featherstonii</i>	2	nzcpcn	<i>Leptinella serrulata</i>	0.05	Lloyd 1972
flora	<i>Melaleuca howeana</i>	3	Australian Flora book vol 49	<i>Melaleuca ericifolia</i>	7	vic flora
flora	<i>Melicope polybotrya</i>	8	Australian Flora book vol 49	<i>Sarcomelicope simplicifolia</i>	12	PlantNET
flora	<i>Melicytus novae-zelandiae subsp. centurionis</i>	5	Australian Flora book vol 49	<i>Melicytus novae-zelandiae subsp. novae-zelandiae</i>	3	Allan 1982
flora	<i>Meryta latifolia</i>	6	Australian Flora book vol 49	<i>Meryta denhamii</i>	3	rarepalmseeds.com
flora	<i>Metrosideros kermadecensis</i>	15	nzflora	<i>Metrosideros excelsa</i>	20	nzflora
herbarium	<i>Myosotidium hortensia</i>	1	K001067060 - confirmed with nzcpcn and field measurements	<i>Cynoglossum paniculatum</i>	0.6	HAL0115079, K000573727,
flora	<i>Myrsine chathamica</i>	12	nzcpcn	<i>Myrsine aquilonia</i>	12	nzflora
flora	<i>Myrsine platystigma</i>	6	Australian Flora book vol 49	<i>Myrsine faberi</i>	6	flora of china
flora	<i>Negria rhabdothamnoidea</i>	8	Australian Flora book vol 49	<i>Lenbrassia australiana</i>	4	australian tropical rainforest plants
flora	<i>Olearia mooneyi</i>	4	Australian Flora book vol 49	<i>Olearia argophylla</i>	9	plantnet
flora	<i>Pandanus forsteri</i>	13	Australian Flora book vol 49	<i>Pandanus kanehirae</i>	20	botany
flora	<i>Pennantia endlicheri</i>	10	Australian Flora book vol 49	<i>Pennantia corymbosa</i>	10	nzflora
flora	<i>Pittosporum bracteolatum</i>	8	Australian Flora book vol 49	<i>Pittosporum umbellatum</i>	12	nzcpcn
herbarium	<i>Plantago aucklandica</i>	0.11	K000438784	<i>Plantago lanigera</i>	0.15	SP104833/A SP089135

flora	<i>Plectorrhiza erecta</i>	0.3	Australian Flora book vol 49	<i>Plectorrhiza tridentata</i>	0.35	plantNet
flora	<i>Poa chathamica</i>	0.9	nzflora	<i>Poa cita</i>	1	nzflora
flora	<i>Pseudopanax chathamicus</i>	7	nzflora	<i>Pseudopanax crassifolius</i>	15	nzflora
flora	<i>Pseudopanax kermadecensis</i>	10	nzflora	<i>Pseudopanax arboreus</i>	8	nzflora
flora	<i>Pteris kingiana</i>	0.9	Australian Flora book vol 49	<i>Pteris tremula</i>	1.3	vicflora
flora	<i>Raoulia goyenii</i>	0.2	nzflora	<i>Raoulia buchananii</i>	0.05	nzflora
flora	<i>Senecio australis</i>	1	nzflora	<i>Senecio minimus</i>	2	nzcnp
herbarium	<i>Sonchus grandifolius</i>	2	K000808042, confirmed by nzflora	<i>Sonchus novae-zelandiae</i>	0.15	K000323043
flora	<i>Sonchus kirkii</i>	1	nzflora	<i>Sonchus oleraceus</i>	1.2	nzflora
flora	<i>Sporadanthus traversii</i>	2.5	nzflora	<i>Sporadanthus ferrugineus</i>	5	nzflora
herbarium	<i>Veronica insularis</i>	1	AK217304, AK183138 confirmed by nzflora	<i>Veronica orchidea</i>	0.65	102778, 102776
herbarium	<i>Xylosma parviflorum</i>	2	MEL582309 MEL100642 MEL582308, confirmed by aussie flora book	<i>Xylosma vincentii</i>	6	P00648883

Table C7 Leaf area dataset measurements and measurement references

measurement type	island species	Island average leaf area (cm ²)	Island leaf measurement reference(s)	Mainland relative	Mainland average leaf area (cm ²)	Mainland leaf measurement reference(s)
herbarium	<i>Abrotanella rosulata</i>	0.24	SP102466	<i>Abrotanella spathulata</i>	0.7	K000796675, SP57761
flora	<i>Alectryon excelsus grandis</i>	97.09	nzflora	<i>Alectryon excelsus excelsus</i>	22.12	nzcnp
flora	<i>Alyxia squamulosa</i>	11.89	Australian Flora book, vol 49	<i>Alyxia reinwardtii</i>	19	eflora
flora	<i>Araucaria heterophylla</i>	0.25	Australian Flora book, vol 49	<i>Araucaria cunninghamii</i>	0.3	eflora
flora	<i>Asplenium dimorphum</i>	1462.5	Australian Flora book, vol 49	<i>Asplenium difforme</i>	182.48	Australian Flora book, vol 49
flora	<i>Blechnum fullagari</i>	440	Australian Flora book, vol 49	<i>Blechnum nigrum</i>	50.63	nzflora
flora	<i>Blechnum howeanum</i>	2800	Australian Flora book, vol 49	<i>Blechnum triangularifolium</i>	3300	nzcnp
herbarium	<i>Brachyglottis arborescens</i>	104	Oliver, 1948	<i>Brachyglottis repanda</i>	187.5	M0030359, BM000810473, CHR 216104 C, CHR 216104 B
flora	<i>Brachyglottis huntii</i>	12.5	nzflora	<i>Brachyglottis stewartiae</i>	37.5	nzflora
herbarium	<i>Carex chathamica</i>	21.76	AK314668	<i>Carex kermadecensis</i>	78.86	AK366570, AK29529

herbarium	<i>Carex ventosa</i>	36	herbarium	<i>carex trifida</i>	78.75	herbarium
flora	<i>Carmichaelia exsul</i>	2.77	Australian Flora book, vol 49	<i>Carmichaelia williamsii</i>	1.45	nzflora
flora	<i>Coprosma acutifolia</i>	18.56	nzflora	<i>Coprosma propinqua</i>	0.39	nzflora
flora	<i>Coprosma pilosa</i>	1.39	Australian Flora book, vol 49	<i>Coprosma fowerakeri</i>	0.22	nzflora
flora	<i>Coprosma propinqua</i> var. <i>martinii</i>	0.61	nzflora	<i>Coprosma propinqua</i> var. <i>propinqua</i>	0.19	nzflora
flora	<i>Corokia macrocarpa</i>	15	nzflora	<i>Corokia cotoneaster</i>	0.51	nzflora
herbarium	<i>Cryptocarya gregsonii</i>	24.41	NSW524068, NSW524032	<i>Cryptocarya densiflora</i>	84.38	L0036112, GH00041368
flora	<i>Cyathea milnei</i>	19000	nzflora	<i>Cyathea dealbata</i>	21218.75	nzflora
flora	<i>Cyperus insularis</i>	345	nzflora	<i>Cyperus ustulatus</i>	103.5	nzcpcn
flora	<i>Dendrobium moorei</i>	17.5	Australian Flora book, vol 49	<i>Dendrobium kingianum</i>	9.75	plantnet
flora	<i>Festuca coxii</i>	1.69	nzflora	<i>Festuca luciarum</i>	0.06	nzflora
flora	<i>Gentianella antipoda</i>	2.01	nzflora	<i>Gentianella cerina</i>	4.71	nzflora
flora	<i>Gentianella chathamica</i> subsp. <i>Chathamica</i>	4.45	nzflora	<i>Gentianella saxosa</i>	5.42	nzflora
flora	<i>Hypolepis dicksonioides</i>	1793.84	nzcpcn	<i>Hypolepis rugosula</i>	3000	Brownsey & Chinnock 1987
herbarium	<i>Korthalsella disticha</i>	5.4	K000912682, AK23262	<i>Korthalsella dichotoma</i>	8	K000912677, L3923569, 2927190, P00078675, P04697482, P05066328, P05097223, P05066329
flora	<i>Korthalsella emersa</i>	1.39	Australian Flora book, vol 49	<i>Korthalsella rubra</i>	0.77	vicflora
flora	<i>Lepidium oblitum</i>	13.2	nzcpcn	<i>Lepidium obtusatum</i>	6.25	nzcpcn
flora	<i>Leptecophylla robusta</i>	0.8	nzflora	<i>Leptecophylla juniperina</i>	0.17	nzcpcn
flora	<i>Leptinella featherstonii</i>	3.3	nzflora	<i>Leptinella serrulata</i>	0.54	nzflora
flora	<i>Melaleuca howeana</i>	0.08	Australian Flora book, vol 49	<i>Melaleuca ericifolia</i>	0.13	vicflora
flora	<i>Melicope polybotrya</i>	51.02	Australian Flora book, vol 49	<i>Sarcomelicope simplicifolia</i>	45	plantnet
flora	<i>Melicytus novae-zelandiae</i> subsp. <i>centurionis</i>	21	Australian Flora book, vol 49	<i>Melicytus novae-zelandiae</i> subsp. <i>novae-zelandiae</i>	21	nzcpcn
flora	<i>Meryta latifolia</i>	1718.75	Australian Flora book, vol 49	<i>Meryta denhamii</i>	2400	Exploring the world of trees
flora	<i>Metrosideros kermadecensis</i>	5.25	nzflora	<i>Metrosideros excelsa</i>	20.41	nzflora
herbarium	<i>Myosotidium hortensia</i>	799.19	K001067060 - confirmed with nzcpcn and field measurements	<i>Cynoglossum paniculatum</i>	4.41	K000573727

flora	<i>Myrsine chathamica</i>	32.22	nzcpcn	<i>Myrsine aquilonia</i>	2.7	nzflora
herbarium	<i>Myrsine platystigma</i>	6	MEL622061, K000756398, BR0000005225002	<i>Myrsine faberi</i>	33	A00062246
flora	<i>Negria rhabdothermnoidea</i>	97.87	Australian Flora book, vol 49	<i>Lenbrassia australiana</i>	66.5	Australian tropical Rainforest Plants plantnet
flora	<i>Olearia mooneyi</i>	17.5	Australian Flora book, vol 49	<i>Olearia argophylla</i>	49.75	botany.cz
flora	<i>Pandanus forsteri</i>	500	Australian Flora book, vol 49	<i>Pandanus kanehirae</i>	1550	nzflora
flora	<i>Pennantia endlicheri</i>	129.06	Australian Flora book, vol 49	<i>Pennantia corymbosa</i>	0.82	nzflora
flora	<i>Pittosporum bracteolatum</i>	21.18	Australian Flora book, vol 49	<i>Pittosporum umbellatum</i>	26.25	nzflora
flora	<i>Plantago aucklandica</i>	26.56	nzflora	<i>Plantago lanigera</i>	3.42	plantnet
flora	<i>Plectorrhiza erecta</i>	3.38	Australian Flora book, vol 49	<i>Plectorrhiza tridentata</i>	6.01	nzflora
flora	<i>Poa chathamica</i>	6.13	nzflora	<i>Poa cita</i>	4.8	nzflora
flora	<i>Pseudopanax chathamicus</i>	95.63	nzflora	<i>Pseudopanax crassifolius</i>	37.5	nzflora
flora	<i>Pseudopanax kermadecensis</i>	68.75	nzcpcn	<i>Pseudopanax arboreus</i>	82.5	nzflora
flora	<i>Pteris kingiana</i>	763.75	Australian Flora book, vol 49	<i>Pteris tremula</i>	3375	nzcpcn
flora	<i>Pteris microptera</i>	22.5	Australian Flora book, vol 49	<i>Pteris comans</i>	3675	nzflora
flora	<i>Raoulia goyenii</i>	0.03	nzflora	<i>Raoulia buechananii</i>	0.08	nzflora
herbarium	<i>Senecio australis</i>	17.87	K000250508, G00468809, G00468791	<i>Senecio minimus</i>	23.2	K000852323 K000852325
flora	<i>Senecio kermadecensis</i>	15	nzflora	<i>Senecio hawaii</i>	1.56	nzflora
flora	<i>Sonchus grandifolius</i>	1600	nzflora	<i>Sonchus novae-zelandiae</i>	0.47	Allan 1982
flora	<i>Sonchus kirkii</i>	134.38	nzflora	<i>Sonchus oleraceus</i>	58.53	nzflora
flora	<i>Sporadanthus traversii</i>	1.91	nzflora	<i>Sporadanthus ferrugineus</i>	10.56	nzflora
herbarium	<i>Veronica insularis</i>	2.5	Royal Botanic Gardens, Kew (K), K001070461	<i>Veronica orchidea</i>	25.6	3308, P03516880, P02502869,
herbarium	<i>Xylosma parvifolium</i>	1.38	MEL582309, MEL100642, MEL582308	<i>Xylosma vincentii</i>	62	L0011394

Table C8 Petiole length dataset measurements and measurement references

measurement type	island species	Petiole length island cm	Island Petiole reference	Mainland relative	Petiole length mainland cm	Mainland Petiole reference
herbarium	<i>Alectryon excelsus grandis</i>	5.5	AK5125, AK210756	<i>Alectryon excelsus excelsus</i>	0.03	AK105236
flora	<i>Alyxia squamulosa</i>	0.4	Australian flora book vol 49	<i>Alyxia reinwardtii</i>	0.5	EFLORA

flora	<i>Blechnum fullagari</i>	7.5	Australian flora book vol 49	<i>Blechnum nigrum</i>	4.5	NZFLORA
flora	<i>Blechnum howeanum</i>	45	Australian flora book vol 50	<i>Blechnum triangularifolium</i>	44	NZCPN
herbarium	<i>Brachyglottis arborescens</i>	3	Oliver 1948	<i>Brachyglottis repanda</i>	5.86	SP58743
herbarium	<i>Carmichaelia exsul</i>	0.9	K000950835, MEL2120317	<i>Carmichaelia williamsii</i>	1	K000950929
flora	<i>Coprosma acutifolia</i>	0.6	NZFLORA	<i>Coprosma propinqua</i>	0.15	NZFLORA
herbarium	<i>Coprosma pilosa</i>	2	Australian flora book vol 50	<i>Coprosma fowerakeri</i>	0.06	NZFLORA
flora	<i>Corokia macrocarpa</i>	1	Allan 1982	<i>Corokia cotoneaster</i>	2	Allan 1982
flora	<i>Cryptocarya gregsonii</i>	1.25	PLANTNET	<i>Cryptocarya densiflora</i>	1.5	EFLORA
flora	<i>Cyathea brownii</i>	40	Australian flora book vol 49	<i>Cyathea robinsonii</i>	90	K000754054 description
flora	<i>Gentianella chathamica</i> subsp. <i>Chathamica</i>	0.95	NZFLORA	<i>Gentianella saxosa</i>	3.925	NZFLORA
flora	<i>Hypolepis dicksonioides</i>	45	NZCPN	<i>Hypolepis rugosula</i>	52.5	Brownsey & Chinnock 1987
flora	<i>Lepidium oblitum</i>	4	NZCPN	<i>Lepidium obtusatum</i>	8	NZCPN
flora	<i>Leptecophylla robusta</i>	0.205	NZCPN	<i>Leptecophylla juniperina</i>	0.115	NZCPN
herbarium	<i>Melaleuca howeana</i>	0.05	NSW365338	<i>Melaleuca ericifolia</i>	0.1	LINN-HS1243-13, B -W 14365 - 01 0 B -W 14365 -02 0
herbarium	<i>Melicope polybotrya</i>	1.3	K000717407	<i>Sarcomelicope simplicifolia</i>	3	P00543913, P00543914
herbarium	<i>Melicytus novae-zelandiae</i> subsp. <i>centurionis</i>	1.25	K000370077	<i>Melicytus novae-zelandiae</i> subsp. <i>novae-zelandiae</i>	1.3	AK369727
herbarium	<i>Metrosideros kermadecensis</i>	0.5	SP095393, SP088606	<i>Metrosideros excelsa</i>	6.62	SP023044
herbarium	<i>Myosotidium hortensia</i>	30	00947912, confirmed with NZCPN	<i>Cynoglossum paniculatum</i>	0.4	K000573727, HAL0115079
flora	<i>Myrsine chathamica</i>	0.75	NZCPN	<i>Myrsine aquilonia</i>	0.195	NZFLORA
flora	<i>Olearia mooneyi</i>	0.75	Australian flora book vol 49	<i>Olearia argophylla</i>	0.9	PLANTNET

flora	<i>Pennantia endlicheri</i>	1.85	Australian flora book vol 50	<i>Pennantia corymbosa</i>	1	Allan 1982
herbarium	<i>Pittosporum bracteolatum</i>	2.62	SP084276	<i>Pittosporum umbellatum</i>	2	AK102344, K000591694
herbarium	<i>Plectorrhiza erecta</i>	1	Dockrill 1967	<i>Plectorrhiza tridentata</i>	0.1	MEL1540868
flora	<i>Pseudopanax chathamicus</i>	0.15	Allan 1982	<i>Pseudopanax crassifolius</i>	0.1	NZCPN
flora	<i>Pseudopanax kermadecensis</i>	15	NZCPN	<i>Pseudopanax arboreus</i>	17.5	NZCPN
flora	<i>Pteris kingiana</i>	40	Australian flora book vol 50	<i>Pteris tremula</i>	31.6	NZFLORA
herbarium	<i>Senecio australis</i>	1	K000250508	<i>Senecio minimus</i>	0.556	K000852325
flora	<i>Sonchus grandifolius</i>	20	NZFLORA	<i>Sonchus novae-zelandiae</i>	7	NZFLORA
herbarium	<i>Sonchus kirkii</i>	0.01	NSW135787	<i>Sonchus oleraceus</i>	0.01	K001118922
herbarium	<i>Xylosma parvifolium</i>	0.25	MEL582309, MEL100642, MEL582308	<i>Xylosma vincentii</i>	1.15	L0011394