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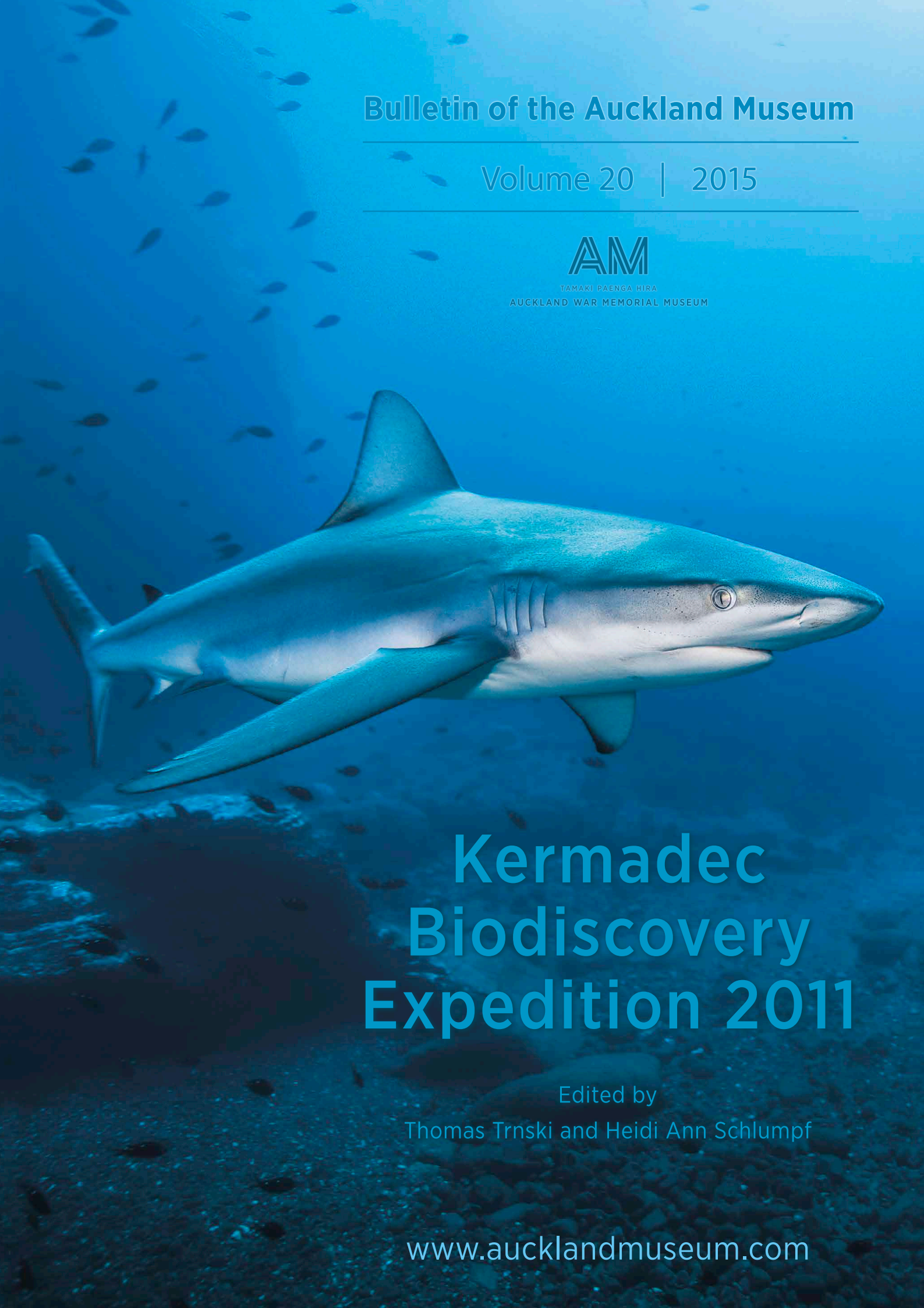

Kermadec Biodiscovery Expedition 2011

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A checklist of the mosses of the Kermadec Islands

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Abstract
A checklist of the mosses of the Kermadec Islands is presented. One hundred and thirty-five mosses from 38 families and 80 genera are recorded for the islands. Allowing for changes in names and some errors in identification this listing increases the moss flora of the islands by 84 taxa on the figures last reported for the Kermadec Islands in 1996. There are still, however, no endemic mosses recognised from the islands. Nevertheless, 11 mosses (all recorded from Raoul Island, the largest island in the Kermadec Islands) are new records for the moss flora of the New Zealand Botanical Region, and 15 taxa previously regarded as endemic to the islands of continental New Zealand are now known from the Kermadec Islands. Eight mosses are regarded as naturalised to the islands. An account of the mosses of each of the main islands of the Kermadec Islands is given, and a tabulated listing of their distribution provided.

Keywords
Bryophytes; mosses; Kermadec Islands; New Zealand botanical region; new records

INTRODUCTION

The Kermadec Islands (Fig. 1), a remote and widely scattered oceanic archipelago of 23 islands, islets and rock stacks, are the most northerly part of the New Zealand Botanical Region (as defined by Allan 1961, but see also de Lange & Rolfe 2010). The islands, located between latitudes 29˚ 15'– 31˚ 30'S, and longitudes 177˚ 55'– 179˚ W (Sykes 1977; Renner & de Lange 2011), are mostly andesitic volcanic islands resulting from ongoing subduction between the overriding Indo-Australian Plate and the subducted Pacific Plate (Lloyd & Nathan 1981). The largest islands are (from North to South): Raoul Island (2943 ha, c.520 m a.s.l.), Macauley Island (323.75 ha, 238 m. a.s.l.) and Curtis (52.6 ha, 137 m a.s.l.) (data from Sykes 1977). Raoul is a volcanically active, cliff-girt, heavily forested island, while Macauley also cliff-girt is currently volcanically quiescent, though often beset by earthquakes. Macauley is mostly vegetated by a dense fernland of *Hypolepis dicksonioides* (de Lange 2015). Curtis is volcanically active and is mostly vegetated by a low turf of Kermadec ice plant (*Disphyma australe* subsp. *stricticaule* Chinnock). Climate data is available only for Raoul Island, where a meteorological station is maintained by the New Zealand Department of Conservation. The climate of that island is described as humid, subtropical, (data from http://en.wikipedia.org/wiki/Raoul_Island accessed 17 August 2011), and mostly warm and wet throughout the year. Climate data for the island (gathered since the 1940s) ranges from an average high of 22.1°C to an average low of 16.7°C, with a mean yearly precipitation of 1558 mm. In the summer months temperatures reach an average recorded maximum of 25.7°C and low of 20.5°C, and in winter temperatures may drop to 13.3°C. Rainfall is more or less evenly distributed throughout the year, though the winter months are slightly wetter. In addition to volcanic and seismic activity all of the islands are subjected to infrequent, high intensity tropical cyclones (Morton 1957; Sykes 1977; Revell 1981; Terry 2007). Not only do tropical cyclones have a major impact on the vegetation cover, but they are also likely to be an important agent in the long distance dispersal of plants and animals to the island group (see de Lange & Galloway 2015).

The Kermadec Islands supports an endemic vascular flora of 22 formally described and accepted endemic vascular plant taxa (Sykes 1977; de Lange *et al*. 2005; Wilmot-Dear & Friis 2006; Perrie & Brownsey 2012; de Lange *et al*. 2013; Cameron & Sykes 2015). There are no endemic vascular plant genera and all of the vascular plant endemics are closely related to taxa on the nearby islands, especially New Zealand (see Sykes 1977; de Lange *et al*. 2005; Wimot-Dear & Friis 2006; de Lange *et al*. 2013). Aside from vascular plants there is now only one doubtfully endemic liverwort (*Plagiochila pacifica* Mitt.) (Braggins *et al*. 2014). While the vascular plant flora has received considerable attention (see especially Sykes 1977; Sykes & West 1996; de Lange *et al*. 2004; de Lange *et al*. 2005; Barkla *et al*. 2008) much less is known about the bryophytes of the islands (Renner & de Lange 2011; Braggins *et al*. 2014). Based largely on W.R. Sykes' own gatherings, preliminary listings of mosses, hornworts and liverworts were assembled by Sykes (1977) and Campbell (1977, 1997), the moss

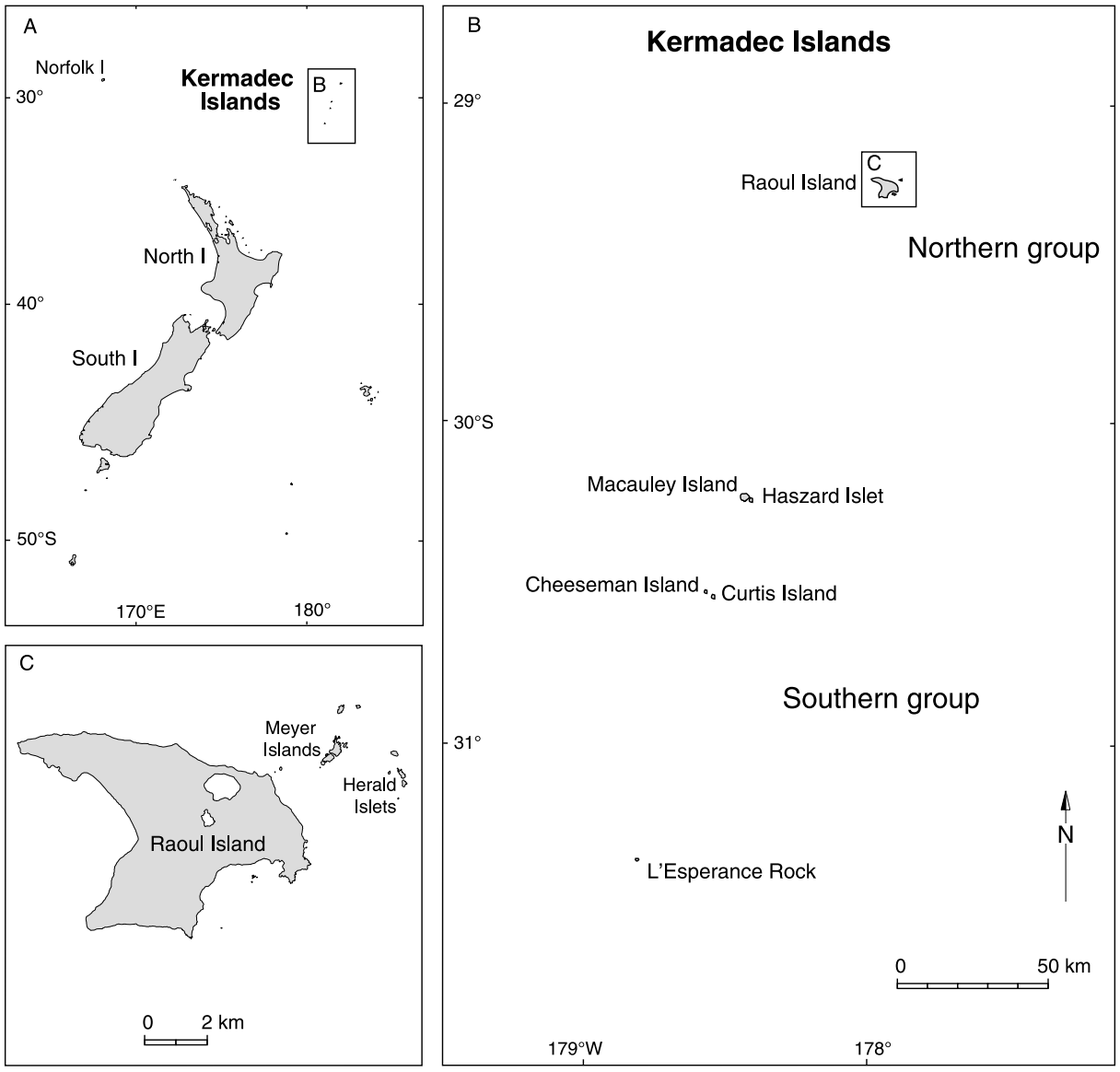

Figure 1. The Kermadec Islands, *A*, Location of the Kermadec Islands in relation to the continental islands of New Zealand. *B*, Spatial relationship between the northern and southern islands of the Kermadec Islands. *C*, Raoul, Meyer and Herald Islets – collectively the Northern Kermadec Islands. *Image: Jeremy Rolfe*.

specimens being identified by bryologist K.W. Allison. The moss listing was then revised and expanded upon by A.J. Fife and J.E. Beever, largely making use of new material collected by Sykes after 1977 and gatherings made in 1994 by E.K. Cameron, and by C. J. West. In that paper (Beever *et al*. 1996) the authors noted that more discoveries in the bryophyte flora of this northern outpost of New Zealand were yet to be made.

In 2009 as part of a New Zealand Department of Conservation supported visit to Raoul Island one of us, Peter J. de Lange (hereafter PdL), was sent to the islands to prepare a checklist of the Kermadec Islands bryophytes to assist with the Department's development of a management plan for the islands (see Renner & de Lange 2011). That visit enabled only two full days in the field and those confined to Raoul Island. Later in May 2011 PdL participated in the three week long Auckland Museum Kermadec 2011 Biodiscovery Expedition. That expedition permitted a more comprehensive coverage of not only Raoul Island but virtually all of the other islands and islets within the archipelago. This paper reports on the mosses collected by PdL during the 2009 and 2011 Kermadec Islands visits, and in addition updates information presented in Beever *et al*. (1996).

THE CHECKLIST

The mosses are arranged according to the nomenclature and treatment advocated by Fife & Beever (2014) – an unpublished Checklist of New Zealand Mosses prepared for the Moss Flora of New Zealand). Authorities for mosses are given in the checklist (see Appendix 1); that of other plants within the main body of the text. For each record a single voucher is cited. This voucher is usually the first undisputed gathering we have seen of a particular taxon from the islands. Herbarium acronyms

Table 1. Moss distribution within the Kermadec Islands. * = Naturalised in the New Zealand Botanical Region

	Northern Kermadec Islands						Southern Kermadec Islands					
	Nugent	Napier	Dayrell	Chanters	North Meyer	South Meyer	Raoul	Haszard	Macauley	Curtis	Cheeseman	L'Esperance
Achrophyllum dentatum							+					
Atrichum androgynum							+					
Barbula calycina				+			+		+			
Brachythecium rutabulum							+					
Breutelia pendula							+					
Bryoerythrophyllum dubium							+					
Bryum argenteum						+	+	+	+		+	+
B. clavatum									+			
B. dichotomum			+		+	+	+	+	+	+	+	
B. preissianum						+						
* *B. radiculosum*									+			
* *B. rubens*							+					
B. sauteri							+		+			
* *Calliergonella cuspidata*							+					
Calomnion complanatum							+					
Calymperes graeffeanum							+					
C. tahitense							+					
C. tenerum							+					
Calyptrochaeta brownii							+					
Campylopus clavatus							+		+			
C. introflexus							+					
C. pyriformis							+			+		
Camptochaete angustata							+					
C. arbuscula var. *arbuscula*							+					
Canalohypopterygium tamariscinum							+					
Ceratodon purpureus							+		+		+	
Cryphaea tenella							+					
Cryptogonium phyllogonioides							+					
Ctenidium pubescens							+					
Cyathophorum bulbosum							+					
Cyclodictyon blumeanum							+					
Dendrohypopterygium filiculaeforme							+					

	Northern Kermadec Islands						Southern Kermadec Islands					
	Nugent	Napier	Dayrell	Chanters	North Meyer	South Meyer	Raoul	Haszard	Macauley	Curtis	Cheeseman	L'Esperance
Dicnemon calycinum							+					
D. semicryptum							+					
Didymodon australasiae							+		+		+	
D. torquatus									+			
D. weymouthii					+		+				+	
Distichophyllum crispulum							+					
D. microcarpum							+					
D. pulchellum var. *pulchellum*							+					
D. rotundifolium							+					
Ditrichum difficile									+			
Echinodium umbrosum							+					
Ectropothecium sandwichense							+					
Eriodon cylindritheca							+					
Eucamptodon muelleri							+					
* *Eurhynchium praelongum*							+					
* *E. speciosum*							+					
Fabronia australis							+					
Fissidens asplenioides							+		+			
* *F. bryoides*							+					
F. crispulus var. *robinsonii*							+					
F. curvatus var. *curvatus*							+		+			
F. dealbatus							+					
F. dietrichiae							+					
F. hylogenes							+					
F. hyophilus						+	+					
F. leptocladus			+		+		+		+		+	
F. linearis. var. *linearis*		+		+	+	+	+		+			
F. megalotis					+		+		+			
F. oblongifolius							+		+			
F. linearis var. *angustifolius*							+					
F. pallidus							+					
F. rigidulus var. *rigidulus*							+					
* *F. taxifolius*							+					
F. taylorii var. *sainsburyanus*							+					
F. tenellus var. *australiensis*							+					

	Northern Kermadec Islands						Southern Kermadec Islands					
	Nugent	Napier	Dayrell	Chanters	North Meyer	South Meyer	Raoul	Haszard	Macauley	Curtis	Cheeseman	L'Esperance
F. tenellus var. *tenellus*							+		+			
F. waiensis							+					
Funaria hygrometrica									+			
Grimmia pulvinata var. *africana*	+						+				+	
Gymnostomum calcareum							+					
Haplohymenium pseudotriste							+					
Holomitrium perichaetiale							+					
Hymenodon pilifer							+					
Hyophila involuta							+					
Hypnodendron arcuatum							+					
Hypnum chrysogaster							+					
H. cupressiforme var. *cupressiforme*							+					
Hypopterygium didictyon							+					
H. tamarisci							+					
Isopterygium albescens							+					
Leptostomum macrocarpum							+					
Leucobryum javense var. *javense*							+					
Macrocoma tenue subsp. *tenue*							+					
Macromitrium brevicaule					+		+		+			
M. gracile							+					
M. incurvifolium							+					
M. ligulaefolium							+					
M. longipes							+					
M. prorepens							+					
Meteoriopsis reclinata							+					
Neckeropsis lepineana							+					
Ochiobryum blandum							+					
Orthorrhynchium elegans							+					
Papillaria crocea							+					
Pendulothecium punctatum							+					
Philonotis tenuis					+		+		+	+		
Plagiomnium novae-zealandiae							+					
Polytrichadelphus magellanicus							+		+			
Polytrichum commune							+		+			
* *Pseudoscleropodium purum*							+					
Ptychomitrium australe						+	+		+			

	Northern Kermadec Islands						Southern Kermadec Islands					
	Nugent	Napier	Dayrell	Chanters	North Meyer	South Meyer	Raoul	Haszard	Macauley	Curtis	Cheeseman	L'Esperance
Pyrrhobryum paramattense							+					
Racopilum cuspidigerum var. *convolutaceum*												
Rhaphidorrhyncium amoenum					+		+					
Rhychnostegium muricutalum							+					
R. tenuifolium							+		+			
Rosulabryum campylothecium							+					
Rosulabryum capillare									+			
Rosulabryum subtomentosum						+	+					
Schistidium apocarpum									+			
Sciadocladus kerrii							+					
Sematophyllum homomallum						+	+					
S. jolliffii							+					
S. subhumile var. *contiguum*							+		+			
Syntrichia antarctica						+	+		+			
S. laevipila					+				+			
S. papillosa							+					
S. phaea			+						+			
Symphysodontella cylindracea							+					
Syrrhopodon armatus			+				+					
Thuidium furfurosum							+					
T. sparsum							+		+			
Tortella flavovirens				+		+			+			
T. knightii						+						
Tortula muralis							+		+			
Trematodon suberectus							+		+	+	+	
Trichostomum c.f. *sciophilum*							+		+			
Vesicularia inflectens							+					
Weissia controversa							+		+		+	
W. "North Cape"							+		+			
Weymouthia cochlearifolia							+					
Wijkia extenuata var. *caudata*							+					
Zygodon intermedius							+					
Totals	1	1	4	3	9	11	123	1	38	4	9	1

follow those used by Thiers (2014). Voucher specimens for this list are those that have been personally examined by the authors from collections held in AK (including AKU), CHR and WELT including specimens that had been previously researched by A.J. Fife and J.E. Beever (Beever *et al*. 1996). The moss collections made by PdL are lodged in AK (mostly 2011 gatherings) and CHR (mostly 2009 gatherings). Duplicates from the 2009 and 2011 visits have been mostly lodged in WELT. The nomenclature and taxonomy used is based on the decisions reached by the authors up to 1 August 2015.

RESULTS

A total of 223 packets of mosses were gathered during the 2009 and 2011 visits to the Kermadec Islands. From these, 84 new moss records (c.f. Beever *et al*. 1996) were obtained. A total of 134 formally described and accepted taxa, and one informally recognized entity in the poorly understood genus *Weissia* (*W*. "N. Cape") are listed here for the Kermadec Islands (Appendix 1). Thus with the inclusion of this unnamed entity there are 135 mosses known on the islands. Eight of mosses recorded here (*Bryum rubens*, *Calliergonella. cuspidata*, *Eurhynchium praelongum*, *Fissidens bryoides*, *F. taxifolius*, *Pseudoscleropodium purum*, *Bryum radiculosum*, and *Eurhynchium speciosum*) are considered naturalised to New Zealand, the latter two tentatively (Fife and Beever August 2012 unpubl.), and hence likewise to the Kermadec Islands. With the exception of *B. radiculosum* (found in this survey only on Macauley Island), these naturalised species are confined to Raoul Island. Eleven taxa (see Appendix 1: Table 1) are new for the New Zealand Botanical Region. A detailed treatment of these new mosses has been provided (e.g., Fife 2014) or will be forthcoming as fascicles of each family in the *Flora of New Zealand – Mosses* series are published. Furthermore, twelve of the taxa listed in this paper are mosses that had been regarded as endemic to the islands of continental New Zealand (see Table 2). Their discovery on the oceanic Kermadec Islands represents not only a significant northerly range extension for these species but also suggests that they may yet be found elsewhere in the South Pacific.

Table 2. Mosses previously regarded as endemic to the islands of continental New Zealand and now recorded from the oceanic Kermadec Islands

Camptochaete angustata
Canalohypopterygium tamariscinum
Dendrohypopterygium filiculaeforme
Dicnemon semicryptum
Didymodon weymouthii
Fissidens hylogenes
Fissidens waiensis
Hypnodendron arcuatum
Macromitrium gracile
Macromitrium longipes
Sciadocladus kerrii
Trichostomum cf. *sciophilum*

THE ISLANDS

Table 1 shows the distribution of mosses through those islands, islets and rock stacks of the Kermadec Islands examined by PdL in 2009 and 2011, and in the case of Curtis (which was not investigated by PdL) includes those mosses collected from there by past visitors (Sykes 1977; AK!, CHR!, WELT!). As one would expect, the much larger, physiographically diverse and densely forested Raoul Island has the largest moss flora (123 taxa), followed by the next largest island Macauley (37), and then the smaller, forested Meyer Islands (18). While the survey coverage of the Kermadec Islands has now been fairly extensive, several parts of Raoul Island still need critical investigation, particularly the caldera floor, fumaroles and craters (all of which for safety reasons remained out of bounds during the 2009 and 2011 visits), and the rugged Hutchison's Bluff portion of that island. Also (aside from a few chance gatherings of mosses made from the base of Haszard Island), West and South Chanter, Dougal Rocks, Haszard, and nearby "Haszardette" have received no bryological attention. No mosses were found on Egeria and Milne Rocks (de Lange 2014).

The Northern Kermadec Islands

The Meyer Islands and Herald Islets

The Meyer Islands and Herald Islets comprise a cluster of 13 vegetated islands, islets and rock stacks and a further 21 low-lying non-vegetated rock stacks and associated exposed reefs. The largest islands are the Meyers, and these support a forest cover dominated by Kermadec pōhutukawa (*Metrosideros kermadecensis* W.R.B.Oliv.) and Kermadec ngaio (*Myoporum rapense* subsp. *kermadecensis* (W.R.Sykes) Chinnock). This forest is similar in composition to that seen on the lower coastal slopes of nearby Raoul Island (Sykes 1977). Napier, Nugent and Dayrell also support similar, though very much smaller, areas of this forest type, although that on Nugent hardly qualifies as such, being merely a scattering of stunted trees and shrubs at the very summit. The vegetation cover of the Chanters was described as one dominated by Kermadec ngaio (reported as *M. obscurum*) by Sykes (1977). At the time PdL visited North Chanter, the vegetation of that island, and indeed that of all of these outer islands and islets, was only just starting to recover from Tropical Cyclone Bune, which had struck the Kermadec Islands on the 28 March 2011 (de Lange 2011). Consequently much of the vegetation was either dead, or the trees and shrubs stripped completely of their foliage (Fig. 2), though many woody species were already sporting "balls" of epicormic regrowth. Aside from the cyclone defoliating and/or killing the taller vegetation, on many of these islands the ground cover had also been completely stripped leaving only bare earth. It is thus likely that this cyclone damage will have contributed to the depauperate moss flora recorded from these islands and islets during this expedition. In total 29 moss gatherings representing 22 taxa were collected from these islands and islets (Table 1). Four species (*Bryum preissianum*, *Syntrichia phaea*, *Tortella flavovirens* and *T. knightii*) have not yet been collected from Raoul

Island, and one, *Tortella knightii*, is so far known from the Kermadec Islands on South Meyer only (the Raoul record cited by Sykes (1977) was a misidentification (see Beever *et al*. 1996)). The Meyer Islands supported 18 taxa (Table 1), 15 of these, as far as the collective body of these outer islands and islets are concerned, exclusively so. North Meyer had seven taxa not seen on South Meyer, and South Meyer nine not seen on North Meyer. The most common mosses on the Meyers were the terricolous *Bryum dichotomum* and *Fissidens linearis* var. *linearis*, both of which formed carpets across much of the petrel-burrowed forest floor, and in the case of the *Fissidens* green turves on drought prone overhanging banks and cliff faces and large clods of soil and weathered saprolite lying below these (Fig. 3). Three other *Fissidens* were found on The Meyers, *F. leptocladus* and *F*. *megalotis* on North Meyer and *F. hyophilus* on South Meyer. Of these species only *Fissidens hyophilus* was common. Another common terricolous moss, seemingly present on North Meyer only, was *Syntrichia laevipila* which was seen growing on weathered scoriaceous tuff overhangs, or, less commonly, corticolous with *Macromitrium brevicaule* on the lower trunks of Kermadec pōhutukawa. On South Meyer, on the eastern side of the main ridgeline, usually around the nesting ledges of red-tailed tropic birds (*Phaethon rubricauda*) and on fine, east-facing scoriaceous banks, *Bryum argenteum* and *B. dichotomum* were abundant, forming dense hummocks amongst the winter annual *Cotula australis* (Fig. 4). Interestingly, *Bryum argenteum* appeared to be absent from North Meyer. There, inexplicably, the same types of habitat were occupied instead by *Didymodon weymouthii*.

All of the outer Herald Islets that were visited supported mosses. Nugent, the northernmost part of the Kermadec Islands had only the one moss, *Grimmia pulvinata* var. *africana,* seen nowhere else in The Meyers or The Herald Islets, while the larger and better vegetated Napier Island, just to the west of Nugent, had *Fissidens linearis* var. *linearis* only (shared in the Heralds otherwise only with North Chanter). Dayrell Island, which had the most intact forest cover of all of these outer islands, supported four mosses. It was also the only outer island to support *Bryum dichotomum* (so common on the nearby Meyer Islands), while the overhanging branches of a few of the Kermadec pōhutukawa (Fig. 5.) near the island's summit were colonised by *Syrrhopodon armatus* (otherwise abundant in this exact habitat type only on Raoul Island). On the coral makatea (Fig. 6) grew the basicolous *Syntrichia phaea*. Previously this species had been reported from the Kermadecs by Sykes (1977) (as *Tortula phaea*) but the voucher specimen was later determined as *Barbula calycina* (Beever *et al*. 1996). *Syntrichia phaea* was also found on Macauley, growing in very different circumstances, amongst black-winged petrel (*Pterodroma nigripennis*) burrows on dacitic-tholeiitic basalt outwash, in association with *Disphyma australe* subsp. *stricticaule*.

Raoul Island

Raoul Island has a vegetation cover entirely dominated by Kermadec pōhutukawa. However, based on gross changes in the canopy and subcanopy composition of mostly vascular plants (and also the abundance of epiphytic mosses), Oliver (1910) partitioned the island's forest cover into two main types, a "dry" and a "wet" forest type (Figs 7,8). This distinction was maintained by Sykes (1977). The "dry" forest was typified by the local dominance of *Myrsine kermadecensis* Cheeseman within the understory (and at times canopy) of the otherwise dominant Kermadec pōhutukawa forest, and also by the absence of hutu (*Ascarina lucida* var. *lanceolata* (Hook.f.) Allan) and of the epiphytic moss *Papillaria crocea* (see comments by Sykes 1977). Conversely the "wet" forest type had an absence of the *Myrsine*, and dominance of māhoe (*Melicytus ramiflorus* J.R.Forst. et G.Forst.), and hutu, with abundant *Papillaria crocea*. These basic forest types, despite some major shifts in forest composition following the successful goat eradication in 1983 and rising dominance of nīkau (*Rhopalostylis baueri* (Seem.) H.Wendl. et Drude) (Fig. 9) (Parkes 1984; de Lange & Stanley 1999; de Lange & Havell 2009), are still used by ecologists visiting the islands today.

With 123 taxa (Table 1) Raoul Island supports the greatest moss diversity in the archipelago. Of the 123 recorded mosses, 88 are known in the archipelago only from Raoul, and seven of these are regarded as naturalised (Table 1). Despite the diversity, very few of the mosses recorded from Raoul are common, while there appears to be a shift in moss assemblages across the island – North to South. The most common (or at least visually obvious) mosses on Raoul are *Bryum dichotomum*, *Campylopus clavatus*, *C. introflexus*, *Echinodium umbrosum*, *Fissidens asplenioides*, *Hypnodendron arcuatum*, *Hypopterygium didictyon*, *Pyrrhobryum paramattense* (Fig. 10), *Racopilum* sp. (possibly all *R. cuspidigerum* var. *convolutaceum*, and treated in this paper as such, though further critical collection of fertile examples of this genus on Raoul is needed to determine whether *R. strumiferum* (Müll.Hal) Mitt. is present there as well), *Wijkia extenuata* var. *caudata* and the possibly exotic *Eurhynchium speciosum*. However some, such as *Ectropothecium sandwichense* (Fig. 11), are common only in the ravines of the northern part of the island, while others, such as *Canalohypopterygium tamariscinum* and *Cryptogonium phyllogonioides* (Fig. 12), are known only from the south-eastern portion of the island. Other mosses, such as *Calymperes tahitense* (Fig. 13), *Cyclodictyon blumeanum* (Fig. 14), *Fissidens crispulus* var. *robinsonii*, and *F. dietrichiae*, appear tied to natural springs and seepages in ravines (Fig. 15), an uncommon habitat on the island, and so they are naturally scarce. *Vesicularia inflectens* (Fig. 16) has been collected twice; once from a weedy situation where it was terricolous on seasonally muddy ground at the margin of the road leading from the Accommodation House to the Generator Shed, and also from wet hollows amongst boulders near Sunshine Bivy at the mouth of the Sunshine Valley. Similarly *Calomnion complanatum* appears to be confined to the upper "wet" forest of Raoul Island, where it is found on the trunks of large examples of the endemic tree ferns *Cyathea milnei* and *C. kermadecensis*. A few mosses, such as *Dicnemon calycinum*, *D. semicryptum*, *Eucamptodon muelleri* (Fig. 17), *Meteoriopsis reclinata* (Fig. 18) and

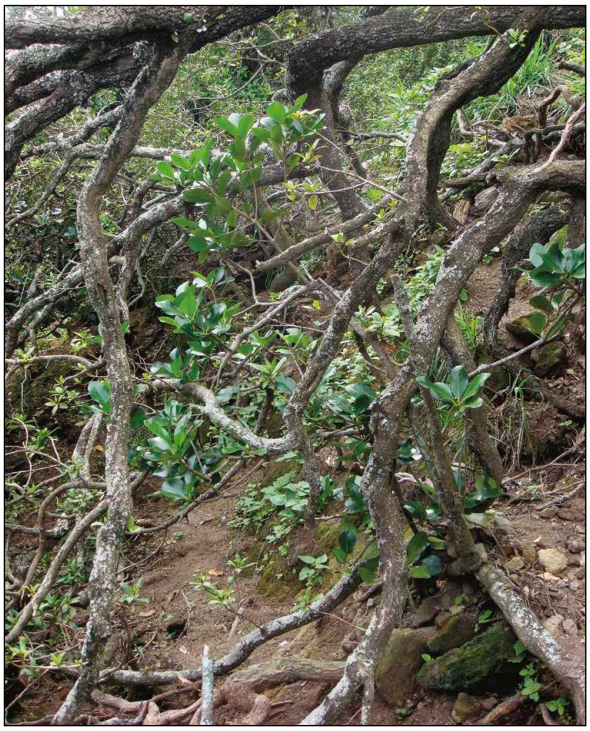

Figure 2. Cyclone-damaged forest dominated by Kermadec pōhutukawa (*Metrosideros kermadecensis*) summit ridgeline of South Meyer. *Photo: Peter J. de Lange*

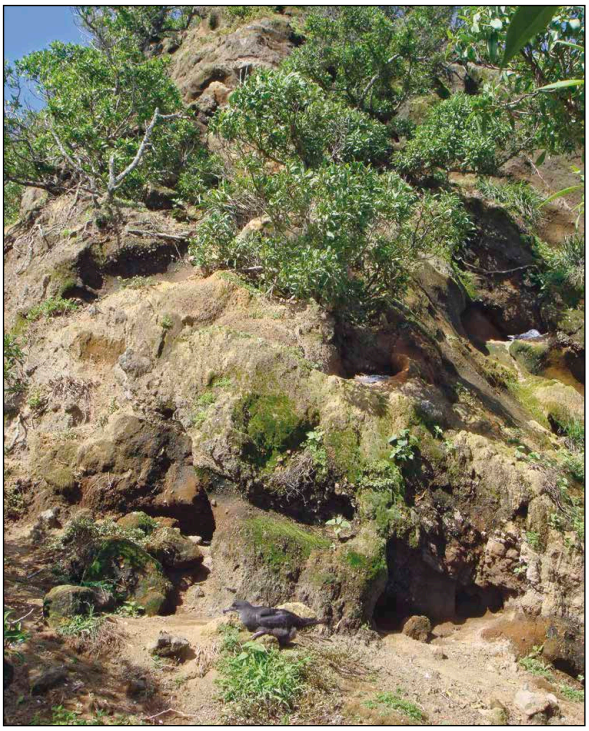

Figure 3. North Meyer, fine scoriaceous slopes on the northern end of the island summit ridge. In these places, densely populated by nesting Kermadec petrels (*Pterodroma neglecta*) *Bryum dichotomum* and *Fissidens linearis* var. *linearis* were the dominant mosses. *Photo: Peter J. de Lange*

Figure 4. South Meyer, along the eastern slopes of the summit ridgeline, on exposed, fine scoriaceous tuff, especially in areas frequented by red-tailed tropic birds (*Phaethon rubricauda*) dense turves of *Bryum argenteum* and *B. dichotomum* were commonly encountered amongst the winter annual *Cotula australis*. *Photo: Peter J. de Lange*

Figure 5. Summit of Dayrell Island, where, on the lower trunks and branch bases of the Kermadec pōhutukawa (*Metrosideros kermadecensis*) trees that form the forest that caps this island, grew *Syrrhopodon armatus*; the green patches on the rocks are mostly a filamentous alga, although in this area *Bryum dichotomum* was also common. *Photo: Peter J. de Lange*

Figure 6. Makatea, Dayrell Island, the habitat of *Syntrichia phaea*. *Photo: Peter J. de Lange*

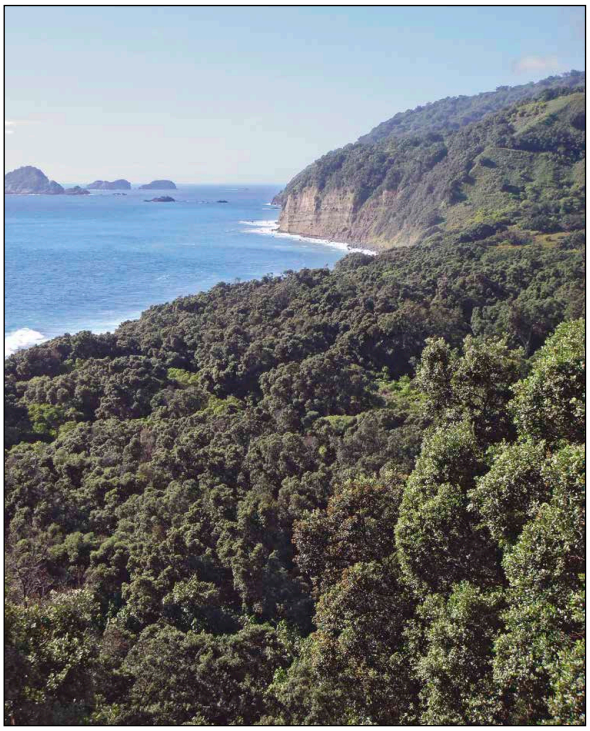

Figure 7. Raoul Island, Bell's Ravine as viewed from the Terraces showing the typical dry forest canopy of Kermadec pōhutukawa (*Metrosideros kermadecensis*). *Photo: Peter J. de Lange*

Figure 8. Raoul Island, slopes of Moumoukai showing the interior of the "wet" forest type. *Photo: Peter J. de Lange*

Figure 9. Raoul Island, slopes of Moumoukai showing the interior of nīkau (*Rhopalostylis baueri)* forest. This is a distinct forest type which, now that goats and rats are gone, seems to be increasing in dominance over large parts of the island. *Photo: Peter J. de Lange*

Figure 10. *Pyrrhobryum paramattense* from a live plant collected from Moumoukai, Raoul Island. *Photo: Jeremy Rolfe*

Figure 12. *Cryptogonium phyllogonioides* from rehydrated material collected from Sunshine Valley, Raoul Island. Scale bar = 10 mm. *Photo: Jeremy Rolfe*

Figure 13. *Calymperes tahitense* from rehydrated material collected from Sunshine Valley, Raoul Island. Scale bar = 1 mm. *Photo: Jeremy Rolfe*

Figure 14. *Cyclodictyon blumeanum* from a live plant collected from upper part of Ravine 8, Raoul Island. Scale bar = 5 mm. *Photo: Jeremy Rolfe*

Figure 11. *Ectropothecium sandwichense* from a live plant collected from Ravine 8, Raoul island. Scale bar = 5 mm. *Photo: Jeremy Rolfe*

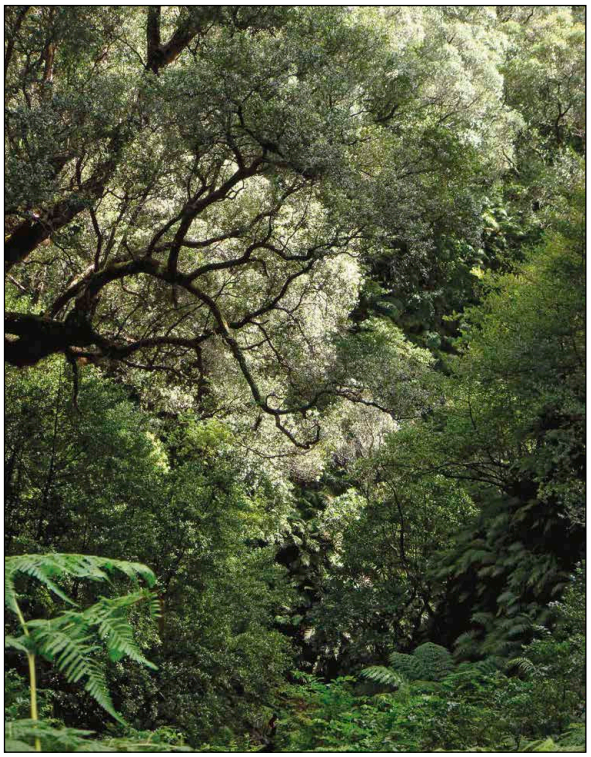

Figure 15. Looking down Ravine 8, Raoul Island from near the head of the ravine. Ravines such as this provide a range of seasonably wet (and sometimes permanently wet) habitats and so are important sites of bryophyte diversity on the island. *Photo: Peter J. de Lange*

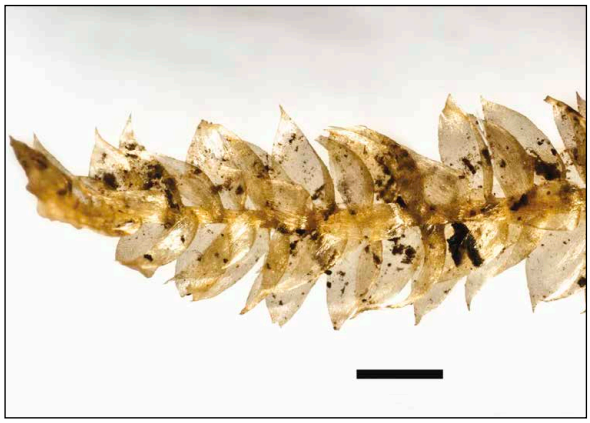

Figure 16. *Vesicularia inflectens* from dried material collected from near Sunshine Bivy, Raoul. Scale bar = 1 mm. *Photo: Jeremy Rolfe*

Figure 17. *Eucamptodon muelleri* from dried material collected from near Mahoe, Smiths Bluff Track, Raoul Island. Scale bar = 5 mm. *Photo: Jeremy Rolfe*

Figure 18. *Meteoriopsis reclinata* from dried material collected from near Mahoe, Smiths Bluff Track, Raoul Island. Scale bar = 1 mm. *Photo: Jeremy Rolfe*

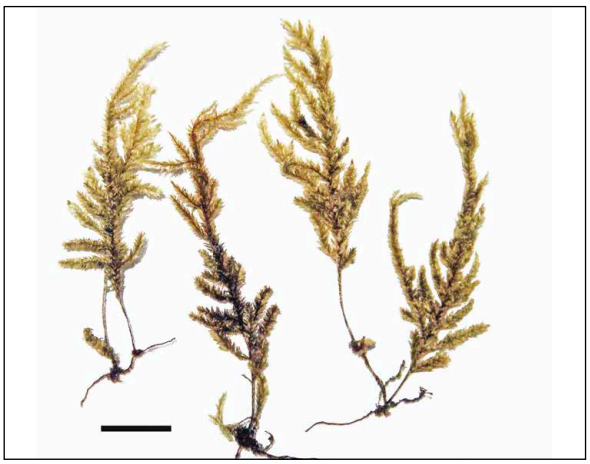

Figure 19. *Symphysodontella cylindracea* from dried material collected from near Mahoe, Smiths Bluff Track, Raoul Island. Scale bar = 10 mm. *Photo: Peter J. de Lange*

Figure 20. Cyclone toppled Kermadec pōhutukawa *(Metrosideros kermadecensis)* on the summit slopes of Prospect, Raoul Island. The canopy branches of trees such as these are significant habitats for a range of bryophytes, fungi and lichens either infrequently seen or not recorded before from Raoul Island. *Photo: Peter J. de Lange*

Figure 21. *Neckeropsis lepineana* from dried material collected from near the eastern flank of Prospect, Raoul Island. Scale bar = 1 mm. *Photo: Jeremy Rolfe*

Symphysodontella cylindracea (Fig. 19), appear to be confined to the upper tree canopy, being known only from fallen canopy tree branches and twigs (Fig. 20), or growing amongst the thalli of such large, foliose, corticolous lichens as *Pseudocyphellaria sulphurea* (see de Lange & Galloway 2015). *Neckeropsis lepineana* (Fig. 21) also appears to be confined to this habitat on Raoul, having been gathered from the upper trunks of nīkau growing amongst *Plagiochila pacifica* near Moumoukai, and from the canopy branches of hutu on the eastern flanks of Prospect.

As has been pointed out by Sykes (1969), Parkes (1984) and de Lange & Galloway (2015), the vegetation of Raoul Island is still recovering from over one hundred years of modification by humans and introduced browsing animals. Browsing animals in particular undoubtedly had a tremendous impact on the cryptogamic flora of Raoul Island by opening up habitats, thereby increasing evapotranspiration and available light, by physical destruction of colonies, and also by decreasing soil nutrient levels and soil cycling through the loss of seabird-induced pedoturbation following the eradication of seabird nesting colonies. Therefore the removal of goats 28 years ago (see Parkes 1984), and later both cats and rats in 2002 (de Lange & Havell 2009), will have had and will continue to have long-term consequences for the flora, fauna and vegetation recovery of Raoul (see comments by Sykes 1969; Parkes 1984). Along with these animal eradications, the extirpation of a range of environmentally damaging weed species, and the ongoing intensive long-term management of others, mean that major disturbance to the indigenous vegetation of Raoul is likely to be effected now only by such natural stochastic events as earthquakes, volcanism and tropical cyclones. While these are potentially very destructive to standing vegetation, such events have undoubtedly contributed to the evolving flora of the islands in the past by creating new, sometimes novel, habitats for colonisation, releasing fresh nutrients, and in the case of tropical cyclones "seeding" the Kermadec Islands with the propagules of fungi and plants (see comments by de Lange & Galloway 2015). Lastly, the role of seabirds in the vegetation recovery and enrichment of the Raoul Island flora needs further consideration, as in the past the island was covered in an array of ground nesting and burrowing seabirds (Cheeseman 1889, 1891; Iredale 1910, 1913, 1914; Bell 1911, 1912; Oliver 1912; Bacon 1957; Sorenson 1964; Straubel 1954; Merton 1970), which not only facilitated soil turn-over and nutrient enrichment but also potentially acted as dispersal agents for plants and fungi from other island groups (see comments by de Lange *et al*. 2004; Fife & de Lange 2009; de Lange & Galloway 2015). Indeed it has already been suggested that the seemingly unusual disjunct distribution of the "weedy" tropical moss *Calymperes tenerum* in the New Zealand Botanical Region (where it is known from Raoul Island, Northern New Zealand and the Chatham Islands) may reflect past (or even ongoing) seabird movements between the greater Pacific, Kermadec and Chatham islands groups and New Zealand (Fife & de Lange 2009; de Lange & Fife 2010).

The Southern Kermadec Islands

Macauley Island

The largest island of the Southern Kermadec Islands, Macauley Island had 37 mosses (de Lange 2015a), which, with the exception of Raoul Island, is the largest total for any of the islands (Table 1). Of the 37 mosses recorded here, six (*Bryum clavatum*, *B. radiculosum*, *Didymodon torquatus*, *Ditrichum difficile*, *Rosulabryum capillare* and *Schistidium apocarpum*) are so far known in the Kermadec Islands from Macauley Island only (Table 1; de Lange 2015a). The record of *Bryum radiculosum* is noteworthy as this is seemingly the only naturalised species to be recorded for the islands that has so far not been collected from Raoul Island.

In the past Macauley Island was said to have had a low forest cover, probably of Kermadec ngaio (see comments in Sykes 1977; Barkla *et al*. 2008; de Lange 2015a). Fairly early on in the island's recorded history pigs and goats were liberated there, and, while the pigs did not thrive, the goats had a serious impact on that island's vegetation cover before they were at last eradicated in 1970 (Sykes 1977). As such the vegetation of Macauley Island is still recovering; currently it is mostly vegetated by dense, almost impenetrable *Hypolepis* fernland and *Cyperus* sedgeland (Fig. 22), with small pockets of Kermadec ngaio shrubland and "forest" present on the more gentle cliff faces and ravines near Mt Haszard, the highest part of that island (see Barkla *et al*. 2008; de Lange 2015a). In places on the plateau the *Hypolepis* fernland has died back, and in these areas a mostly seasonal vascular flora of asteraceous weeds (*Bidens pilosa* L., *Conyza* spp., *Euchiton* spp., *Gamochaeta* spp.), tangles of the vine *Sicyos mawhai* I.Telford et P.Sebastian, and turf of *Oxalis thompsoniae* B.J.Conn et P.G.Richards has developed. These die-back areas are also being colonised by Kermadec ngaio and Kermadec poplar (*Homalanthus polyandrous* (Müll.Arg.) Cheeseman). In one area a small copse of Kermadec poplar has now established around the remains of a solitary tree discovered there in 2006 (Barkla *et al*. 2008). Its semi-decorticated trunk (Fig. 23) supported dense patches of *Macromitrium brevicaule* and *Syntrichia laevipila* (de Lange 2012, 2015a). Although most of the plateau is now choked by a dense, monospecific fernland, in the ravines, gullies and canyons which drain the plateau are a range of habitats mostly free of *Hypolepis*. Also on the steep, eroding scoria cliffs of the Mt Haszard crater system, *Hypolepis* is less common, and in these areas, in addition to Kermadec ngaio, a low vegetation of Devil's horsewhip (*Achyranthes velutina* Hook. et Arn.), *Scaevola gracilis* Hook.f. and *Ipomoea cairica* (L.) Sweet is present. Between these patches of vegetation lie large blocks of scoriaceous tuff that have calved from the cliff tops of the crater (Fig. 24).

The most commonly encountered mosses were *Bryum argenteum*, *B. clavatum*, *B. dichotomum*, *Macromitrium brevicaule*, *Tortula muralis*, *Weissia controversa*, *W.* "North Cape", *Fissidens linearis* var. *linearis*, and *Syntrichia laevipila*. With the exception of the last two these are hardy species that tolerate much exposure. Of the other mosses recorded most were confined to the deep ravines, such as "Access" and "Quadrat" gullies and the

Figure 22. Macauley Island looking east across the Macauley Crater, the plateau, and across to Haszard and "Haszardette" Islands. This image shows the two main vegetation types on the island *Hypolepis dicksonioides* fernland and *Cyperus insularis* sedgeland. *Photo: Peter J. de Lange*

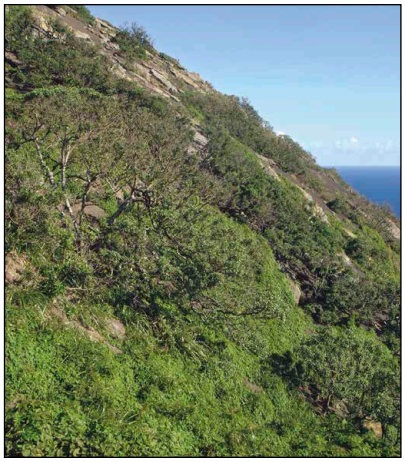

Figure 24. Scoria slopes on the north-western cliff faces below Mt Haszard, Macauley Island. In these areas, which mostly supported a Kermadec ngaio (*Myoporum rapense* subsp. *kermadecensis*) shrub-treeland, areas of *Ipomoea cairica* vineland and a small shrub (Devil's horsewhip (*Achyranthes velutina*)), grew the greatest diversity of mosses seen on the island. *Photo: Peter J. de Lange*

Figure 26. Cheeseman Island, near the base of "*Cyperus* Gully" looking north. This fault bounded trench, partially choked with boulders and vegetated by *Cyperus insularis* and Kermadec ice plant (*Disphyma australe* subsp. *stricticaule*) supported the greatest diversity of mosses seen on the island. *Photo: Warren Chinn*

Figure 23. Dead Kermadec poplar (*Homalanthus polyandrous*) tree in dense Kermadec poplar copse. The semi-decorticated Kermadec poplar trunk seen here supported two mosses, *Macromitrium brevicaule* and *Syntrichia laevipila*. *Photo: Peter J. de Lange*

Figure 25. Cheeseman Island viewed from the northern side. Despite the small size and low altitude (60 m a.s.l.) of this island, 11 collections representing nine species, one *Campylopus* (species not determined) and one undetermined moss, were collected from Cheeseman Island, seven more than presently known from the much larger Curtis Island whose western flanks are just visible in this image. *Photo: Peter J. de Lange*

Figure 27. Summit saddle of L'Esperance Rock looking north toward the northern summit. On this saddle, dominated mostly by lichenfield and Kermadec ice plant (*Disphyma australe* subsp. *stricticaule*) was where the only bryophytes (*Bryum argenteum*, *Frullania pentapleura* Taylor) to be found on L'Esperance grew. *Photo: Peter J. de Lange*

major ravine system of the "Grand Canyon", or in shaded overhangs on the scoria slopes of the Mt Haszard crater. A few mosses, such as *Fissidens oblongifolius*, were only found growing on fine scoriaceous tuff amongst *Cyperus insularis* in the nesting grounds of Tasman boobies (*Sula dactylatra tasmani*) or, such as *Syntrichia phaea*, on the dacitic-tholeiitic basalt outwash nearer the coast.

Haszard Island

Virtually inaccessible from the sea, the flora of this island was poorly known until it was accessed by helicopter in 2002 (Gaskin 2011). However, until 2011 bryophytes had not been gathered from the island. Although not visited by PdL in 2011, one of the crew of the *RV Braveheart*, C. Rogers, made a gathering of *Bryum dichotomum* (Table 1) from the cliffs of Haszard on the Boat Passage side. Of all the larger islands of the Kermadec Islands, Haszard remains the least well explored bryologically and should be regarded as a priority for further surveys. To the north of Haszard lies the informally named "Haszardette", a large block of tholeiitic basalt, which, though seemingly bare of vegetation, also warrants investigation.

Cheeseman Island

Eleven mosses were collected from Cheeseman Island (Table 1) (Fig. 25) of which ten have been identified at least to genus level (de Lange 2015b). None of the mosses recorded from the island were abundant. However, as with all the other islands, islets and rock stacks examined in the Kermadec Islands, the vegetation of Cheeseman had been severely damaged by the passage of Tropical Cyclone Bune some 45 days prior to our expedition (de Lange 2012, 2015b). Therefore it is possible that some of the mosses found on this survey may become more common once the vegetation of the island has recovered. Nevertheless *Trematodon suberectus* was locally common near the southern summit of the island where it grew on hydrothermally altered rock ledges (the rock almost reduced to clay) used by black-winged petrels and red-tailed tropic birds as nesting sites. It was most often found associated with *Chenopodium trigonon* subsp. *trigonon*, *Lepidium castellanum* and *Disphyma australe* subsp. *stricticaule*. In this same general area was the only place where *Bryum argenteum*, *Didymodon weymouthii*, *Fissidens leptocladus* and *Grimmia pulvinata* var. *africana* were found. Lower down, within the *Cyperus insularis* sedgeland that dominates a small fault-bounded depression ("*Cyperus* Gully", Fig. 26), grew small amounts of *Bryum dichotomum*, a *Campylopus* sp., *Ceratodon purpureus*, *Didymodon australasiae*, *D. weymouthii*, and *Weissia controversa*.

Curtis Island

Although no landfalls were made on Curtis during the Kermadec 2011 Biodiscovery Expedition, mosses have been collected from that island in the past in 1970, 1988 and 1989. However the majority of these collections (because they are sterile and/or poor specimens) are unable to be determined below genus level (gatherings of *Bryum* and *Campylopus*). Nevertheless, at least four species occur on the island (Table 1): *Bryum dichotomum*, *Campylopus pyriformis*, *Philonotis tenuis* and *Trematodon suberectus* (Sykes 1977; this paper). As Curtis is much larger, higher and has a greater diversity of habitats than Cheeseman it is quite likely that it supports other mosses. Therefore future bryological surveys should focus on this island.

L'Esperance Rock

Rising to 70 m a.s.l., L'Esperance is the most isolated of the Kermadec Islands and the least vegetated. Only ten vascular plants make up its flora (de Lange 2015c), including *Senecio lautus* subsp. *esperensis* which is endemic to that rock (Sykes 1971, 1977; de Lange *et al*. 2010). Despite being sparsely vegetated, and at the time of our visit even more so because of cyclone damage, one moss, *Bryum argenteum*, was found near the northern end of the main summit saddle of the rock (Table 1, Fig. 27).

DISCUSSION

The Kermadec Islands Moss Flora

Forty-seven species were listed from the Kermadec Islands by Sykes (1977). This listing was subsequently updated by Beever *et al*. (1996) who examined Kermadec gatherings made by C. Bullard, J. MacGillivray, W.G. Milne, A.H. Beckett, A.C.S. Wright, W.R.B. Oliver, R.C. Cooper, G.W. Ramsay, W.R. Sykes, C.J. West, and E.K. Cameron, from which they recorded 53 taxa from 23 families and 35 genera. Beever *et al*. (1996) also excluded, or treated as doubtful, past records of a further ten taxa. Our listing recognises 134 formally described mosses and one unnamed entity from 38 families and 80 genera from the Kermadec Islands (Appendix 1). Eight of these mosses are naturalised, three of which (*Fissidens bryoides*, *F. taxifolius* and *Pseudoscleropodium purum*) appear to have been successfully eradicated since they were first observed on Raoul Island in 2009. One species, *Eurhynchium speciosum*, which was previously accepted as indigenous to the islands (Beever *et al*. 1996), is now considered probably naturalised to New Zealand (Fife & Beever 2014, unpubl.), and so by default to the Kermadec Islands. If it is shown to be naturalised then, judging by its abundance within forest settings on Raoul Island, this European species has probably been established on Raoul for a long time, especially as all the other naturalised species seen were virtually confined to the Accommodation Grounds and heavily modified pastureland of The Terraces.

One moss, first recorded for the Kermadec Islands from Raoul Island by Beever *et al*. (1996) as *Campylopus holomitrium* (*sensu* Sainsbury 1955; non *Campylopus holomitrium* (Müll.Hall) A.Jaeger), requires some discussion. Earlier regarded as a moss endemic to solfatara (Sainsbury, 1955), Sainsbury's *Campylopus holomitrium* is considered here to be a geothermally induced phenotype of the widespread *Campylopus pyriformis*. Details of their tissue anatomy are identical, and, further, when plants of this phenotype growing on thermally heated ground are dislodged, and thus placed in suboptimal growing conditions, they can produce at

their shoot apices the distinctive deciduous leaves of *Campylopus pyriformis* (JE Beever pers.obs.). For these reasons we reject *Campylopus holomitrium* from the New Zealand moss flora. Thus the sole Raoul Island collection cited by Beever *et al*. (1996), WELT M029539, is now referred to *C. pyriformis*, and this species' range in the Kermadec Islands is extended to Curtis Island. One moss, *Calymperes graeffeanum*, doubtfully accepted from the Kermadec Islands by Beever *et al*. (1996) on the basis of a single specimen ascribed to an obscure collector, remains unconfirmed. The identity of the specimen is not in doubt, having been recently reconfirmed by L. Ellis (pers. comm.), a specialist in the family Calymperaceae, but its provenance maybe. Nevertheless we have retained this species in this listing (see Biogeography section below). There are, as yet, no mosses regarded as endemic to the Kermadec Islands. We also record here (based on 2009 and 2011 gatherings) as new records for the Kermadec Islands *Fissidens oblongifolius*, *Macromitrium prorepens*, *Syntrichia phaea* and *Tortella knightii*. Previously these four species had been recorded from the Kermadec Islands by Sykes (1977), only to be excluded by Beever *et al*. (1996) because the voucher specimens on which earlier records were based had been incorrectly identified. In addition the record of *Sematophyllum subhumile* var. *contiguum*, listed as doubtful by Beever *et al*. (1996), has been confirmed by new collections.

The genera *Weissia* and *Trichostomum*, closely related in Subfamily Trichostomoideae of Pottiaceae, are in need of a full revision on a world scale (Zander 2007). The New Zealand members are currently under study by one of us (JEB), and their taxonomic delimitation is proving complex. Amongst the collections from the Kermadec Islands are two formally described taxa: *Weissia controversa* and plants that seem to match *Trichostomum sciophilum*. The former is a species widespread in both Northern and Southern Hemispheres, whereas *T. sciophilum* is currently accepted as endemic to New Zealand, found in both North and South Islands. In addition, female plants (without capsules) of an informally recognised entity, *Weissia* "N Cape", known also from Te Paki at North Cape at the eastern extremity of the northern tip of the North Island of New Zealand, is present (see Appendix 1). Neither *Weissia patula* (Knight) Fife nor *Trichostomum brachydontium* Bruch, both listed by Beever *et al*. (1996), are currently considered to be present in the flora of the Kermadec Islands.

Biogeography

The present study confirms earlier observations (Sykes 1977; Beever *et al*. 1996) that the moss flora of the Kermadec Islands has its greatest affinity with that of New Zealand. Of the 135 taxa now recorded for the Kermadec Islands, 125 are already known from New Zealand. Otherwise the moss flora of the Kermadec Islands (though notably much richer) also shares some 44 taxa with the next closest major island group to the west, Norfolk Island (Streimann 2002) and again, further south and west, 39 taxa with Lord Howe Island (Ramsay 1984). Of these two westerly island groups, Norfolk Island has the smaller recorded moss flora with only 69 taxa from 23 families and 37 genera. Two species, *Calomnion lillianae* and *Splachnobryum crassinervium*, are regarded as endemic to that island group (Streimann 2002). Lord Howe Island has 105 species from 36 families and 58 genera (Ramsay 1984). Of these, 21 species (20%) are regarded as endemic (Ramsay 1984).

As noted by de Lange & Galloway (2015) Norfolk Island had been considerably modified by humans long before it was critically examined by botanists and as such it is highly likely that the moss flora now accepted for that island group is much reduced from what it may have been prior to human settlement. Thus absences from the Norfolk Island flora cannot be given significance, and direct comparison between the moss flora of Norfolk and Kermadec islands is difficult. Lord Howe Island, which is more mountainous and has retained its indigenous cover at high altitudes (Ramsay 1984), is obviously different. However at this stage, as the bryophyte biogeography of Lord Howe and Norfolk islands is under revision for a doctoral study (M.J. Bayly pers. comm.), we feel that, beyond noting that taxa are shared between these three island groups, further comparison would be inappropriate. Nevertheless, we discuss briefly the apparent lack of moss endemism on the Kermadec Islands, notwithstanding the occurrence of examples on Lord Howe and Norfolk Islands. One might argue that this accords with the age of the island groups; Lord Howe is 7 million years (m.y.) old (Hutton 1986) and Norfolk is late Pliocene (c. 3.0-2.3 m.y.) (Holloway 1977), while the Kermadecs are late Pleistocene (c. 1.5-0.5 m.y.) in age (Brothers & Searle 1970; Lloyd & Nathan 1981). So there has perhaps been insufficient time and stability to allow the development of an endemic moss flora. Nevertheless the Kermadec Islands supports 22 endemic vascular plants and one apparently endemic liverwort. Neither the young geological age, nor the highly volatile volcanically and seismically active nature of the Kermadec Islands adequately explain why there are as yet no endemic mosses recorded from the islands. Sykes (1977) and Beever *et al*. (1996) recorded a small tropical moss component for the Kermadec Islands. However of the taxa regarded by Sykes (1977) as tropical only two, *Ectropothecium sandwichense* and *Calymperes graeffeanum* (as *C. australe* Besch.), can be currently accepted as such. To that limited tropical component Beever *et al*. (1996) added *Cyclodictyon blumeanum* (Fig. 14), first collected by C.J. West in 1994, and which is confined in the New Zealand Botanical Region to Raoul Island. They also reaffirmed *Ectropothecium sandwichense* (Fig. 11) (which is otherwise known only as a very uncommon moss from northern New Zealand and the Chatham Islands (see Beever *et al*. 1992; de Lange & Rolfe 2011; de Lange *et al*. 2011)). As noted above, they also reluctantly accepted the widespread tropical *Calymperes graeffeanum*, on the basis that the Kermadec islands had yet to be critically explored by a bryologist, and that being an inconspicuous moss it was easily overlooked. Fife (2014) listed it as an "excluded species" for New Zealand, commenting that the record must be viewed with doubt. Although the islands have now been much more extensively explored the presence of this species cannot be discounted. After all, there

are other similarly enigmatic and even older records of tropical lichens that have been tenuously accepted in the past for the Kermadec Islands, and yet have subsequently been rediscovered there quite by chance e.g., *Pseudocyphellaria prolificans* (see Galloway 1994; de Lange & Galloway 2015).

In this paper, in addition to these three "tropical mosses", we recognise a further 14 species that are common in north-eastern Australia (Queensland) and those Pacific Islands northwest and northeast of the Kermadec Islands (Table 3) bringing the total "tropical moss component" of the Kermadec islands to 17. Of these, 13 (9.7 % of the Kermadec moss flora) are not yet known to extend to continental New Zealand, although the Australian range of one, *Eucamptodon muelleri* (Fig. 17), extends south through eastern Australia to Victoria (Streimann & Klazenga 2002) and so may well also occur in northern New Zealand. Aside from that possibility, only *Calymperes tenerum*, *Ectropothecium sandwichense* (Fig. 11), *Pyrrhobryum paramattense* (Fig. 10) and *Syrrhopodon armatus* are definitely known to extend south to the northern North Island of New Zealand and Chatham Islands (Fife & de Lange 2009; de Lange & Rolfe 2011; de Lange *et al*. 2011) where they are all regarded as very uncommon species (Glenny *et al*. 2011).

The conclusion that the affinity of the moss flora of the Kermadec Islands is primarily with the temperate flora further south is reinforced by the results of the 2009 and 2011 field surveys. Of the 11 "common northern New Zealand mainland" mosses whose unexpected absence from the Kermadec Islands was noted by Beever *et al*. (1996; p. 470), all but *Ptychomnion aciculare*, *Dicranoloma billardierei*, *D. menziesii* and *Camptochaete pulvinata* have now been found to be present.

That the Kermadec moss flora has such a strong affinity with the rest of New Zealand, and yet has a minor but biogeographically interesting tropical Pacific component, probably reflects the main avenues for the dispersal of moss propagules to the islands. It is known that during the winter months the Kermadec Islands are subjected to a strong south-westerly air stream while during the summer the main air stream direction changes to one derived from north-eastern Pacific (Bannister & Blanchon 2003; Blanchon *et al*. 2012). These shifts in wind stream easily account for the strong affinity between the Kermadec Islands and New Zealand moss floras. Further, the seemingly anomalous north-eastern Australian, western Pacific moss occurrences on the Kermadec Islands are likely to reflect uplift of moss propagules by tropical cyclones which are generated in that part of the Pacific, and whose tracking regularly crosses the Kermadec Islands (Revell 1981; Terry 2007; de Lange & Galloway 2015). Similar patterns are also evident in the vascular flora, for example the recently described endemic fern *Lastreopsis kermadecensis* has a closer morphological affinity to the northeastern Australian endemic *L. smithiana* Tindale than to any other New Zealand species (Perrie & Brownsey 2012). Further the role of seabirds in the dispersal of plant propagules has also been suggested to explain the presence of such tropical plants as *Achyranthes velutina* and *Calymperes tenerum* on the Kermadec Islands and, in the case of the moss, in the wider New Zealand archipelago (de Lange *et al*. 2004; Fife & de Lange 2009).

Whilst it must be acknowledged that dedicated bryological survey on the Kermadec Islands was only initiated in 2009 and that many finds stem from this increased effort, it is possible that the increase of 84 moss taxa since Beever *et al*. (1996) was published includes some taxa newly arrived on the islands. As mosses were largely gathered by location, habitats and representation within each habitat, rather than by differentiating taxa, this means that the sampling methodology employed provides some indication of natural abundance. Nearly 90% of the 135 mosses recorded for the islands are known from three or fewer gatherings, which suggests that many cryptogamic plants are naturally uncommon on the islands. For example, on Raoul Island, only *Bryum dichotomum*, *Campylopus clavatus*, *C. introflexus*, *Echinodium umbrosum*, *Fissidens asplenioides*, *F. hyophilus*, *Hypnodendron arcuatum*, *Hypopterygium didictyon*, *Leucobryum javense*, *Macromitrium brevicaule*, *Papillaria crocea*, *Pyrrhobryum paramattense* (Fig. 10), *Racopilum cuspidigerum* var. *convolutaceum* (Raoul Island records of which may also include *R. strumiferum* (see comments on this issue above)), *Wijkia extenuata* var. *caudata* and the possibly naturalised *Eurhynchium speciosum*, are conspicuously abundant. While on the smaller, drier, lower lying and sparingly forested outer islands, islets and rock stacks only *Bryum argenteum*, *B. dichotomum*, *Fissidens linearis* var. *linearis*, *Macromitrium brevicaule* and *Syntrichia laevipila* were reasonably common. This pattern mirrors that already described for the Lobariaceace (de Lange & Galloway 2015), in which only two (*Pseudocyphellaria argyracea* (Delise) Vain. and *Crocodia aurata* (Ach.) Link) of the 32 species recorded were regarded as common. Collectively these observations suggest that the

Table 3. Tropical mosses of the Kermadec Islands.
† – denotes those taxa which extend to the islands of continental New Zealand

	Calymperes graeffeanum
	Calymperes tahitense
†	*Calymperes tenerum*
	Cyclodictyon blumeanum
	Cryptogonium phyllogonioides
†	*Ectropothecium sandwichense*
	Eucamptodon muelleri
	Fissidens crispulus var. *robinsonii*
	Fissidens dietrichiae
	Hyophila involuta
	Macromitrium incurvifolium
	Meteoriopsis reclinata
	Neckeropsis lepineana
†	*Pyrrhobryum paramattense*
	Symphysodontella cylindracea
†	*Syrrhopodon armatus*
	Vesicularia inflectens

moss flora of the Kermadec Islands, and especially that of Raoul Island (which supports most of the moss diversity) is still in a process of expansion and recovery following the successful eradication of cats, goats and rats and ongoing weed control (see de Lange & Galloway 2015). Although our observations cannot tease out what may be the recovery of past relict moss populations from that of recent arrivals to the islands, we think it possible that both processes are active. We also predict that the moss flora will continue to change, not only as the vegetation recovers from past human-induced disturbance, but also in relation to tropical cyclone events, volcanism and seismic activity. A common moss of soil in exposed sites throughout lowland New Zealand, *Weissia controversa*, was described by Sykes (1977) as "very common on the Fishing Rock Road and Low Flat" on Raoul Island. It is now scarce on Raoul presumably because of shading through forest succession. Although specimens referred to *Weissia controversa* by Sykes (1977) are now segregated into several taxa, collectively these taxa are still scarce on Raoul Island, though common in the less densely vegetated outer islands and islets of the Kermadec Islands. A similar change in abundance is reported by de Lange & Galloway (2015) for various photophilous lichens.

Although further bryological survey of the islands will no doubt reveal overlooked taxa, there is now a sufficiently robust base line to enable examination of a changing moss flora in relation to ongoing vegetation recovery of the islands, long distance dispersal of propagules from New Zealand and the wider Pacific, and the impact of the extreme natural disturbance events which periodically occur.

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APPENDIX 1: Mosses of the Kermadec Islands.

‡ – Denotes addition to the moss flora of the Kermadec Islands, † – denotes an addition to the moss flora of the New Zealand Botanical Region, * – denotes naturalised in the New Zealand Botanical Region

	Achrophyllum dentatum (Hook.f. et Wilson) Vitt et Crosby	Daltoniaceae	CHR 616508
‡	*Atrichum androgynum* (Müll.Hal.) A.Jaeger	Polytrichaceae	CHR 616546
	Barbula calycina Schwägr.	Pottiaceae	CHR 500920
‡	*Brachythecium rutabulum* (Hedw.) Bruch et Schimp.	Brachytheciaceae	AK 327056
‡	*Breutelia pendula* (Sm.) Mitt.	Bartramiaceae	CHR 616633
‡	*Bryoerythrophyllum dubium* (Schwägr.) P.Sollman	Pottiaceae	CHR 616664
	Bryum argenteum Hedw.	Bryaceae	AK 18747
	B. clavatum (Schimp.) Müll.Hal.	Bryaceae	CHR 163430
	B. dichotomum Hedw.	Bryaceae	CHR 161102
	B. preissianum Hampe	Bryaceae	AK 330472
‡ *	*B. radiculosum* Brid.	Bryaceae	AK 326996
*	*B. rubens* Mitt.	Bryaceae	CHR 161768
‡	*B. sauteri* Bruch et Schimp.	Bryaceae	CHR 499360
‡ *	*Calliergonella cuspidata* (Hedw.) Loeske	Amblystegiaceae	AK 327055
	Calomnion complanatum (Hook.f. et Wilson) Lindb.	Calomniaceae	AK 181736
	Calymperes graeffeanum Müll.Hal.	Calymperaceae	BM
† ‡	*C. tahitense* (Sull.) Mitt.	Calymperaceae	AK 326945
‡	*C. tenerum* Müll.Hal.	Calymperaceae	AK 326954
‡	*Calyptrochaeta brownii* (Dixon) J.K.Bartlett	Daltoniaceae	CHR 616507
	Campylopus clavatus (R.Br.) Hook.f. et Wilson	Dicranaceae	AK 181740
	C. introflexus (Hedw.) Brid.	Dicranaceae	AK 181730
	C. pyriformis (Schultz) Brid.	Dicranaceae	AK 12529

	Camptochaete angustata (Mitt.) Reichardt	Lembophyllaceae	CHR 266094
‡	*C. arbuscula* (Sm.) Reichardt var. *arbuscula*	Lembophyllaceae	CHR 616542
‡	*Canalohypopterygium tamariscinum* (Hedw.) Kruijer	Hypopterygiaceae	AK 330773
	Ceratodon purpureus (Hedw.) Brid.	Ditrichaceae	AK 181748
‡	*Cryphaea tenella* (Schwägr.) Müll.Hal.	Cryphaeaceae	CHR 616550
† ‡	*Cryptogonium phyllogonioides* (Sull.) Isov.	Pterobryaceae	AK 325647
‡	*Ctenidium pubescens* (Hook.f. et Wilson) Broth.	Hypnaceae	AK 326940
‡	*Cyathophorum bulbosum* (Hedw.) Müll.Hal.	Hypopterygiaceae	AK 326929
	Cyclodictyon blumeanum (Müll.Hal.) Kuntze	Pilotrichaceae	AK 223757
	Dendrohypopterygium filiculaeforme (Hedw.) Kruijer	Hypopterygiaceae	AK 167804
‡	*Dicnemon calycinum* (Hook.) Schwägr.	Dicnemonaceae	CHR 616571
‡	*D. semicryptum* Müll.Hal.	Dicnemonaceae	AK 326934
‡	*Didymodon australasiae* (Hook. et Grev.) R.H.Zander	Pottiaceae	AK 327070
‡	*D. torquatus* (Taylor) Catches.	Pottiaceae	AK 326993
‡	*D. weymouthii* (R.Br.bis.) R.H.Zander	Pottiaceae	CHR 617497
‡	*Distichophyllum crispulum* (Hook.f. et Wilson) Mitt.	Daltoniaceae	AK 325976
	D. microcarpum (Hedw.) Mitt.	Daltoniaceae	WELT M031600
‡	*D. pulchellum* (Hampe) Mitt. var. *pulchellum*	Daltoniaceae	AK 325979
‡	*D. rotundifolium* (Hook.f. et Wilson) Müll.Hal. et Broth.	Daltoniaceae	CHR 616519
‡	*Ditrichum difficile* (Duby) M.Fleisch.	Ditrichaceae	AK 326984
	Echinodium umbrosum (Mitt.) A.Jaeger	Echinodaceae	CHR 161118
	Ectropothecium sandwichense (Hook. et Arn.) Mitt.	Hypnaceae	AK 181734
‡	*Eriodon cylindritheca* (Dixon) Dixon et Sainsbury	Brachytheciaceae	AK 329195
† ‡	*Eucamptodon muelleri* Müll.Hal. et Hampe	Dicnemonaceae	CHR 6161583
‡ *	*Eurhynchium praelongum* (Hedw.) Schimp.	Brachytheciaceae	AK 329405
*	*E. speciosum* (Brid.) Jur.	Brachytheciaceae	AK 181728
‡	*Fabronia australis* Hook.	Fabroniaceae	AK 329759
	Fissidens asplenioides Hedw.	Fissidentaceae	AK 44177
‡ *	*F. bryoides* Hedw.	Fissidentaceae	CHR 616681
†‡	*F. crispulus* var. *robinsonii* (Broth.) Z.Iwats. et Z.H.Li	Fissidentaceae	AK 325964
	F. curvatus Hornsch. var. *curvatus*	Fissidentaceae	CHR 9474
‡	*F. dealbatus* Hook.f. et Wilson	Fissidentaceae	CHR 616690
† ‡	*F. dietrichiae* Müll.Hal.	Fissidentaceae	CHR 617493
‡	*F. hylogenes* Dixon	Fissidentaceae	CHR 616683
	F. hyophilus Mitt.	Fissidentaceae	CHR 24285
	F. leptocladus Müll.Hal. ex Rodway	Fissidentaceae	WELT M031621
	F. linearis var. *angustifolius* (Dixon) I.G.Stone	Fissidentaceae	CHR 616690
	F. linearis Brid. var. *linearis*	Fissidentaceae	CHR 484799
‡	*F. megalotis* Müll.Hal	Fissidentaceae	AK 326882
‡	*F. oblongifolius* Hook.f. et Wilson	Fissidentaceae	AK 326983
‡	*F. pallidus* Hook.f. et Wilson	Fissidentaceae	AK 326944
	F. rigidulus Hook.f. et Wilson var. *rigidulus*	Fissidentaceae	CHR 9293
‡ *	*F. taxifolius* Hedw.	Fissidentaceae	CHR 6616694
‡	*F. taylorii* var. *sainsburyanus* Allison	Fissidentaceae	AK 330476
	F. tenellus var. *australiensis* (A.Jaeger) J.E.Beever et I.G.Stone	Fissidentaceae	CHR 242485
‡	*F. tenellus* Hook.f. et Wilson var. *tenellus*	Fissidentaceae	CHR 616689
‡	*F. waiensis* J.E.Beever	Fissidentaceae	AK 326943

	Funaria hygrometrica Hedw.	Funariaceae	AK 332140
‡	*Grimmia pulvinata* var. *africana* (Hedw.) Hook.f. et Wilson	Grimmiaceae	CHR 616544
‡	*Gymnostomum calcareum* Nees et Hornsch.	Pottiaceae	CHR 616663
‡	*Haplohymenium pseudotriste* (Müll.Hal.) Broth.	Anomodontaceae	CHR 616584
‡	*Holomitrium perichaetiale* (Hook.) Brid.	Dicranaceae	AK 326926
‡	*Hymenodon pilifer* Hook.f. et Wilson	Rhizogoniaceae	AK 326937
† ‡	*Hyophila involuta* (Hook.) A.Jaeger	Pottiaceae	CHR 617498
	Hypnodendron arcuatum (Hedw.) Mitt.	Hypnodendraceae	WELT M031607
‡	*Hypnum chrysogaster* Müll.Hal.	Hypnaceae	CHR 616629
‡	*H. cupressiforme* Hedw. var. *cupressiforme*	Hypnaceae	CHR 616632
	Hypopterygium didictyon Müll.Hal.	Hypopterygiaceae	AK 12531
‡	*H. tamarisci* (Sw.) Müll.Hal.	Hypopterygiaceae	CHR 616528
	Isopterygium albescens (Hook.) A.Jaeger	Hypnaceae	WELT M031600
‡	*Leptostomum macrocarpum* (Hedw.) Bach.Pyl.	Leptostomataceae	CHR 616606
	Leucobryum javense (Brid.) Mitt. var. *javense*	Leucobryaceae	AK 12537
‡	*Macrocoma tenue* (Hook. et Grev.) Vitt subsp. *tenue*	Orthotrichaceae	CHR 616609
	Macromitrium brevicaule (Besch.) Broth.	Orthotrichaceae	CHR 242477
‡	*M. gracile* (Hook.) Schwägr.	Orthotrichaceae	CHR 616611
† ‡	*M. incurvifolium* (Hook. et Grev.) Schwägr.	Orthotrichaceae	AK 327888
	M. ligulaefolium Broth.	Orthotrichaceae	AK 224078
‡	*M. longipes* (Hook.) Schwägr.	Orthotrichaceae	AK 325488
‡	*M. prorepens* (Hook.) Schwägr.	Orthotrichaceae	CHR 616615
† ‡	*Meteoriopsis reclinata* (Müll.Hal.) M.Fleisch.	Meteoriaceae	CHR 604748
† ‡	*Neckeropsis lepineana* (Mont.) M.Fleisch.	Neckeraceae	CHR 616549
‡	*Ochiobryum blandum* (Hook.f. et Wilson) J.R.Spence et H.P.Ramsay	Mniaceae	AK 330897
‡	*Orthorrhynchium elegans* (Hook.f. et Wilson) Reichardt	Orthorrhynchiaceae	CHR 616533
	Papillaria crocea (Hampe) A.Jaeger	Meteoriaceae	AK 181744
‡	*Pendulothecium punctatum* (Hook.f. et Wilson) Enroth et S.He	Neckeraceae	AK 325489
	Philonotis tenuis (Taylor) Reichardt.	Bartramiaceae	CHR 418774
‡	*Plagiomnium novae-zealandiae* (Colenso) T.J.Kop.	Mniaceae	CHR 616564
	Polytrichadelphus magellanicus (Hedw.) Mitt.	Polytrichaceae	WELT M029570
	Polytrichum commune Hedw.	Polytrichaceae	CHR 499357
‡ *	*Pseudoscleropodium purum* (Hedw.) M.Fleisch.	Brachytheciaceae	CHR 616504
‡	*Ptychomitrium australe* (Hampe) A.Jaeger	Ptychomitriaceae	CHR 616562
	Pyrrhobryum paramattense (Müll.Hal.) Manuel	Rhizogoniaceae	CHR 161701
	Racopilum cuspidigerum var. *convolutaceum* (Müll.Hal.) Zanten et Dijkstra	Racopilaceae	AK 12543
	Rhaphidorrhynchium amoenum (Hedw.) M.Fleisch.	Sematophyllaceae	CHR 161117
‡	*Rhynchostegium muriculatum* (Hook.f. et Wilson) Reichardt	Brachytheciaceae	AK 330471
	R. tenuifolium (Hedw.) Reichardt.	Brachytheciaceae	AK 12545
‡	*Rosulabryum campylothecium* (Taylor) J.R.Spence	Bryaceae	CHR 616605
‡	*Rosulabryum capillare* (Hedw.) J.R.Spence	Bryaceae	AK 327054
‡	*Rosulabryum subtomentosum* (Hampe) J.R.Spence	Bryaceae	AK 327066
‡	*Schistidium apocarpum* (Hedw.) BSG	Grimmiaceae	AK 326970
‡	*Sciadocladus kerrii* (Mitt.) Broth.	Hypnodendraceae	AK 326932
‡	*Sematophyllum homomallum* (Hampe) Broth.	Sematophyllaceae	AK 326958

‡	*S. jolliffii* (Hook.f. et Wilson) Dixon	Sematophyllaceae	AK 326960
‡	*S. subhumile* var. *contiguum* (Mitt.) B.C.Tan, W.B.Schofield et H.P.Ramsay	Sematophyllaceae	AK 326955
‡	*Syntrichia antarctica* (Hampe) R.H.Zander	Pottiaceae	CHR 616657
‡	*S. laevipila* Brid.	Pottiaceae	AK 326982
‡	*S. papillosa* (Wilson) Jur.	Pottiaceae	CHR 616651
‡	*S. phaea* (Hook.f. et Wilson) R.H.Zander	Pottiaceae	AK 326906
† ‡	*Symphysodontella cylindracea* (Mont.) M.Fleisch	Pterobryaceae	CHR 616719
	Syrrhopodon armatus Mitt.	Calymperaceae	WELT M031628
	Thuidium furfurosum (Hook.f. et Wilson) Reichardt.	Thuidiaceae	CHR 161759
	T. sparsum (Hook.f. et Wilson) Reichardt	Thuidiaceae	AK 181743
‡	*Tortella flavovirens* (Bruch) Broth.	Pottiaceae	AK 326975
‡	*T. knightii* (Mitt.) Broth.	Pottiaceae	AK 330473
‡	*Tortula muralis* Hedw.	Pottiaceae	AK 326963
	Trematodon suberectus Mitt.	Bruchiaceae	AK 181732
	Trichostomum cf. *sciophilum* Müll.Hal.	Pottiaceae	WELT M031625
† ‡	*Vesicularia inflectens* (Brid.) Müll.Hal.	Hypnaceae	CHR 608225
	Weissia controversa Hedw.	Pottiaceae	CHR 161751
‡	*W.* “North Cape”	Pottiaceae	CHR 616661
‡	*Weymouthia cochlearifolia* (Schwägr.) Dixon	Lembophyllaceae	CHR 616535
	Wijkia extenuata var. *caudata* Fife	Sematophyllaceae	CHR 161756
	Zygodon intermedius Bruch et Schimp.	Orthotrichaceae	CHR 616608