

# Saving rainforests in the South Pacific: challenges in *ex situ* conservation

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**Abstract.** Rainforests in the South Pacific hold a considerable amount of plant diversity, with rates of species endemism >80% in some countries. This diversity is rapidly disappearing under pressure from logging, clearing for agriculture or mining, introduced pests and diseases and other anthropogenic sources. *Ex situ* conservation techniques offer a means to limit the loss of plant diversity. Seed banking is considered the most efficient and cost effective of these techniques but is applicable only to seed capable of tolerating desiccation and cold storage. Data on the degree of tolerance of these conditions was lacking for more than half of the 1503 South Pacific rainforest genera examined for this review. Of the 710 genera for which data were available, the storage behaviour of 324 was based on an assessment of only one or two species, although 76% of those genera contained at least 10 species. Many of the unstudied or poorly studied genera are shared across several South Pacific nations, providing an excellent opportunity for collaboration on future *ex situ* research and conservation. Of the 386 genera for which three or more species have been studied, 343 have a very high proportion of species (>95% of those tested) that are suitable for seed banking. Seed banking could therefore provide a suitable means for preserving a large proportion of the rainforest flora before it becomes extinct in the wild. Alternatives for preserving species that are not suitable for seed banking are also discussed.

**Additional keywords:** cryopreservation, living collections, orthodox, recalcitrant, restoration, seed banking, seed storage behaviour, tissue culture.

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## Introduction

The word ‘rainforest’ evokes images of deep green foliage, dripping leaves, tangled vines and the calls of a multitude of forest-dwelling fauna. Few vegetation types have captured the imagination and support of the public as well as rainforest, but while many people seem to be familiar with the high-profile, highly-threatened rainforests of the Amazon and South-East Asia, the rainforests of the South Pacific are less well known. Though mostly small in size compared with the Amazon, South Pacific rainforests support a wide variety of flora and fauna and are also, with less publicity, under great threat. To facilitate collaboration among members of the Pacific Community

(<http://www.spc.int/our-members/>, accessed 27 November 2017) in conserving these forests, we present a review of the extent to which rainforest genera are shared among Pacific nations situated south of the equator. We discuss ongoing threats to rainforest habitat in the region, and look at options for *ex situ* conservation of seed-producing plants.

## The scope of ‘rainforest’

Rainforests are usually defined as evergreen plant communities with a closed tree canopy (>70% projective foliage cover; Floyd 1990a), occurring in areas of relatively high annual rainfall (>1300 mm, Williams *et al.* 1984) and incorporating

plant groups with special characteristics such as cauliflory, buttressed trunks, thick-stemmed vines, leaves with drip tips, and epiphytic growth (Harden *et al.* 2006). Climax rainforest species can be distinguished from non-rainforest plants by their dependence on humidity, especially in the early life-cycle stages, and their ability to regenerate in shade and in the absence of fire (Floyd 1990a; Baskin and Baskin 2014). The vegetation encompassed by the above definitions varies considerably with latitude, altitude, temperature, rainfall, soil type and the availability of shelter, with some rainforests able to survive in areas of much lower annual rainfall where shelter is sufficient, where there is access to groundwater, or where rainfall is concentrated in a wet season.

Mueller-Dombois and Fosberg (1998) described several rainforest types that are common across the tropical Pacific islands: 'lowland tropical rainforest', described as relatively tall, with multiple layers and many canopy-dwelling epiphytes; 'seasonally dry evergreen forest', which occurs on leeward, drier slopes and experiences a distinct dry season; 'montane rainforest', which occurs at higher elevations, is lower in stature but rich in shrubs and epiphytes; and 'cloud forest' (or mossy forest), which occurs at higher elevations in the cloud zone, has a very low canopy, is dominated by small-leaved species and rich in mosses and liverworts. The upper levels of a hierarchical scheme proposed by Webb (1968) suggested a similar classification: 'evergreen vine forests', occurring in wet tropical-subtropical habitats, 'raingreen vine forests', occurring in tropical-subtropical habitats and containing one or more species that are deciduous during the dry winter season; 'fern forest', occurring in submontane or warm temperate habitats; and 'mossy forest', occurring in montane or cool temperate habitats. The descriptions of these vegetation types correspond approximately to the commonly used Australian classifications of tropical to subtropical rainforest, dry rainforest and vine thickets (including monsoon vine forest), warm temperate rainforest, and cool temperate rainforest (as described by Beadle and Costin 1952; Harden *et al.* 2006; Metcalfe and Green 2017). A subcategory of tropical-subtropical rainforest is 'littoral rainforest' (Floyd 1990b), which grows in close proximity to the sea and often contains species distributed widely across the South Pacific (such as *Guetarda speciosa*, *Hernandia nymphaeifolia*, *Hibiscus tiliaceus*, *Morinda citrifolia*, *Neisosperma oppositifolium* and *Heliotropium foertherianum*; Mueller-Dombois and Fosberg 1998).

For simplicity, we here consider rainforests to be terrestrial forest communities, composed largely of evergreen species, with a tree canopy that is closed for either the entire year or during the wet season. Within this definition, we consider three broad rainforest biomes: tropical-subtropical rainforest, tropical-subtropical seasonal forest (also referred to as tropical dry forest, monsoon forest and dry rainforest), and warm to cool-temperate rainforest (Fig. 1). These rainforest types occur within the Köppen climate classifications of Af, Am and Aw (tropical), Cwa and Cfa (humid subtropical) and Cfb (temperate oceanic) (Köppen 1936; Peel *et al.* 2007). Although some might argue against the inclusion of tropical-subtropical seasonal forest as a type of rainforest, we include it here as many species occurring in that habitat often also occur in more humid rainforest (for examples, see Smith 1979; Harden *et al.* 2006; Munzinger

*et al.* 2016) and seeds released during the wet season can have characteristics similar to those released in continuously moist rainforest (i.e. desiccation sensitivity; Daws *et al.* 2005).

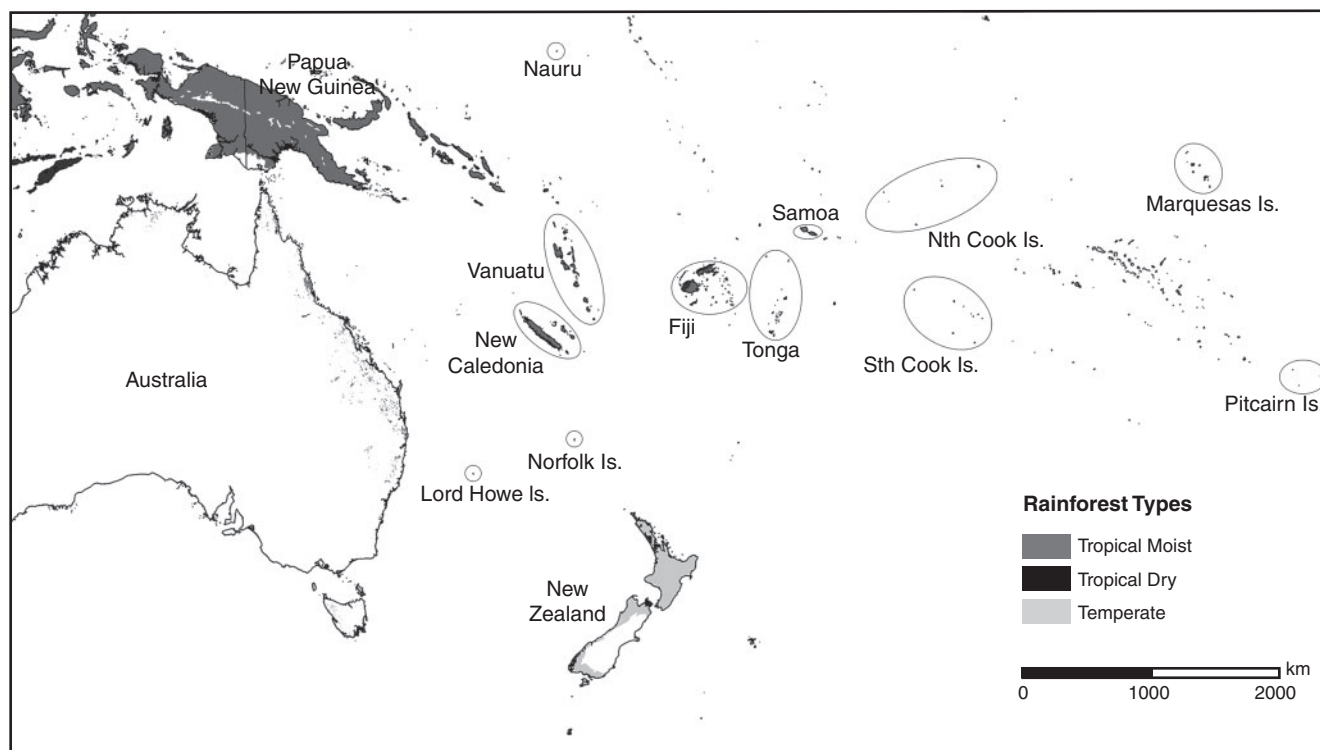
### Rainforest origins

The current distribution and composition of rainforest in the South Pacific has been strongly influenced by the area's geological history. At the time Australia separated from Antarctica 30 million years ago (mya), much of it was covered in rainforest (Christophel 1989; Greenwood 1996). As the continent drifted north towards warmer latitudes, conditions became increasingly arid (Martin 2006; Byrne *et al.* 2008) and the moisture-dependent vegetation contracted in range. Today rainforests in Australia are mostly restricted to higher rainfall areas on the east and north coasts of the mainland and the west coast of Tasmania (Adam 1992). Species in the cool temperate rainforests of the south have their origins in the ancient Gondwanan forests (Dettmann 1989), whereas the tropical rainforests in the north contain many South-east Asian elements, which likely arrived through long-distance dispersal as Australia drifted closer to Asia (Burbidge and Whelan 1982; Byrne *et al.* 2011). Over the last 2 million years or so, both temperate and tropical rainforests repeatedly contracted to refugia during ice ages, which were accompanied by drier climates and lower sea levels (Schneider and Moritz 1999; Kooyman *et al.* 2013).

Island groups in the South Pacific have more complex geological histories, including various combinations of uplift of continental fragments (e.g. New Caledonia), formation of islands at plate boundaries due to subduction (e.g. Viti Levu in Fiji), formation of islands over volcanic hot spots (e.g. Samoa and Pitcairn Islands), and formation of coralline atolls built on subsided volcanoes (e.g. the Cook Islands; Mueller-Dombois and Fosberg 1998; Neall and Trewick 2008). New Caledonia and New Zealand, for example, were originally part of a continental fragment that began to separate from Gondwana 85 mya, became mostly (or possibly entirely) submerged, and began to re-emerge around 25 mya (Trewick *et al.* 2007). These two island groups contain several genera with Gondwanan ancestry (such as *Araucaria* in New Caledonia, and *Nothofagus* and *Dacrydium* in both countries) that have been considered relicts of the original Gondwanan flora but may be the result of long distance dispersal events post separation (Grandcolas *et al.* 2008).

The southern half of New Guinea resulted from uplift of the Australian continental plate while the northern part resulted from the convergence of several islands on the Pacific plate that were brought into contact with the southern half through continental drift (Hall 2001). The rainforests of New Guinea thus share some Gondwanan elements with Australia (*Araucaria* and *Nothofagus*) and many species originating from South-east Asia. The remaining islands in the South Pacific region steadily gained species through dispersal and speciation after their emergence – in some cases <5 mya – with South-east Asia and Australia as key source areas (Keppel *et al.* 2009; Franklin *et al.* 2013).

South Pacific rainforests today harbour floristic elements of both Gondwanan (e.g. *Araucariaceae*, *Nothofagus*, *Proteaceae*)



**Fig. 1.** Pre-disturbance distribution of rainforest across the South Pacific. For the purpose of this study, rainforest has been defined as a terrestrial forest community, composed largely of evergreen species, with a tree canopy that is closed for either the entire year or during the wet season. Within this definition, we consider three broad rainforest biomes: tropical–subtropical rainforest (‘tropical moist’), tropical–subtropical seasonal forest (‘tropical dry’) and warm to cool-temperate rainforest (‘temperate’). Distributions for rainforest in Australia were derived from the National Vegetation Information System ver. 4.2 (Commonwealth of Australia 2016). Distributions for the remaining regions were derived from the Terrestrial Ecoregions of the World dataset (Olson *et al.* 2001). The combined data were transformed and projected in Robison’s World Project with a central meridian of 180 degrees.

and Asian origin (e.g. Lauraceae, Orchidaceae) in the west, with some elements from the Americas in the east (e.g. *Fitchia* and *Oparanthus* in the Asteraceae; van Balgooy *et al.* 1996; Keppel *et al.* 2009). The influence of these key sources varies among locations and ecosystems, with the Gondwanan influence being more pronounced in south-eastern Australia, New Caledonia and New Zealand, while the Asian influence is more pronounced in New Guinea and the Solomon Islands (Burbidge 1960; Keppel *et al.* 2009; Sniderman and Jordan 2011). The number and variety of species present on a given island has been influenced by the age of the island, its size, the complexity of its habitats, and its proximity to the key source points (Keppel *et al.* 2010; Gillespie *et al.* 2013; Keppel *et al.* 2016).

### Diversity and importance

The biodiversity in the South Pacific is rich, with a high proportion of endemic species (Kier *et al.* 2009), and this is reflected in the six biodiversity hotspots (of 35 globally) that occur in the region: the Forests of East Australia, East Melanesian Islands, New Zealand, New Caledonia, Polynesia-Micronesia and the Galapagos Islands (Mittermeier *et al.* 2011). Though the common origins of the flora mean that many genera are shared among island groups (see Supplementary Material to this paper), isolation and speciation has led to a very high level of endemism. Among flowering plant species, for example, it has

been estimated that 82% are endemic in New Zealand, 80% in New Caledonia, 70% in the Marquesas Islands and 61% in Fiji (Jaffré 1993). More than half of 552 orchid species known to occur on eight Pacific archipelagos are endemic to that region (Keppel *et al.* 2016).

Rainforest floras contribute a substantial amount to this biodiversity. Australian rainforests, for example, occupy less than 0.5% of the mainland (Stork *et al.* 2011) yet hold more than 3500 seed plant species representing at least 1219 genera in 198 families (AVH 2016). New Caledonia’s tropical rainforests and seasonal forests hold at least 2188 seed plants representing 451 genera in 116 families (Morat *et al.* 2012; Munzinger *et al.* 2016), and Fiji’s rainforests hold around 1024 seed plants representing 369 genera in 111 families (Smith 1979, 1981, 1985, 1988, 1991; Heads 2006). The diversity of tree species (with a diameter at breast height (dbh)  $\geq 10$  cm) in rainforests is particularly high, ranging from 81–85 ha<sup>−1</sup> in the Wet Tropics of Australia (Tng *et al.* 2016), up to 96 ha<sup>−1</sup> in the rainforests of New Caledonia (Ibanez *et al.* 2017) and up to 124, 131 and 167 ha<sup>−1</sup> in Fiji, the Solomon Islands and Papua New Guinea, respectively (Table 1; Keppel *et al.* 2010).

The importance of this diversity cannot be overstated. Rainforests provide important ecosystem services (Haddad *et al.* 2015) and hold extensive carbon stocks (Wardell-Johnson *et al.* 2011; Vincent *et al.* 2015). They are also of great cultural importance and a vital source of food, fibres,

**Table 1. Extent, diversity and endemism of rainforest ecosystems in the South Pacific**

The extent of rainforest in Australia (pre- and post-disturbance) was derived from the National Vegetation Information System ver. 4.2 (Commonwealth of Australia 2016) from raster data projected in GDA 1994 using Albers equal area projection. With the exception of Papua New Guinea (PNG), the pre-disturbance extent of rainforest for remaining regions was derived from the Terrestrial Ecoregions of the World dataset (Olson *et al.* 2001) projected in WGS 1984. Rainforest extent for PNG was calculated from this dataset manually after separating PNG from West Papua and reprojecting the data onto an equidistant conical projected coordinate system centred on South East Asia. Abbreviation: nd, not determined

| Rainforest biome                            | Extent of primary rainforest (km <sup>2</sup> ) |                      | No. spp              | Diversity of indigenous seed plants |                            |
|---------------------------------------------|-------------------------------------------------|----------------------|----------------------|-------------------------------------|----------------------------|
|                                             | Historic                                        | Current              |                      | % Endemic                           | Tree spp. ha <sup>-1</sup> |
| <i>Tropical–subtropical rainforest</i>      |                                                 |                      |                      |                                     |                            |
| Australia                                   | 21 006 <sup>A</sup>                             | 13 053 <sup>A</sup>  | >1788 <sup>N</sup>   | 45 <sup>I</sup>                     | 81–85 <sup>I</sup>         |
| Cook Islands                                | 69 <sup>B</sup>                                 | 0 <sup>B</sup>       | 81 <sup>F</sup>      | 15 <sup>F</sup>                     | nd                         |
| Fiji                                        | 11 346 <sup>B</sup>                             | 3162 <sup>C,D</sup>  | 971 <sup>F</sup>     | 66 <sup>F</sup>                     | 85–124 <sup>G</sup>        |
| Marquesas Islands                           | 1074 <sup>B</sup>                               | nd                   | 168 <sup>F</sup>     | 56 <sup>F</sup>                     | nd                         |
| New Caledonia                               | 14 523 <sup>B</sup>                             | 3451 <sup>C,D</sup>  | 1888 <sup>H</sup>    | 88 <sup>H</sup>                     | 71–96 <sup>J</sup>         |
| Nauru                                       | 20 <sup>M</sup>                                 | 0 <sup>B</sup>       | 101 <sup>M</sup>     | 0 <sup>M</sup>                      | nd                         |
| Papua New Guinea                            | 435 952 <sup>B</sup>                            | 241 865 <sup>E</sup> | >10 000 <sup>F</sup> | (trees) 11–16 <sup>G</sup>          | 85–167 <sup>G</sup>        |
| Samoa                                       | 2877 <sup>B</sup>                               | nd                   | 757 <sup>F</sup>     | (trees) 17–18 <sup>G</sup>          | 35–41 <sup>G</sup>         |
| Solomon Islands                             | 26 898 <sup>B</sup>                             | 11 050 <sup>D</sup>  | nd                   | (trees) 8–14 <sup>G</sup>           | 82–131 <sup>G</sup>        |
| Tonga                                       | 669 <sup>B</sup>                                | 40 <sup>D</sup>      | 197 <sup>F</sup>     | 5 <sup>F</sup>                      | nd                         |
| Vanuatu                                     | 12 378 <sup>B</sup>                             | <900 <sup>P</sup>    | 1032 <sup>F</sup>    | (trees) 22 <sup>G</sup>             | 62 <sup>G</sup>            |
| <i>Tropical–subtropical seasonal forest</i> |                                                 |                      |                      |                                     |                            |
| Australia                                   | 15 750 <sup>A</sup>                             | 10 240 <sup>A</sup>  | >970 <sup>N</sup>    | 37 <sup>N</sup>                     | nd                         |
| Fiji                                        | 6890 <sup>B</sup>                               | 948 <sup>C</sup>     | 190 <sup>F</sup>     | 53 <sup>F</sup>                     | nd                         |
| New Caledonia                               | 4408 <sup>B</sup>                               | 859 <sup>C</sup>     | 318 <sup>H</sup>     | 61 <sup>H</sup>                     | 20 <sup>J</sup>            |
| Marquesas Islands                           | nd                                              | nd                   | 22 <sup>F</sup>      | 36 <sup>F</sup>                     | nd                         |
| <i>Temperate rainforest</i>                 |                                                 |                      |                      |                                     |                            |
| Australia                                   | 13 913 <sup>A</sup>                             | 13 190 <sup>A</sup>  | nd                   | nd                                  | nd                         |
| New Zealand                                 | >207 000 <sup>L</sup>                           | 21 600 <sup>D</sup>  | 2300 <sup>K</sup>    | 81 <sup>K</sup>                     | nd                         |

<sup>A</sup>Commonwealth of Australia (2016).

<sup>B</sup>Olson *et al.* (2001).

<sup>C</sup>Gillespie *et al.* (2014).

<sup>D</sup>FAO (2015), the current extent of tropical-subtropical rainforest for Fiji and New Caledonia was calculated by subtracting the value for seasonal forest<sup>C</sup> from the value for total primary forest<sup>D</sup>.

<sup>E</sup>Bryan *et al.* (2015).

<sup>F</sup>See Supplementary Material for applicable references and methodology.

<sup>G</sup>Keppel *et al.* (2010).

<sup>H</sup>Morat *et al.* (2012).

<sup>I</sup>Tng *et al.* (2016) in which the number of species per hectare refers to trees ≥10 cm DBH only.

<sup>J</sup>Ibanez *et al.* (2017).

<sup>K</sup>Mittermeier *et al.* (2011), this figure includes species from surrounding islands and non-rainforest habitats.

<sup>L</sup>Wiser *et al.* 2011.

<sup>M</sup>Thaman (1994).

<sup>N</sup>CSIRO (2010), this figure excludes species restricted to subtropical rainforest and most orchids.

<sup>O</sup>Pauku (2009).

<sup>P</sup>Corrigan (2009).

timber, fuel, medicines and other materials important to Pacific Islanders (Thaman 1994; Whistler 2000). Many remote Pacific Island communities still greatly depend on these forests for daily living (Cox and Elmqvist 1993; Hviding 2003). Despite their importance, however, rainforests are disappearing at a rapid rate.

### Threats and losses

In many regions of the South Pacific, the extent of primary (undisturbed) rainforest, particularly in lowland regions, has been greatly reduced by human activities. Initial disturbances were caused by the first human settlers (ancestors of the current indigenous inhabitants) through clearing for agriculture, increased fire frequency and the introduction of non-native

plant and animal species. The rate and scale of disturbance has greatly increased since European settlement, particularly with the introduction of commercial logging and clearing for intensive agriculture or mining (Keppel *et al.* 2014). These disturbances have resulted in substantial losses of primary rainforest in many areas (Table 1), with some islands almost completely deforested (e.g. Tongatapu, Kingdom of Tonga; Wiser *et al.* 2002) or degraded by logging (e.g. New Georgia, Rendova and Isabel Province in the Solomon Islands; Pauku 2009; Katovai *et al.* 2015).

Logging and clearing for agriculture is still ongoing in areas such as the Solomon Islands (Pauku 2009) and Papua New Guinea (Corlett and Primack 2008; Bryan *et al.* 2015). The Solomon Islands were relatively untouched in the middle



of the last century (Whitmore 1969), but the extent of primary rainforest has now been reduced by >40% (Table 1). In Papua New Guinea, 25% of commercially accessible (mainly lowland) rainforest on the mainland, and 62% on nearby islands, has now been degraded by logging (Bryan *et al.* 2015); the FAO (2015) estimated an overall reduction in primary rainforest of 56% over the period from 2009 to 2015. Given that the number of described species for these two nations is substantially less than the estimated number present (Pauku 2009; Gideon 2015), there is a great potential for species to become extinct before they have been identified.

The rainforest fragments remaining following logging and clearing are further threatened by secondary impacts. Fragmentation can reduce opportunities for breeding, particularly for species that were already sparsely distributed (Laurance *et al.* 2000, 2006) and the increase in exposed edges can increase the risk of fire and weed invasion (Ibanez *et al.* 2013). Invasive weeds, in turn, can limit the natural regeneration of native species (Meyer and Florence 1996; Minden *et al.* 2010; Wallace *et al.* 2017). On some of the smaller islands in the South Pacific, the number of non-native plant species now greatly exceeds the number of indigenous species. The Flora of Australia, for example, lists 125 indigenous but 273 naturalised angiosperms for Norfolk Island (Wilson 1994). Similarly, Sykes (2016) reported 187 indigenous but 424 naturalised angiosperms for the Cook Islands.

Loss of dispersal agents, or large distances between fragments, can limit opportunities for regeneration, particularly for larger-seeded species (Meehan *et al.* 2002; McConkey and Drake 2006; Rossetto *et al.* 2015; Goosem *et al.* 2016). Regeneration can also be limited by the activities of pest or agricultural animals. In New Zealand, for example, ground disturbance by wild pigs (*Sus scrofa*) can have a detrimental impact on plant establishment, plant growth and ecosystem structure, and can expedite invasion by weeds (Krull *et al.* 2016). Rodents such as rats and mice can limit plant establishment by consuming seed (Auld *et al.* 2010; McConkey *et al.* 2003), and browsing by herbivores such as red deer (*Cervus elaphus scoticus*) can alter plant growth and cause loss of seedlings (Forsyth *et al.* 2015). In Australia, six species of deer have established feral populations and the environmental degradation they cause through herbivory, trampling and weed dispersal has been listed as a 'key threatening process' potentially impacting rainforest plants and communities (<http://www.environment.nsw.gov.au/determinations/FeralDeerKtp.htm>, accessed 27 November 2017). In the Norfolk Island group, grazing by goats, pigs, rabbits and cattle has contributed to extensive losses of indigenous vegetation including rainforest communities (Mills 2009). Though the removal of rabbits in the 1980s, and pigs and goats in the 1990s, did allow for regeneration in some areas, the loss of native vegetation continues where feral animals cannot be excluded (Director of National Parks 2010).

Introduced diseases can also be problematic in disturbed rainforests. Myrtle rust (*Austropuccinia psidii*, Beenken 2017) has become a particular problem in rainforest habitats in Australia. This disease originated in South America and affects more than 300 species in the family Myrtaceae (Giblin and Carnegie 2014). Since it was first observed in New South

Wales in 2010, Myrtle Rust has had such a devastating effect on two once common rainforest shrubs – *Rhodamnia rubescens* and *Rhodomyrtus psidioides* (Carnegie *et al.* 2016) – that they have now been nominated for listing as 'Critically Endangered' under the *NSW Threatened Species Conservation Act*. Myrtle rust has the potential to spread further through the South Pacific, affecting susceptible genera such as *Metrosideros* (Teulon *et al.* 2015) and *Syzygium* (Giblin and Carnegie 2014) that are present across several island groups (see Supplementary Material to this paper) and are often highly diverse (Ahmad *et al.* 2016). The disease has already progressed across water to Tasmania (<http://dpipwe.tas.gov.au/biosecurity-tasmania/plant-biosecurity/pests-and-diseases/myrtle-rust>, accessed 27 November 2017), to mainland New Zealand and to the remote Raoul Island (<http://www.doc.govt.nz/news/media-releases/2017/myrtle-rust-found-in-new-zealand/>, accessed 27 November 2017).

Diseases caused by various *Phytophthora* species are also having a serious impact in some areas. In New Zealand, *Phytophthora agathidicida* has caused extensive dieback in Kauri (*Agathis australis*, Scott and Williams 2014; Weir *et al.* 2015), with potential flow on effects for a suite of plant taxa dependent on the soil environment created by this species (Wyse *et al.* 2014). In Australia, *Phytophthora cinnamomi* has been linked to the decline of a variety of rainforest species in the Wet Tropics (e.g. *Acronychia vestita* (Rutaceae), *Alphitonia petriei* (Rhamnaceae), *Carnarvonia araliifolia* (Proteaceae), *Cinnamomum oliveri* (Lauraceae) and *Polyosma alangiaceae* (Escalloniaceae); Brown 1999).

South Pacific rainforests face unprecedented threats and are declining in response to increasing population sizes and intensive exploitation (Woinarski 2010; Wardell-Johnson *et al.* 2011). Habitat loss and degradation, invasive species, overexploitation and pollution are the key threats to rainforest biodiversity in the region and island biotas are especially vulnerable (Kingsford and Watson 2011; Keppel *et al.* 2014). Current policies and management efforts appear inadequate in preventing vegetation and biodiversity loss, suggesting the need for new legislation and economic incentives (Wardell-Johnson *et al.* 2011). Implementing new policies is likely to be particularly challenging in developing Pacific Island nations, where past conservation efforts have often been unsuccessful, and administrative and land-tenure complexities add difficulty (Kingsford and Watson 2011; Keppel *et al.* 2012).

## Conservation options

The rapid loss of rainforest diversity indicates that measures to conserve that diversity are needed urgently. *In situ* conservation such as the creation of national parks or reserves is often considered the most effective option; however, the declaration of a reserve does little to mitigate secondary pressures which can continue to act without immediately observable effects. The long lifespan of trees and shrubs, for example, can mean that the impacts of limited mates, absence of pollinators and barriers to regeneration can take a very long time to manifest (Cronk 2016).

On-ground conservation efforts have been successful in some areas where broad scale clearing has largely ceased, such as in the tropical and subtropical rainforests of Australia (Catterall *et al.* 2004), but have been difficult to implement in other areas of the

South Pacific (Keppel *et al.* 2012). Secondary rainforests – rainforests that develop on previously cleared land or primary rainforest that has been partially degraded – can have great conservation value but their diversity is dependent on the availability of propagules and agents to disperse them (Putz and Romero 2014). Secondary rainforests developed on abandoned pastures in Queensland, for example, failed to match the diversity shown in nearby mature forests even after six decades of growth (Goosem *et al.* 2016). Elliott *et al.* (2013) noted that some tree planting is often required to restore full biodiversity in regenerating forests, particularly for species with large seeds that are poorly dispersed. Supplementary planting in turn requires a source of seed or other propagules and knowledge of appropriate methods of propagation. *Ex situ* conservation of plants is therefore a necessity – both as insurance against the loss of diversity and as a source of material that can be used to aid the restoration of diversity.

### Challenges in *ex situ* conservation of rainforest species

Target 8 of the Global Strategy for Plant Conservation calls for 75% of threatened plant species to be held in *ex situ* collections by 2020, preferably in the country of origin, with at least 20% available for recovery and restoration programs (Convention on Biological Diversity 2012). The *ex situ* conservation options currently employed to meet this target include seed banking (the storage of dry seeds at subzero temperatures), the maintenance of whole plants in orchards and botanic gardens, the establishment of tissue cultures *in vitro*, and cryopreservation of tissue cultured material or seed embryos (Offord and Meagher 2009). The most appropriate option for a given situation is dependent on the biology of the species itself and the resources available to conserve it.

Seed banking is generally considered the most efficient and cost effective option in terms of capturing maximum diversity while minimising storage space and ongoing maintenance requirements (Offord and Meagher 2009). Long-term storage is accomplished by drying seeds to 3–7% moisture content and

storing them in airtight containers at temperatures  $\leq -18^{\circ}\text{C}$  (Martyn *et al.* 2009). The method is therefore only suitable for seeds that are ‘orthodox’; that is, tolerant of drying and storage at cold temperatures (Roberts 1973). Tweddle *et al.* (2003) predicted that 50% of non-pioneer woody rainforest species were likely to be intolerant of drying (although recent modelling by Wyse and Dickie (2016) indicates this figure is likely to be much lower when herbaceous species are included). This prediction of desiccation intolerance has meant that, until recently, the seed banking of rainforest species has not been considered a priority, unless a species was particularly threatened or of economic importance. Initial testing of desiccation tolerance is the first logical step to overcome this barrier and, in light of the rapid destruction of rainforests globally (Corlett and Primack 2008), this research is imperative.

Although some predictions of desiccation tolerance can be made based on taxonomy, habitat, and certain seed characteristics, definitive results can best be achieved by experimentation. Over 98% of tested species (representing 34% of genera) in the Fabaceae, for example, are desiccation tolerant (Dickie and Pritchard 2002), but rainforest species from several previously untested genera in that family have recently been found to be desiccation sensitive (e.g. *Archidendron*, Sommerville *et al.* 2016; and *Cynometra*, Baskin and Baskin 2014). Work by Hamilton *et al.* (2013) showed that seed size can be a predictor of desiccation tolerance but the small seeds of whitewood (*Endospermum medullosum*) are just as sensitive to drying as the large seeds of hairy walnut (*Endiandra pubens*) (Fig. 2). The use of the seed coat ratio and dry seed weight to predict desiccation sensitivity (Daws *et al.* 2006) has some value; however, this method has not been found useful for predicting desiccation sensitivity in smaller rainforest seeds (KD Sommerville, G Errington, Z-J Newby, CA Offord, unpubl. data).

The expectation that a significant proportion of rainforest seeds are likely to be intolerant of drying has been borne out by recent assays of Australian mainland species. This proportion, however, has been less than expected with only a quarter of



**Fig. 2.** The small seeds of whitewood (*Endospermum medullosum*) and the large seeds of the hairy walnut (*Endiandra pubens*) are both highly sensitive to drying. Photographs by: P Macdonell (a), K Hamilton (b).

**Table 2.** A selection of plant families with  $\geq 19$  genera occurring in rainforest in the South Pacific, including the proportion of genera in which seed storage behaviour has been tested for at least one species, and genera for which no species have been reported as tested  
Note that the number of tested genera reported for a given family includes genera not restricted to rainforest

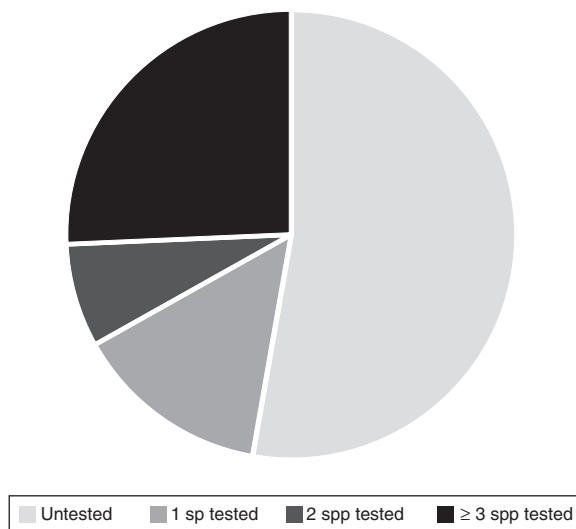
| Family        | No. genera <sup>A</sup> | No. tested <sup>B</sup> | Untested genera <sup>C</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|---------------|-------------------------|-------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Acanthaceae   | 19                      | 10                      | <i>Brunoniella</i> , <i>Dipteracanthus</i> , <i>Graptophyllum</i> , <i>Harnieria</i> , <i>Hemigraphis</i> , <i>Isoglossa</i> , <i>Peristrophe</i> , <i>Pseuderanthemum</i> , <i>Rostellularia</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Annonaceae    | 20                      | 3                       | <i>Artabotrys</i> , <i>Cananga</i> , <i>Cyathocalyx</i> , <i>Cyathostemma</i> , <i>Desmos</i> , <i>Fissistigma</i> , <i>Fitzalanina</i> , <i>Goniothalamus</i> , <i>Haplostichanthus</i> , <i>Huberantha</i> , <i>Meiogyne</i> , <i>Melodorum</i> , <i>Milusa</i> , <i>Mitrella</i> , <i>Mitrephora</i> , <i>Monoon</i> , <i>Pseuduvaria</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Apocynaceae   | 31                      | 15                      | <i>Anodendron</i> , <i>Artia</i> , <i>Carruthersia</i> , <i>Cerbera</i> , <i>Cerberiopsis</i> , <i>Dischidia</i> , <i>Gunnessia</i> , <i>Gymnanthera</i> , <i>Hoya</i> , <i>Ichnocarpus</i> , <i>Kopsia</i> , <i>Lepinia</i> , <i>Melodinus</i> , <i>Ochrosia</i> , <i>Phyllanthera</i> , <i>Sarcobolus</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Arecaceae     | 39                      | 13                      | <i>Actinokentia</i> , <i>Balaka</i> , <i>Basselinia</i> , <i>Burretio kentia</i> , <i>Carpentaria</i> , <i>Chambeyronia</i> , <i>Clinosperma</i> , <i>Clinostigma</i> , <i>Corypha</i> , <i>Cyphokentia</i> , <i>Cyphophoenix</i> , <i>Cyphosperma</i> , <i>Drymophloeus</i> , <i>Hedyscepe</i> , <i>Heterospathe</i> , <i>Kentiopsis</i> , <i>Lepidorachis</i> , <i>Licuala</i> , <i>Linospadix</i> , <i>Metroxylon</i> , <i>Oraniopsis</i> , <i>Pelagodoxa</i> , <i>Physokentia</i> , <i>Saribus</i> , <i>Veitchia</i> , <i>Wodyetia</i>                                                                                                                                                                                                                                                               |
| Celastraceae  | 20                      | 6                       | <i>Brassiantha</i> , <i>Cassine</i> , <i>Dicarpellum</i> , <i>Dinghoua</i> , <i>Hedraianthera</i> , <i>Hexaspora</i> , <i>Hippocratea</i> , <i>Hypsophila</i> , <i>Menepetalum</i> , <i>Perrottetia</i> , <i>Pleurostylia</i> , <i>Salacia</i> , <i>Salaciopsis</i> , <i>Siphonodon</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Cunoniaceae   | 21                      | 4                       | <i>Ackama</i> , <i>Anodopetalum</i> , <i>Bauera</i> , <i>Caldcluvia</i> , <i>Callicoma</i> , <i>Codia</i> , <i>Cunonia</i> , <i>Geissois</i> , <i>Gillbeea</i> , <i>Hooglandia</i> , <i>Karrabina</i> , <i>Pancheria</i> , <i>Pseudoweinmannia</i> , <i>Pullea</i> , <i>Schizomeria</i> , <i>Spiraeanthemum</i> , <i>Vesselowskyia</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Ericaceae     | 21                      | 8                       | <i>Acrothamnus</i> , <i>Acrotriche</i> , <i>Archeria</i> , <i>Cyathodes</i> , <i>Leptecophylla</i> , <i>Melichrus</i> , <i>Montitega</i> , <i>Paphia</i> , <i>Pentachondra</i> , <i>Prionotes</i> , <i>Sprengelia</i> , <i>Styphelia</i> , <i>Trochocarpa</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Euphorbiaceae | 36                      | 13                      | <i>Adriana</i> , <i>Baloghia</i> , <i>Bertya</i> , <i>Beyeria</i> , <i>Bocquillonia</i> , <i>Claoxylon</i> , <i>Cleidion</i> , <i>Cocconerion</i> , <i>Codiaeum</i> , <i>Dimorphocalyx</i> , <i>Fontainea</i> , <i>Hylandia</i> , <i>Microstachys</i> , <i>Neoguillauminia</i> , <i>Omphalea</i> , <i>Pimelodendron</i> , <i>Ricinocarpos</i> , <i>Rockinghamia</i> , <i>Shonia</i> , <i>Stillingia</i> , <i>Suregada</i> , <i>Trigonostemon</i> , <i>Wetria</i>                                                                                                                                                                                                                                                                                                                                         |
| Malvaceae     | 43                      | 28                      | <i>Acropogon</i> , <i>Androcalva</i> , <i>Argyrodendron</i> , <i>Firmiana</i> , <i>Franciscodendron</i> , <i>Howittia</i> , <i>Indagator</i> , <i>Kleinhovia</i> , <i>Lebronnecia</i> , <i>Maxwellia</i> , <i>Microcos</i> , <i>Pterocymbium</i> , <i>Schoutenia</i> , <i>Solmsia</i> , <i>Ungeria</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Myrtaceae     | 50                      | 21                      | <i>Allosyncarpia</i> , <i>Archirhodomyrtus</i> , <i>Arillastrum</i> , <i>Backhousia</i> , <i>Barongia</i> , <i>Cloezia</i> , <i>Gossia</i> , <i>Kanakomyrtus</i> , <i>Lenwebbia</i> , <i>Lindsayomyrtus</i> , <i>Lithomyrtus</i> , <i>Lophomyrtus</i> , <i>Mitrantia</i> , <i>Neomyrtus</i> , <i>Osbornia</i> , <i>Pilidiostigma</i> , <i>Piliocalyx</i> , <i>Pleurocalyptus</i> , <i>Rhodamnia</i> , <i>Ristantia</i> , <i>Sannantha</i> , <i>Sphaerantia</i> , <i>Stereocaryum</i> , <i>Stockwellia</i> , <i>Thaleropia</i> , <i>Tristaniopsis</i> , <i>Uromyrtus</i> , <i>Welchiodendron</i> , <i>Xanthomyrtus</i>                                                                                                                                                                                    |
| Proteaceae    | 45                      | 14                      | <i>Alloxylon</i> , <i>Athertonia</i> , <i>Austromuellera</i> , <i>Beauprea</i> , <i>Bellendena</i> , <i>Bleasdalea</i> , <i>Cardwellia</i> , <i>Carnarvon</i> , <i>Catalepidia</i> , <i>Cenarrhenes</i> , <i>Eidothea</i> , <i>Finschia</i> , <i>Floydia</i> , <i>Garnieria</i> , <i>Helicia</i> , <i>Hicksbeachia</i> , <i>Hollandaea</i> , <i>Kermadecia</i> , <i>Lasjia</i> , <i>Megahertzia</i> , <i>Musgravea</i> , <i>Neorites</i> , <i>Nothorites</i> , <i>Opisthiolopsis</i> , <i>Placospermum</i> , <i>Sleumerodendron</i> , <i>Sphalmium</i> , <i>Toronia</i> , <i>Triunia</i> , <i>Turrillia</i> , <i>Virotia</i>                                                                                                                                                                             |
| Rubiaceae     | 64                      | 24                      | <i>Aidia</i> , <i>Airosperma</i> , <i>Amaracarpus</i> , <i>Augusta</i> , <i>Badusa</i> , <i>Bikkia</i> , <i>Bobea</i> , <i>Calycosia</i> , <i>Canthium</i> , <i>Coelospermum</i> , <i>Cyclophyllum</i> , <i>Dentella</i> , <i>Dolicholobium</i> , <i>Everistia</i> , <i>Exallage</i> , <i>Geophila</i> , <i>Gillespiea</i> , <i>Guetarda</i> , <i>Gynochthodes</i> , <i>Hedstromia</i> , <i>Hodgkinsonia</i> , <i>Hydnophytum</i> , <i>Kadua</i> , <i>Knoxia</i> , <i>Larsenaikia</i> , <i>Lasianthus</i> , <i>Leptopetalum</i> , <i>Margaritopsis</i> , <i>Mastixiodendron</i> , <i>Morierina</i> , <i>Morinda</i> , <i>Myrmecodia</i> , <i>Neonauclea</i> , <i>Readea</i> , <i>Squamellaria</i> , <i>Timonius</i> , <i>Tinadendron</i> , <i>Triflorensia</i> , <i>Wendlandia</i> , <i>Xanthophytum</i> |
| Rutaceae      | 40                      | 12                      | <i>Acradenia</i> , <i>Asterolasia</i> , <i>Bosistoa</i> , <i>Bouchardatia</i> , <i>Brombya</i> , <i>Coatesia</i> , <i>Comptonella</i> , <i>Crossosperma</i> , <i>Dinosperma</i> , <i>Dutailliopsis</i> , <i>Dutaillyea</i> , <i>Eriostemon</i> , <i>Geijera</i> , <i>Halfordia</i> , <i>Harrisonia</i> , <i>Leionema</i> , <i>Lunasia</i> , <i>Luvunga</i> , <i>Medicosma</i> , <i>Nematolepis</i> , <i>Pentaceras</i> , <i>Phebalium</i> , <i>Philotheca</i> , <i>Picrella</i> , <i>Pitaviaster</i> , <i>Sarcomelicope</i> , <i>Wenzelia</i> , <i>Zieria</i>                                                                                                                                                                                                                                            |
| Sapindaceae   | 32                      | 15                      | <i>Arytera</i> , <i>Castanospora</i> , <i>Cnesmocarpon</i> , <i>Dictyoneura</i> , <i>Elattostachys</i> , <i>Ganophyllum</i> , <i>Gongrodiscus</i> , <i>Jagera</i> , <i>Lepiderema</i> , <i>Mischarytera</i> , <i>Mischocarpus</i> , <i>Podonephelium</i> , <i>Sarcopteryx</i> , <i>Sarcotoechia</i> , <i>Storthocalyx</i> , <i>Synima</i> , <i>Tristiropsis</i>                                                                                                                                                                                                                                                                                                                                                                                                                                          |

<sup>A</sup>Initial species lists were derived from a combination of online herbarium databases and published floras. The Australian Plant Census (APC, <https://biodiversity.org.au>) and Plants of the World Online (PWO, [www.plantsoftheworldonline.org](http://www.plantsoftheworldonline.org)) were used to check current taxon names, with reference to the World Checklist of Selected Plant Families (<http://wcp.science.kew.org>) and the Plant List ([www.theplantlist.org](http://www.theplantlist.org)) if taxa were not present in APC or PWO (all sites were accessed September–October 2017). Corrected species names were then used to derive the list of genera for each country. Family names follow Angiosperm Phylogeny Group III (2009) and Mabberley (2008) for gymnosperms.

<sup>B</sup>Data on number of genera tested for seed storage behaviour was derived from the Seed Information Database (Royal Botanic Gardens Kew 2017; <http://data.kew.org/sid>, accessed February 2017), Hamilton *et al.* (2013) and Baskin and Baskin (2014).

<sup>C</sup>Seed storage behaviour for species from several previously untested genera is currently being studied at the Australian PlantBank.





**Fig. 3.** The proportion of rainforest genera in the South Pacific for which data on seed storage behaviour is currently lacking.

species tested showing full sensitivity to desiccation at 15% RH (Sommerville *et al.* 2016). Based on studies of the tropical Hawaiian flora, the proportion of desiccation sensitive seeds on remote oceanic islands is likely to be even lower. Of 207 taxa screened (including wet rainforest species), 78% were not sensitive to drying and a further 20% were categorised as ‘probably not sensitive’ (Yoshinaga and Walters 2003). The authors attributed this result (in part) to the inability of desiccation sensitive seeds to survive long-distance dispersal and successfully colonise remote islands.

Around one third of the Australian rainforest species found tolerant of drying to date have either not been tolerant of subsequent freezing or have been comparatively short-lived in storage. These species can still be conserved; however, a modification of standard seed banking protocols is necessary. Freezing-sensitive species, for example, can be held in a refrigerator until more effective long-term storage conditions can be identified. Differential scanning calorimetry coupled with an analysis of lipid content can aid in determining what those conditions should be (Crane *et al.* 2003). Short-lived species, in contrast, can be stored at much lower temperatures

#### Box 1. Case study – *Cryptocarya* spp.

*Cryptocarya* (Lauraceae) is an important taxon in the rainforests of the South Pacific. The genus contains 47 Australian rainforest species, including some that are threatened (e.g. *C. dorrigoensis*, *C. floydii*, *C. foetida*, *C. williwilliana*). The seeds of two species (*C. laevigata* and *C. rigida*) were recently found to be desiccation sensitive during testing at the Australian PlantBank, and a third (*C. microneura*) was found to be desiccation tolerant. Freshly germinated seedlings resulting from germination trials of *C. microneura*, *C. rigida* and a fourth species, *C. glaucescens*, were transferred into potting mix and grown on, initially under glasshouse conditions and subsequently under 70% shade (V. Viler, pers. comm). Shoot tips were harvested from the species after ~1 years’ growth and used to initiate tissue cultures. All three species have grown well in culture and two have been successfully transferred from sterile culture back to potting mix and from pots to the field (A. Rollason, pers. comm). Material retained in tissue culture will now be used to develop cryopreservation protocols for desiccation sensitive species in the genus.



**Fig. 4.** Desiccation sensitive *Cryptocarya microneura* in sterile culture (a) and following successful transfer to growing medium (b). Photographs by: N Emery (a), K Sommerville (b).



(e.g.  $-80$  or  $-192^{\circ}\text{C}$ ) to extend their longevity (Sommerville and Offord 2015).

While the storage behaviour of some genera occurring in South Pacific rainforests is fairly well studied (e.g. *Melaleuca* (Myrtaceae), *Plectranthus* (Lamiaceae) and *Hibiscus* (Malvaceae)), little to no information is available for others (Table 2). Data on seed storage behaviour was lacking for more than half of the 1503 rainforest genera examined for this paper and nearly a quarter of the 209 families (Fig. 3, see Supplementary Material to this paper). Of the 710 genera for which storage behaviour data was found in the Seed Information Database (Royal Botanic Gardens Kew 2017), Hamilton *et al.* (2013) or Baskin and Baskin (2014), the behaviour of 324 genera was based on an assessment of only one or two species although 76% of those genera contained at least 10 species. Many of the unstudied or poorly studied genera are shared across several South Pacific nations, providing an excellent opportunity for collaboration on *ex situ* research and conservation. Of the 386 genera for which three or more species have been studied, 343 have a very high proportion of species ( $>95\%$  of those tested) that are suitable for seed banking. However, the data available are

biased towards species occurring in dryland areas (Wyse and Dickie 2016), so caution should be used in predicting the storage behaviour of rainforest species based on species already assayed in the same genus.

Determining whether rainforest seeds are suitable for storage can be frustrated by an inability to germinate the seed, either due to dormancy or lack of data on the optimum germination conditions. From germination studies performed using fresh seeds from non-pioneer rainforest trees, Baskin and Baskin (2014) inferred that half of over 1900 species tested had some form of dormancy. The seeds of some of these species took more than two years just to begin germinating. Germination experiments on rainforest plants can also be frustrated by the prolific growth of fungi, to which tropical fruit and seeds tend to be particularly susceptible (Berjak and Pammenter 2014).

The determination of storage behaviour can be further complicated by the difficulty in collecting rainforest seeds in sufficient quantity to enable useful testing. There are several factors contributing to this problem. For some species, individuals grow far apart (km) in the landscape so that

### Box 2. Case study – *Dysoxylum spectabile* (kohekohe)

Seeds of the endemic New Zealand tree kohekohe (*Dysoxylum spectabile*, Meliaceae, Fig. 5) have been found to be relatively intolerant of drying, with germination declining from 93% at 50% seed moisture content (MC) to 58% after drying to 29% MC and 3% after drying to 21% MC (Park 2013). Though not wholly desiccation sensitive, kohekohe cannot be dried to the low seed moisture content required for standard seed banking. Rapid drying of excised embryos followed by cryopreservation may be an alternative option for conserving this species; while no excised embryo's survived desiccation to 34% MC following slow drying, 10% remained viable following rapid drying to 10% MC. Another option for enhancing the survival of desiccation sensitive tissue is to encapsulate the tissue in a sodium-alginate bead. In kohekohe, encapsulation enabled around 17% of embryos to survive drying to a bead moisture content of around 17%. Pre-treatment with cryoprotectants can also protect tissue from freezing injury and enabled around 20% of excised kohekohe embryos to survive cryopreservation. Subsequent tissue culture of the embryos, however, failed to produce any normal seedlings (radicle elongation occurred but shoots failed to develop; Park 2013). This work suggests that desiccation sensitive species in the South Pacific may potentially be cryopreserved but that post-cryopreservation recovery protocols need to be developed.



Fig. 5. Fruit and seed of kohekohe (*Dysoxylum spectabile*). Photographs by R Southward.

finding and collecting from many individuals can take a considerable amount of time. In primary rainforests, fruiting of tree and vine species can occur high in the canopy which can be very difficult to access. Asynchronous ripening of fruit (i.e. ripening staggered over a long period) is a common feature of rainforest plants and can mean that multiple collecting trips may be required to make a useful collection. Given the enormous number of rainforest species yet to be studied, these difficulties point to the need for much greater collaboration among research institutions, government and conservation organisations if any headway is to be made in conserving species before they become extinct.

### Options for conserving desiccation sensitive species

Species with seeds that do not tolerate any drying can be conserved by tissue culture (growing plants in a nutrient medium under sterile conditions, Box 1, Fig. 4) or cryopreservation of tissue-cultured material (involving pre-treatment with chemicals to reduce freezing injury and storage at temperatures  $\leq -190^{\circ}\text{C}$ ). Tissue cultures can be initiated from plant material collected directly from the wild (eliminating the need to find fruiting specimens) and can even be initiated in the

field if anti-microbial agents are used to control fungal and bacterial growth (Pence 2005). Alternatively, material for initiation can be obtained by germinating seeds in a sterile environment, or by growing seedlings in pots under controlled conditions; both methods reduce the amount of fungal and bacterial contamination encountered during initiation. Once established, tissue cultured material can be maintained by regular sub-culturing (transfer of shoot tips to fresh media). This is a labour-intensive process but the length of time between subcultures can be increased by storing the plantlets at low temperatures under low light (*in vitro* storage; Engelmann 2011).

Tissue cultures can also be used to produce buds for cryopreservation. This is a long-term storage option that requires far less maintenance than tissue culture but can require a considerable investment of time and resources at the outset, both to develop suitable protocols for culturing the species, and to develop protocols for cryopreservation (Ashmore *et al.* 2011). Though tissue culture and cryopreservation protocols have been developed for many economically important species (Reed 2008), relatively little work has been done on wild rainforest species in the South Pacific.

### Box 3. Case study – *Endospermum medulosum* (whitewood)

*Endospermum medulosum* (Euphorbiaceae) is economically important to Vanuatu because of its high-value timber (Settle *et al.* 2012); however, populations of the species are being degraded or lost through logging and land clearing for agriculture. The seed of this species is sensitive to drying, seed viability is characteristically low (13%) and refrigeration has not been found useful in extending the storage life of either the drupes or the cleaned seed (Page and Doran 2016). In the late 1990s, in an attempt to secure populations and provide easy access to high quality seed for replanting, seed was collected from 14 populations and used to establish stands suitable for *ex situ* conservation and seed production on the island of Santo (Fig. 6). In a follow-up project in 2010–2015, it was found that nine of the 14 populations originally sampled no longer existed as a result of changes in land use (Doran *et al.* 2012). These populations are now only represented in the *ex situ* stands. This highlights the importance of *ex situ* plantings for species where long-term seed storage has proven difficult. The conservation stands, however, are also at risk from land use changes and environmental disasters. Although research enabling the long-term storage of seed could provide another avenue for securing this species into the future, the establishment of a secure network of *ex situ* plantings across a range of sites, possibly extending to international locations, would provide the best security for the immediate future.



Fig. 6. Saplings (a) and conservation stand (b) of whitewood (*Endospermum medulosum*). Photographs by: J Doran.

A promising option for conserving desiccation sensitive species that bypasses tissue culture is to excise the embryonic axis from a seed, dry the axis rapidly in a flow of gas with low humidity (e.g. air or nitrogen), and then preserve it in liquid nitrogen (Berjak and Pammenter 2014). This technique has been successfully applied to several desiccation sensitive horticultural species (Normah and Makeen 2008) but has so far proven difficult to optimise for individual rainforest species (see Box 2, case study on *Dysoxylum spectabile*).

An alternative option for conserving desiccation sensitive species is to grow whole plants in pots, orchards or botanic gardens. Though establishing genetically diverse living collections requires a great deal more time and effort than seed banking, such collections can provide a valuable source of

material for restoration (see Box 3, case study on Whitewood), and can also provide a readily accessible source of individuals for further research into issues related to conservation and management (Offord and North 2009). Land and resources for conservation are often limited, however, so this type of collection is only likely to be applied to species that are highly threatened or have some economic importance.

### *Ex situ* conservation facilities in the South Pacific

At present, the only long-term seed banking facilities available in the South Pacific are located in Australia, New Zealand and Fiji. The majority of these are situated within botanic gardens and are dedicated to the preservation of native plant diversity (Table 3). Three of these seed banks also house facilities for

**Table 3. The conservation focus and capacity of *ex situ* conservation facilities in the South Pacific**

Abbreviations: BG, Botanic Gardens; CSIRO, Commonwealth Scientific Industry Research Organisation; NARI, National Agricultural Research Institute; SPC, Secretariat of the Pacific Community

| Institution                            | Location                             | Facilities |                |                   | Conservation focus                                   |
|----------------------------------------|--------------------------------------|------------|----------------|-------------------|------------------------------------------------------|
|                                        |                                      | Seed bank  | Tissue culture | Cryo-preservation |                                                      |
| <i>Australia</i>                       |                                      |            |                |                   |                                                      |
| Australian National BG                 | Canberra, ACT                        | *          | —              | —                 | Australian native species                            |
| Australian BG, Mount Annan             | Mount Annan, NSW                     | *          | *              | *                 | Australian native species                            |
| Australian Grains Genebank             | Horsham, Vic.                        | *          | —              | —                 | Grains, crops and crop wild relatives                |
| BG of South Australia                  | Adelaide, SA                         | *          | —              | —                 | Australian native species                            |
| Brisbane BG                            | Toowong, Qld.                        | *          | —              | —                 | Australian native species                            |
| CSIRO Australian Tree Seed Centre      | Canberra, ACT                        | *          | —              | —                 | Australian native and non-native trees               |
| George Brown Darwin BG                 | Darwin, NT                           | *          | —              | —                 | Australian native species                            |
| Griffith University                    | Brisbane, Qld.                       | —          | *              | *                 | Research only                                        |
| Hunter Region BG                       | Heatherbrae, NSW                     | *          | —              | —                 | Australian native species                            |
| Kings Park and BG                      | West Perth, WA                       | *          | *              | *                 | Australian native species                            |
| North Coast Regional BG                | Coffs Harbour, NSW                   | *          | —              | —                 | Australian native species                            |
| Royal BG, Victoria                     | Melbourne, Vic.                      | *          | *              | —                 | Australian native species                            |
| Royal Tasmanian BG                     | Hobart, Tas.                         | *          | *              | —                 | Australian native species                            |
| Threatened Flora Seed Centre           | Perth, WA                            | *          | —              | —                 | Australian native species                            |
| <i>Fiji</i>                            |                                      |            |                |                   |                                                      |
| SPC Centre for Pacific Crops and Trees | Narere, Suva                         | —          | *              | *                 | Taro, yam, sweet potato, banana, cassava, breadfruit |
| SPC Pacific Islands Tree Seed Centre   | Narere, Suva                         | *          | —              | —                 | Pacific Islands native and non-native trees          |
| Koronivia Research Station             | Nausori                              |            | *              | —                 | Agricultural research                                |
| Legalega Research Centre               | Nadi                                 | *          | —              | —                 | Breadfruit field genebank                            |
| <i>New Zealand</i>                     |                                      |            |                |                   |                                                      |
| Margot Forde Germplasm Centre (MFGC)   | Palmerston North                     | *          | —              | —                 | Pasture and turf grasses                             |
| New Zealand Indigenous Flora Seed Bank | Palmerston North<br>(hosted by MFGC) | *          | —              | —                 | New Zealand native species                           |
| Plant & Food Research Limited          | Lincoln, Canterbury                  | *          | *              | —                 | Vegetable, fodder and cereal crops                   |
| Plant & Food Research Limited          | Palmerston North                     | —          | *              | *                 | Tuber and fruit crops                                |
| Plant & Food Research Limited          | Motueka                              | —          | *              | —                 | Berry fruits                                         |
| Cawthron Institute                     | Nelson                               | —          | —              | *                 | Micro-algae and aquaculture species                  |
| <i>Papua New Guinea</i>                |                                      |            |                |                   |                                                      |
| NARI Highlands Regional Centre         | Aiyura, Eastern Highlands Province   | —          | *              | —                 | Taro, sweet potato, banana, cassava, yams, aibika    |
| NARI Islands Regional Centre           | Keravat, East New Britain            | —          | *              | —                 | Food and cash crops                                  |
| <i>Samoa</i>                           |                                      |            |                |                   |                                                      |
| The University of the South Pacific    | Apia                                 | —          | *              | —                 | Taro, yams, sweet potato, bele, breadfruit, vanilla  |



the tissue culture and cryopreservation of native species not suitable for seed banking. Tissue culture and cryopreservation facilities are also located in Fiji, Papua New Guinea and Samoa, but these are focussed on the conservation of food and cash crops such as taro, yams, sweet potato, cassava and breadfruit (Table 3).

Of the *ex situ* conservation facilities available, only the Australian PlantBank currently has a program dedicated to research into the conservation of rainforest species. The first stage of this program (The Rainforest Conservation Project, 2010–2012) involved screening over 100 rainforest species for desiccation tolerance (Hamilton *et al.* 2013). Stage two of the program (2013–2017) has focussed on screening a further 250 species, while collecting and storing species found to be desiccation tolerant, and developing alternative storage methods for species found to be sensitive to desiccation or freezing. The experience and knowledge accumulated under this program could now serve as the basis for expanding the work into other regions of the South Pacific. Given that desiccation sensitive species can be difficult to transport long distances without loss of viability, and permits to import species into other countries can be difficult to obtain (particularly for species with the potential to become weeds or to carry disease), such work would require collaboration with conservation entities within the country of origin to be effective.

### The way forward

Considering the large number of rainforest species in the South Pacific, the high level of endemism, and the rapidity with which primary forest is being lost or degraded, it would be beneficial to all South Pacific nations to invest greater resources in *ex situ* conservation of their native plant diversity. As conservation facilities for wild plants are limited at present (outside of Australia), one initial approach could be to utilise in-country forestry, agriculture and university facilities to conduct preliminary research and to house collections of orthodox seeds. Established seed bank facilities in Australia, New Zealand and Fiji could also be used to house orthodox seeds till in-country facilities could be established.

As pioneer rainforest species are most likely to have orthodox seeds (Tweddle *et al.* 2003), building up a diverse collection of such species could be a useful way to start a seed conservation program and would aid in efforts to begin restoring deforested areas. Working with genera that are common across several nations, that are important as crop wild relatives (e.g. genera in Rutaceae), or that are particularly threatened by disease (e.g. genera in Myrtaceae), could also be good ways to focus initial efforts and attract funding. Training in appropriate techniques could be provided at established facilities, or in-country by staff experienced in working with rainforest species.

Species that occur in multiple rainforest types (such as *Cryptocarya triplinervis*, *Endiandra floydii*, *Litsea australis* and *Neolisteia dealbata* in Lauraceae), or multiple locations across the South Pacific (such as *Alyxia stellata*, *Cerbera manghas*, *Neisosperma oppositifolium* and *Tabernaemontana pandacauai* in the Apocynaceae), raise the question of how many populations need to be sampled to adequately represent the genetic diversity of a species. Investigating the extent of

genetic differentiation among populations of these species would provide useful information on the number of seed collections required to conserve the species effectively. The latter group of species also provide an opportunity to investigate survival following long distance dispersal in relation to seed storage behaviour.

Addressing the ongoing decline in rainforest diversity in the South Pacific demands knowledge, partnerships and facilities to support *ex situ* conservation. A potentially large number of rainforest plant species could be conserved using standard or modified seed banking techniques; however, our window of opportunity for utilising these techniques may be limited. The resources we invest in seed banking and conservation research over the coming years will determine whether we can conserve these species before their habitats are lost.

### Conflicts of interest

The authors declare no conflicts of interest.

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