

Prioritizing conservation of tropical dry forests in the Pacific

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Abstract To identify forests of high priority for conservation in tropical dry forests of New Caledonia, Fiji, the Marquesas and Hawaii, we examined patterns of woody plant species richness (total, native and endemic) and threatened species (IUCN categorization and density) at the stand level, using Gentry's transect method. There were associations between total, native and endemic plant species richness in all four Pacific dry forest regions but we found no significant association with the presence or density of species listed on the IUCN Red List. Dry forests in New Caledonia and Hawaii merit the highest conservation priority in the Pacific, based on level of endemism and number of threatened species. The study sites that merit high conservation priority are Metzdorf, Nekoro and Pindai, in New Caledonia, Kokee and Kaupulehu, in Hawaii, and Vatia, in Fiji. New Caledonia and Fiji have a small dry forest extent and protected area extent compared with other dry forests in biodiversity hotspots. Although we identified priority areas for dry forest conservation, more comparative plot data, presence/absence data in fragments and regional geographical data are needed to adequately manage and protect dry forests in the Pacific.

Keywords Biodiversity hotspots, dry forest, geographical information system, IUCN Red List, Pacific, species richness

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Introduction

Tropical dry forest, also known as seasonally dry tropical forest, can be loosely defined as forest in frost-free regions with 500–2,000 mm of precipitation annually and a pronounced dry season of 4–7 months (Walter, 1971; Murphy & Lugo, 1986; Miles et al., 2006). Isolated oceanic islands in the Pacific contain tropical dry forest and a number of endemic plant species with small geographical ranges (Mueller-Dombois & Fosberg, 1998). There have been high levels of deforestation and degradation of tropical dry forests on these islands, which have a long history of anthropogenic disturbance (Rolett & Diamond, 2004). New Caledonia, Fiji, the Marquesas and Hawaii have been deforested for agriculture, and forests have been degraded by fire, grazing and invasion of non-native species of plants and animals (Cuddihy & Stone, 1990; Cabin et al., 2002; Meyer, 2004). According to the definition of Fisher & Lindenmayer (2007) the majority of remaining native dry forest fragments in the Pacific can be considered relictual because they have been reduced to <10% of their original cover, and almost all remaining fragments are <100 ha. Thus, they provide a good opportunity to examine methods used to identify patterns of species richness in fragmented systems and compare the conservation status of these forests with other regions (Gordon et al., 2003).

There is a growing interest in identifying tropical forests and forest fragments in regions that have a high conservation priority at a global spatial scale (Miles et al., 2006; Schmitt et al., 2009). However, there are few comparative data on the relationship between various metrics and stand species richness across different geographical regions (Gordon et al., 2003) and there is an ongoing debate about the importance of species richness as a metric for conservation planning. Levels of species richness in stands of tropical forests have been identified as an important metric for studying the conservation value of forests and nature reserves (Arroyo-Rodriguez et al., 2008). However, some researchers maintain that the number of range-restricted or endemic species and presence or densities of threatened species are equally important metrics for prioritizing conservation areas (Kerr, 1997; Chapman et al., 2009).

Biodiversity hotspots are regions that contain exceptional concentrations of endemic species whose habitat is threatened by human activity (Myers et al., 2000; Myers, 2003; Conservation International, 2009). The resources

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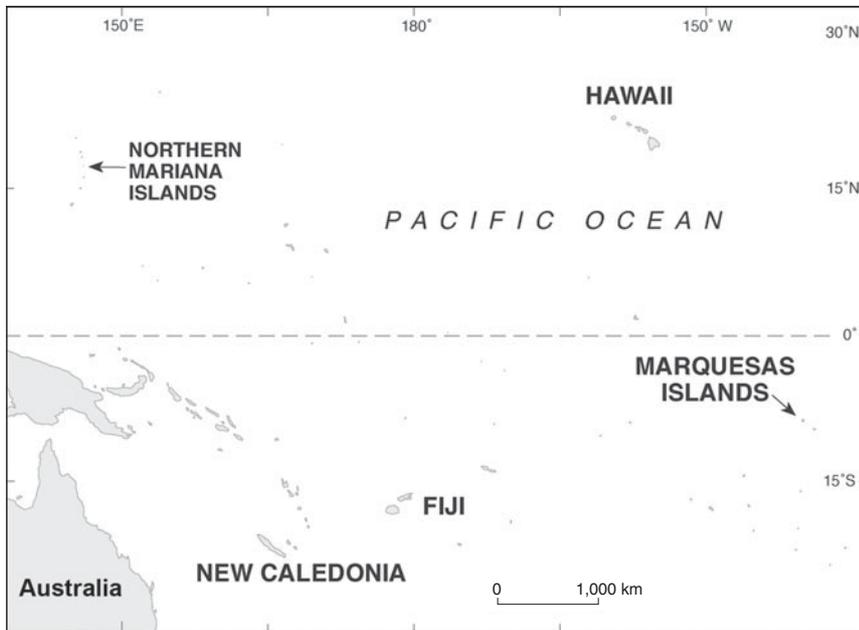


FIG. 1 Pacific archipelagos with tropical dry forests.

available for conservation in biodiversity hotspots are inadequate to protect all species and therefore it would be more effective to concentrate conservation efforts in areas with the highest levels of biodiversity and the highest numbers of threatened species. Gentry transects provide a standard and repeatable method that can be used to compare levels of species richness and risk of extinction (Gentry, 1995; Phillips & Miller, 2002), and geographical information system (GIS) polygons of tropical dry forest regions and satellite imagery (MODIS 500 m resolution) have been used to identify the extent of dry forests at a global spatial scale (Miles et al., 2006; Schmitt et al., 2009; Portillo-Quintero & Sánchez-Azofeifa, 2010), although there are few comparative plot or forest extent data for biodiversity hotspots in the Pacific (Miles et al., 2006; Pau et al., 2009; Pennington et al., 2009; Schmitt et al., 2009). There have been significant advances in the spatial resolution of GIS and remote-sensing data, which can be used to assess the extent and conservation status of dry forests in biodiversity hotspots. WWF's ecoregions approach has provided comparative data on large units of land and water containing geographically distinct assemblages of species, natural communities and environmental conditions, at a global spatial scale (Olson et al., 2001), and there have been advances in the spatial resolution of land-cover classifications such as the European Space Agency's GlobCover dataset, which provides 22 land-cover classes (six terrestrial forest types) at a 300 × 300 m pixel resolution (ESA, 2010).

Our research had three primary objectives. Firstly, we examined the relationship between total species richness, native species richness, number of endemic species and number of threatened woody plant species (trees, shrubs, lianas) at the stand level. In particular, we tested the

hypothesis that total species richness at the stand level is positively associated with native species richness, endemic species richness, and presence and density of threatened species across all four regions (New Caledonia, Fiji, Hawaii and the Marquesas). Secondly, we assessed the conservation priorities of tropical dry forest sites in the Pacific based on the presence and density of threatened species and levels of endemism. Thirdly, we calculated the extent of tropical dry forests and protected areas in the New Caledonia and Polynesia–Micronesia biodiversity hotspots to assess the conservation priorities in the region.

Study area

This research was undertaken on four oceanic island archipelagoes (New Caledonia, Fiji, the Marquesas and Hawaii) within the New Caledonia and Polynesia–Micronesia biodiversity hotspots (Myers et al., 2000; Fig. 1). Study sites were selected based on Landsat ETM+ data from 2005, WorldClim climate data extrapolated from climate stations (WorldClim, 2009), and Shuttle Radar Topography Mission data, to identify the best-preserved forest fragments in regions with 500–2,000 mm of annual precipitation and a pronounced dry season (Hijmans et al., 2005). We conducted field visits to potential sites to ensure that they hosted native tree species. We surveyed a total of 37 dry forest sites (Fig. 2). Seven sites were surveyed on the western side of Grand Terre, New Caledonia. Nine sites were surveyed in western Fiji: Yasawa group (4), Mamanuca group (1), Viti Levu (2) and islands near Viti Levu and Vanua Levu (2). Six sites were surveyed on the two largest islands in the Marquesas: Nuku Hiva (3) and

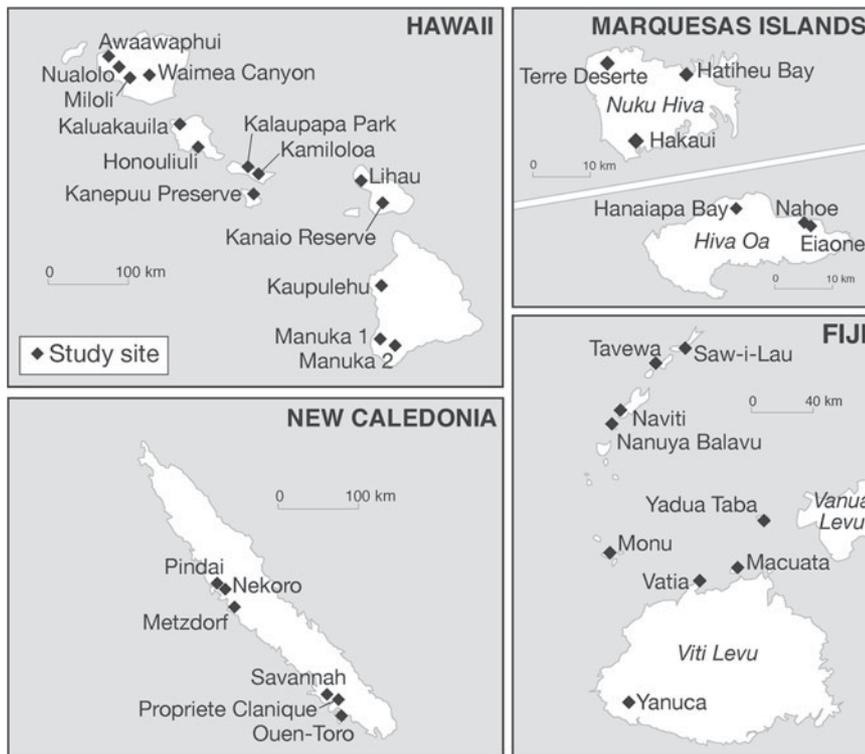


FIG. 2 Locations of our study sites in tropical dry forests on the Pacific islands of Hawaii, New Caledonia, the Marquesas and Fiji.

Hiva Oa (3). Fifteen sites were surveyed on six Hawaiian islands: Kauai (4), Oahu (2), Molokai (1), Lanai (3), Maui (2), and the island of Hawaii (3). Detailed overviews of each region and our study areas are available at Gillespie (2013).

Methods

Data on species richness, floristic composition and forest structure at each study site were collected following Gentry (1988). Belt transects of 1,000 m² (0.1 ha) were established at each site. Each survey consisted of 10 transects (2 × 50 m), spaced 10 m apart, in which all plants of diameter at breast height ≥ 2.5 cm rooted in the sample area were recorded (Gentry, 1988). In New Caledonia, Fiji, and Hawaii, plants were identified to species or morphospecies at the local herbaria: Institut de recherche pour le développement (IRD) in Nouméa, New Caledonia; South Pacific Regional Herbarium (SUVA) at the University of the South Pacific in Suva, Fiji; and Bishop Museum in Honolulu, Hawaii (BISH). All species from the Marquesas were identified according to Wagner & Lorence (2003). At each site species were identified as native, endemic to the regional archipelago or non-native, and threatened species were categorized as Critically Endangered, Endangered or Vulnerable according to the IUCN Red List (IUCN, 2012).

We collected four GIS layers to identify the extent of ecoregion, dry forest and protected forest in Pacific

biodiversity hotspots. Ecoregion polygons were acquired from WWF (2009) for dry forest in the New Caledonia and Polynesia–Micronesia biodiversity hotspots (Conservation International, 2009). We acquired the European Space Agency's *GlobCover v. 2.1* dataset (ESA, 2010), which contains three terrestrial forest land-cover classifications that correspond to tropical dry forest: (1) > 5 m tall closed to open (>15%) broadleaved evergreen or semi-deciduous forest; (2) closed (>40%) broadleaved deciduous forest; (3) open (15–40%) broadleaved deciduous forest. Protected area polygons were acquired from the World Database on Protected Areas (IUCN/UNEP, 2009). Only terrestrial protected areas in categories I to VI were included (IUCN, 2009).

Species richness data (total richness, native richness and endemic richness) had a normal distribution within each region, based on a one-sample Kolmogorov–Smirnov test, and therefore a Pearson product correlation was used to identify whether total species richness was associated with native richness or endemic richness. The number and density of Red-Listed species did not have a normal distribution, and thus we used a Spearman's rank correlation between total species richness and number and density of threatened species in 0.1 ha plots. We ranked conservation priorities of sites, based on the number and density of Red-Listed species and the number of endemic species in the 0.1 ha plots. Ecoregions within the Polynesia–Micronesia and New Caledonia biodiversity hotspots that contain dry forest were overlain on GlobCover data

TABLE 1 Number (and percentage) of native, endemic and non-native species, number of Red-Listed species (Critically Endangered, Endangered or Vulnerable), and number of individuals of Red-Listed species of woody plants ≥ 2.5 cm diameter at breast height rooted within Gentry transects at our study sites on the Pacific islands of New Caledonia, Fiji, Marquesas and Hawaii (Fig. 2).

	New Caledonia	Fiji	Marquesas	Hawaii
Native species	45 (37%)	46 (57%)	10 (59%)	7 (10%)
Endemic species	73 (59%)	25 (31%)	2 (12%)	45 (67%)
Non-native species	5 (4%)	10 (12%)	5 (29%)	15 (23%)
Red-Listed species	13	1	0	7
Individuals of Red-Listed species	72	40	0	123

TABLE 2 Correlations of total species richness with native and endemic species richness (Pearson product correlation) and number and density of Red-Listed species (Spearman's rank correlation) in 0.1 ha plots in tropical dry forest in New Caledonia, Fiji, Marquesas and Hawaii (Fig. 2). Blank cells indicate that no Red-Listed species were encountered in plots.

	New Caledonia	Fiji	Marquesas	Hawaii
Native species richness	0.892**	0.830**	0.920**	0.521*
Endemic species richness	0.885**	0.824**	0.583	0.889***
Number of Red-Listed species	-0.081	0.550		0.380
Density of Red-Listed species	-0.037	0.588		0.146

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

to calculate forest extent in each ecoregion. Protected area polygons were then overlain to identify the extent of forest in protected areas.

Results

A total of 265 species or morphospecies were identified from 8,769 stems at the 37 sites. Forests in New Caledonia and Fiji contained the highest species richness (Table 1), and forests in New Caledonia and Hawaii had the highest number and proportion of endemic and threatened species and the highest number of threatened individuals (Table 1; Supplementary Table 1). The dry forests of Fiji and the Marquesas had a high proportion of native species and a lower number and density of threatened species than New Caledonia and Hawaii.

There were significant positive correlations between total woody plant species richness and native species richness in all four Pacific dry forests (Table 2). Total species richness was significantly correlated with endemic species richness in New Caledonia, Fiji and Hawaii. There were no correlations between total species richness and number of threatened species or density of threatened species in any of the forests.

We ranked the conservation priorities of the tropical dry forest sites (Supplementary Table 1). New Caledonia had the most sites with a high number and density of threatened species and number of endemic species, followed by Hawaii, Fiji and the Marquesas (Supplementary Table 2). In New Caledonia, Metzdorf, Nekoro and Pindai have a high conservation priority, and in the Hawaiian Islands

Kokee (on the island of Kauai) and Kaupulehu (on the island of Hawaii) have a high conservation priority. Vatia, on the island of Viti Levu, has the highest conservation priority in Fiji, although Naviti and Yanuca both had a high number of endemic species. In the Marquesas we did not encounter any threatened species, and Hatiheu and Hakauai, on Nuku Hiva, had the highest levels of endemism.

There are six tropical dry forest ecoregions (WWF, 2009) within the New Caledonia and Polynesia–Micronesia biodiversity hotspots (Table 3). Marquesas tropical dry forest is not recognized as an ecoregion and there are no land-cover data for this forest in the GlobCover dataset. Fijian tropical dry forest had the largest ecoregion extent, followed by Hawaii and New Caledonia tropical dry forest (Table 3). Forest extents within ecoregions were relatively similar for New Caledonia dry forest (18%), Hawaiian tropical dry forest (15%) and Fijian tropical dry forest (8%). Fiji had the smallest extent of forest in protected areas (< 1%), followed by New Caledonia (7%).

Discussion

Relationships between species richness, endemism and endangerment

There were correlations between total species richness, native species richness and endemic species richness in fragmented stands of dry forest in the Pacific. However, there were no correlations between total species richness and number or density of Red-Listed species. This suggests

TABLE 3 Extent of dry forest (from GlobCover; ESA, 2010) and protected forest in ecoregions with tropical dry forest in the New Caledonia and Polynesia–Micronesia biodiversity hotspots. Blank cells indicate that no data are available.

Ecoregion	Ecoregion extent (km ²)	Dry forest extent (km ²)	Protected forest extent (km ²)
New Caledonia dry forest	4,753	859	62
Fiji tropical dry forest	12,187	948	7
Marquesas tropical dry forest			
Hawaii tropical dry forest	5,419	836	276
Marianas tropical dry forest	1,071	26	6
Yap tropical dry forest	103	41	0

that caution should be taken when assessing the conservation priority of fragments on the basis of total species richness within stands (Kerr, 1997; Chapman et al., 2009). For example, if simple measures of species richness were used to prioritize regions in the Pacific, Hawaii would have a low conservation priority. However, 90% of the 109 species of trees and shrubs in the dry forest of Hawaii are endemic and 45% are included on the IUCN Red List (Pau et al., 2009). Thus, studies of species richness patterns should also provide data on endemism and risk of extinction to accurately assess conservation priorities.

Gentry's transect method appears to be appropriate for quantifying patterns of species richness and forest structure in regions where few comparative field data exist. Applying this method, 48% of known dry forest trees and shrubs of Hawaii were encountered at 15 sites that covered a total of 1.5 ha (Pau et al., 2009) and 29% of all known dry forest woody plants in New Caledonia were encountered at six sites that covered a total of 0.6 ha (Jaffré et al., 1993). However, only 16% of the 49 Red-Listed dry forest species were encountered in Hawaii and 11% of 117 Red-Listed dry forest species were encountered in New Caledonia (Jaffré et al., 1993; Pau et al., 2009). This suggests that rare species may be missed and that extensive presence/absence data for remaining forest fragments are still needed.

Conservation assessment of tropical dry forests in the Pacific

Based on the number of threatened species and levels of endemism the highest-priority sites for dry forest conservation within the Pacific are in New Caledonia and Hawaii. The most extensive surveys of species in forest fragments have been carried out in New Caledonia, with comparative presence data for woody species available for > 71 sites (Jaffré et al., 2008). Gentry transects have been used to quantify the regeneration status of stands and threatened species, based on tree size class (Hequet & Rigault, 2007). New Caledonia also has high levels of microendemism; i.e. subspecies that have evolved in select dry forest locations (Jaffré et al., 2008). These morphological variations are not as pronounced in other dry forest regions in the Pacific.

Presence/absence data are available for islands and the dry forest region of Hawaii (Wagner et al., 1999; Pau et al., 2009) but there are few publicly available data on the distribution of native or threatened species for the dry forest region. For other dry forests in the USA (e.g. in South Florida), presence/absence data are available for all vascular plants for each fragment and standardized plot data are available for a majority of the remaining fragments (Gillespie, 2006; IRC, 2012). These types of occurrence data per fragment or reserve are useful for conservation assessments and monitoring the status of threatened species, especially given that 45% of dry forest tree species are on the federal endangered species list (Pau et al., 2009).

Dry forest fragments in Fiji occur in a highly modified landscape where frequent fires occur; only a small fraction of these remnants (0.7% of the forest cover) are in protected areas. Although species occurrence data exist for 10 dry forest sites in Fiji (Keppel & Tuiwawa, 2007) there are no published data for the Yasawa Islands, the driest region in Fiji. There is potential for conservation of forest fragments on these islands but systematic floristic inventories are needed. The IUCN categorization of tropical dry forest species in Fiji is not as complete as in New Caledonia, Hawaii and the Marquesas.

The tropical dry forests of the Marquesas contain some of the lowest levels of native species richness at the stand level because of the relatively small size and young age of the archipelago (1,050 km²; 3.7 million years old) and its isolation from continental land masses (Wagner & Lorence, 2003). Decker (1973) highlighted the importance of protecting lowland dry and coastal forests in the Marquesas, which are threatened by overgrazing by feral ungulates (goats, sheep and pigs). Presence/absence data have been recorded for all of the Marquesas islands (Wagner & Lorence, 2003) but extensive and systematic plant inventories are needed at dry, low elevations on smaller islands not included in our survey. Surveys of the dry lowlands of the Marquesas are also needed to identify the distribution of threatened small trees such as *Abutilon sachetianum* (Malvaceae; Vulnerable), *Chamaesyce sachetiana* (Euphorbiaceae; Vulnerable), and *Rauvolfia sachetiae* (Apocynaceae; Critically Endangered; Lorence & Butaud, 2011; IUCN, 2012).

Comparisons with other tropical dry forests in biodiversity hotspots

We compared the species richness and the number of Red-Listed species categorized as Critically Endangered, Endangered or Vulnerable with other tropical dry forests in biodiversity hotspots in which Gentry's transect method has been employed and where 95% of the plants encountered were identified to species (Lott et al., 1987; Gentry, 1995; Gillespie et al., 2000; Phillips & Miller, 2002). We found that species richness at the stand level was lower in the Pacific than in mainland biodiversity hotspots (Supplementary Table 3). Stands of dry forest in New Caledonia, Costa Rica, Tanzania, Thailand and Ecuador contain the highest number of threatened species. However, many trees in Costa Rica and Thailand are on the IUCN Red List because they are threatened by logging but they may yet be very common and have large geographical ranges (Phillips & Miller, 2002; Gordon et al., 2003). In comparison, Red-Listed species in New Caledonia are restricted to a small number of sites (Jaffré et al., 2008) and New Caledonian dry forests have a high proportion of Red-Listed species compared to other regions in which Gentry's transect method has been employed. The dry forests of New Caledonia therefore appear to be a high priority for conservation compared to other tropical dry forests in biodiversity hotspots (Jaffré et al., 1998).

Dry forests in the Pacific and Caribbean have a smaller geographical extent and are included in fewer protected areas compared to other dry forests in biodiversity hotspots (Supplementary Table 4). Dry forests in Fiji, Ecuador and New Caledonia have the lowest percentage of protected area of forest. The dry forest cover in the Pacific is estimated to be < 1,000 km² but the actual extent of native forest may be significantly less. Although ecoregions are useful for identifying the location and distribution of ecosystem types at a global spatial scale and the World Database on Protected Areas is useful for identifying protected areas within ecoregions, there are currently no remote-sensing or GIS data on native forests vs non-native forests (i.e. plantations, forests dominated by non-native tree species) for forest fragments in the Pacific outside of Hawaii, which recently produced a gap analysis or land cover map at a 30 × 30 m pixel resolution with non-native forest types (Gillespie et al., 2008). Such data would be useful in the Pacific and other biodiversity hotspots that have a large extent of forest dominated by non-native species.

Implications for conservation

There are associations between total plant species richness and native and endemic species richness in the dry forests of the four Pacific island groups that we studied but we found no significant association between species richness

and the number or density of Red-Listed species. This suggests that although Gentry's transect method provides important comparative data on patterns of species richness, the method does not correlate with the number or density of Red-Listed species. Conservation priorities within regions should be based on occurrence and density data for threatened species in remaining fragments. Globally, the dry forests of Hawaii and New Caledonia merit a high conservation priority because of their high endemism and high numbers of species at risk of extinction. New Caledonia and Fiji have a small extent of dry forest and protected forest compared with other biodiversity hotspots that contain dry forest. Although our study identified high priority areas for conservation of dry forest it also highlighted the limited floristic data available for many Pacific dry forests and the limitations of applying global datasets for the region (i.e. there are no land-cover data for the Marquesas). More comparative plot data, presence/absence data in fragments, and GIS data are required to adequately assess and protect the dry forests of the Pacific.

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