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Review

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Sustainable Utilization and Conservation of Forest Genetic Resources in Pacific Island Countries and Territories: A Review of Emerging Trends and Institutional Gaps

Iliesa Koroi [1,*,†], Tamara Osborne-Naikatini [2], Ole R. Vetaas [3] and Hilda-Waqa Sakiti [4]

[1] Department of Geography, Faculty of Social Sciences, University of Bergen, SV-bygget, Lauritz Meltzers hus, Fosswinckels gate 6, 5007 Bergen, Norway
[2] Consultant, School of Agriculture, Geography, Environment, Ocean and Natural Sciences, The University of the South Pacific, Suva 1168, Fiji
[3] Department of Geography, Faculty of Social Sciences, University of Bergen, SV-bygget, Lauritz Meltzers hus, Fosswinckels gate 6, 5007 Bergen, Norway
[4] Pacific Centre for Environment and Sustainable Development (PaCE-SD), The University of the South Pacific (USP), Suva, Fiji
* Correspondence: iliesakoroi0@gmail.com; Tel.: +679 9815 376
† Current address: School of Agriculture, Geography, Environment, Ocean and Natural Sciences, University of the South Pacific, Suva 1168, Fiji.

Abstract

This review explores the sustainable utilization and conservation of forest genetic resources (FGR) in Pacific Island Countries and Territories (PICTs), highlighting their vital role in enhancing environmental resilience and economic sustainability amid climate change. FGRs support adaptive forest ecosystems and provide essential goods and services, including food, fuelwood, timber, medicinal resources, and cultural values rooted in traditional knowledge systems. A systemic review of 969 and 41 records of peer-reviewed from ISI Web of Science and Scopus, respectively, was conducted using keywords such as "forest", "plantation", and "genetic resources". The analysis reveals significant gaps in institutional capacity and knowledge systems across PICTs, largely due to limited technical, financial and educational investments. These findings underscore the need for integrated and coordinated efforts to sustainably manage priority FGRs. This review advocates for strengthening centralized, accessible repositories–such as the Centre for Pacific Crops and Trees (CePaCT)–to support ecological integrity, socio-economic development, and cultural continuity for future generations in the Pacific.

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1. Introduction

Melanesia, along with Polynesia, Micronesia, and the Galápagos Islands, forms a critical biodiversity hotspot within the broader Oceania and Indo-Pacific regions [1]. The insular nature of Pacific ecosystems has fostered high species turnover and localized endemism, shaped by evolutionary processes such as speciation and geographic isolation [2–4]. However, these ecosystems are inherently vulnerable due to small population sizes, limited genetic diversity, and increasing anthropogenic pressures [5,6]. Habitat loss, overexploitation, and invasive species continue to threaten biodiversity and forest genetic resources (FGR) across the tropical Pacific [7–9]. These threats are further intensified by global trade, development pressures, and demographic shifts, all of which undermine socio-ecological resilience [10,11].

In Pacific Island Countries and Territories (PICTs), FGRs are not only biological assets but also culturally embedded resources that sustain traditional knowledge systems, livelihoods, and ecological identities [12,13]. Species such as *Canarium indicum* (valued for its edible 'ngali' nut in Papua New Guinea), *Santalum yasi* (sandalwood in Fiji and Tonga), and introduced timber species such as mahogany (*Swietenia macrophylla*) and pine (*Pinus caribaea*), exemplify the ecological and economic importance of FGRs [14]. The coconut tree, widely regarded as the "tree of life", and culturally significant species such as *Intsia bijuga* (Vesi), traditionally used canoe building and communal meeting spaces under large *Ficus* spp. (banyan) trees in Vanuatu, further illustrate the deep interconnection between forests and Pacific cultural heritage [13,15]. Conserving these resources is therefore essential not only for ecological resilience but also for preserving cultural continuity in the face of climate change and environmental stressors [16].

Although PICTs account for less than 0.5% of the world's terrestrial surface (553,959 km^2), they collectively harbour approximately 20% of global forest cover [17,18], positioning them as forest-rich regions within Oceania [19]. However, smaller island nations in Micronesia and Polynesia face acute land-use pressures due to limited land availability and growing populations–pressures expected to intensify with global demographic trends [20,21]. Forest conversion, unsustainable logging, plantation expansion, and overexploitation have been shown to negatively affect the genetic structure of tree populations [22,23]. Given the ecological fragility and limited landmass of PICTs, the sustainable conservation of FGRs is vital for maintaining environmental resilience and economic viability [24].

Regional efforts to conserve FGRs have evolved through initiatives such as the South Pacific Regional Initiative on Forest Genetic Resources (SPRIG projects 1997-2006), which laid the groundwork for germplasm collection, conservation capacity, and ethical exchange protocols [16]. These efforts were further strengthened by the establishment of the Centre for the Pacific Crops and Trees (CePaCT), and the development of a regional action plan, and the implementation of national reporting mechanisms. While these initiatives have improved coordination and technical infrastructure, national-level implementation remains uneven. Sustained progress will require stronger national ownership, long-term investment, and policy continuity [25].

Global momentum for conserving tree genetic diversity gained traction following the Earth Summit and Rio Convention [26]. Despite this, the FAO's *State of the World's Forest Genetic Resources* (2014) report emphasized the ongoing need for robust knowledge systems to support sustainable FGR management. While monitoring frameworks developed in Europe and Asia have informed practices in the Pacific [27–30], significant gaps remain in regional monitoring and capacity building [31,32].

This review applies the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) framework and bibliometric analysis to examine the state of FGR research in PICTs. It identifies prevailing research trends, knowledge gaps, and implications for sustainable forest management. The aim is to inform future research priorities and policy development by ensuring that FGRs retain high levels of intra- and interspecific genetic diversity–an essential foundation for adaptation and evolutionary resilience [33,34].

2. Materials and Methods

This review employed a systemic archival search of peer-reviewed literature using the ISI Web of Science (WoS) and Scopus databases. The search strategy applied the Boolean logic ("forest" OR "plantation") AND "genetic resources across titles, abstracts, and keywords to retrieve relevant studies. To ensure geographic relevance to Pacific Island Countries and Territories (PICTs), the following inclusion criteria were applied:

(1) The publication must be a peer-reviewed journal article (including original research, short communications, or data papers);
(2) The study must include at least one country within the PICTs;
(3) The article must be written in English.

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No temporal restrictions were imposed, allowing for a comprehensive historical and contemporary overview of forest genetic resources (FGR) research in the region. The search was conducted in September/2024, and duplicate records were removed prior to analysis.

To analyse the retrieved literature, a bibliometric approach was adopted. Bibliometric analysis is a robust method for identifying research patterns, influential publications, and uncovering collaboration networks within a field [35,36]. Unlike traditional literature narrative reviews, bibliometric techniques offer a systematic and quantitative framework to organizing and visualizing bibliographic data [37].

This study utilized RStudio version 4.3.3 and the Bibliometrix package to conduct the analysis. Bibliometrix provides tools for importing, cleaning, and analysing metadata from major academic databases, including WoS and Scopus [36]. Custom R scripts were used to extract and analyse data related to author affiliations, publication sources, institutional contributions, research themes, productivity trends, co-citation networks, and international collaborations [36]. This approach enabled a structured, reproducible, and data-driven synthesis of the FGR research landscape in the Pacific region.

3. Results and Discussions

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

This review identifies three principal gaps in the current body of research on forest genetic resources (FGR) within Pacific Island Countries and Territories (PICTs):

(i) Quantitative gap – There is a limited volume of published research on FGR in the region, reflecting an overall scarcity of scholarly attention.
(ii) Geographic gap – Existing studies are unevenly distributed across PICTs, with certain countries and subregions significantly underrepresented in the literature.
(iii) Temporal gap – Few studies have focussed on long-term monitoring of FGR, highlighting the need for sustained research efforts to infom comprehensive conservation and management strategies.

3.1. Bibliometric Insights into FGR Research in PICTs

A total of 969 records (0.12%) out of the 796,872 indexed in the ISI Web of Science (WoS) and 41 records (0.11%) out of 24,261 in Scopus included at least one Pacific Island Countries and Territories (PICT). In contrast, 46,612 records (5.85%) in WoS and 1,598 records (6.59%) in Scopus featured at least one country from the broader Oceania region (Figure 1). The United States accounted for the highest proportion of indexed studies, with 285,946 (35.88%) in WoS and 6,084 (25.08%) in Scopus.

Within the PICTs, an average of seventy forest resource studies were identified. However, fewer than 1% of the total indexed studies from both the databases explicitly addressed forest genetic resource (FGR) diversity or had implications for FGR conservation and management (Table 1). This represents a significant gap, particularly given the ecological, cultural, and economic importance of FGRs in the Pacific [25,38].

The limited representation of FGR-focused research in global databases highlights a broader issue of underinvestment in Pacific-based forest science. This underrepresentation may stem from limited research infrastructure, funding constraints, and challenges in regional data sharing. These findings underscore the urgent need for increased research funding, institutional capacity building, and international collaboration to support the sustainable management of FGRs in the region. Without targeted efforts to strengthen the knowledge base, PICTs risk losing critical genetic resources that underpin biodiversity and traditional livelihoods.

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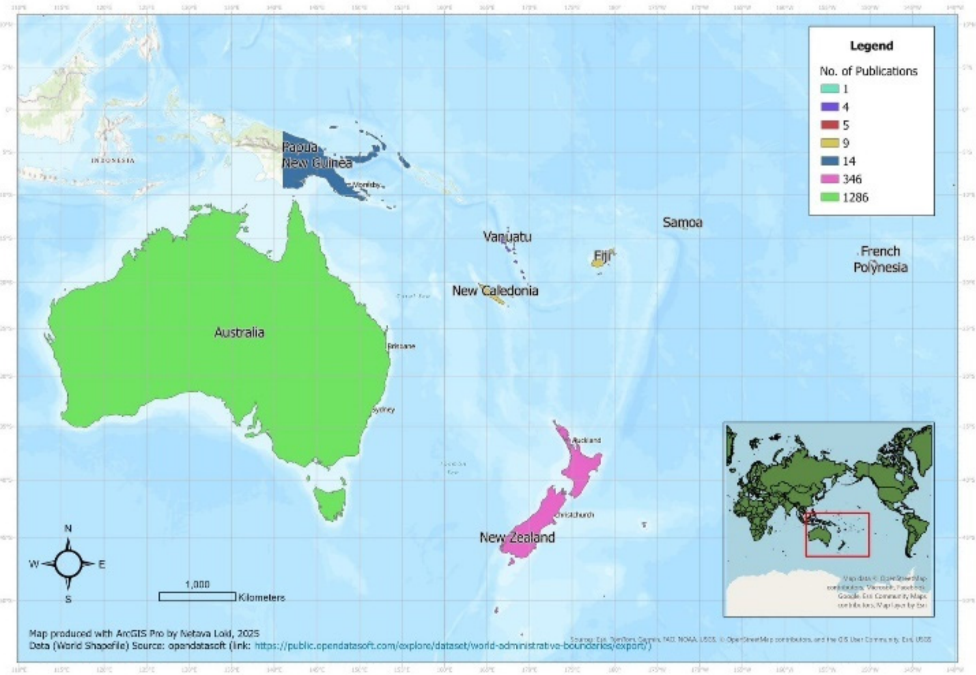

Figure 1. Percentage of studies that satisfied the search criteria for the Oceania region.

3.2. Geographical Representation of FGR Studies

Research on forest genetic resource (FGR) management has been predominantly concentrated in developed nations, particularly Australia, the United States, and several European countries [39]. Systematic reviews consistently highlight to a pronounced geographic imbalance, with limited scholarly output from Pacific Island Countries and Territories (PICTs) and Southeast Asian nations [40]. Bibliometric analyses have identified emerging research themes–including genetic diversity, forest productivity, resistance, and resilience–as central to advancing the field, especially within the Asia–Pacific context [29,41]. However, the marked underrepresentation of developing countries in FGR research, as illustrated in Figures 1 and 2, remains a significant concern.

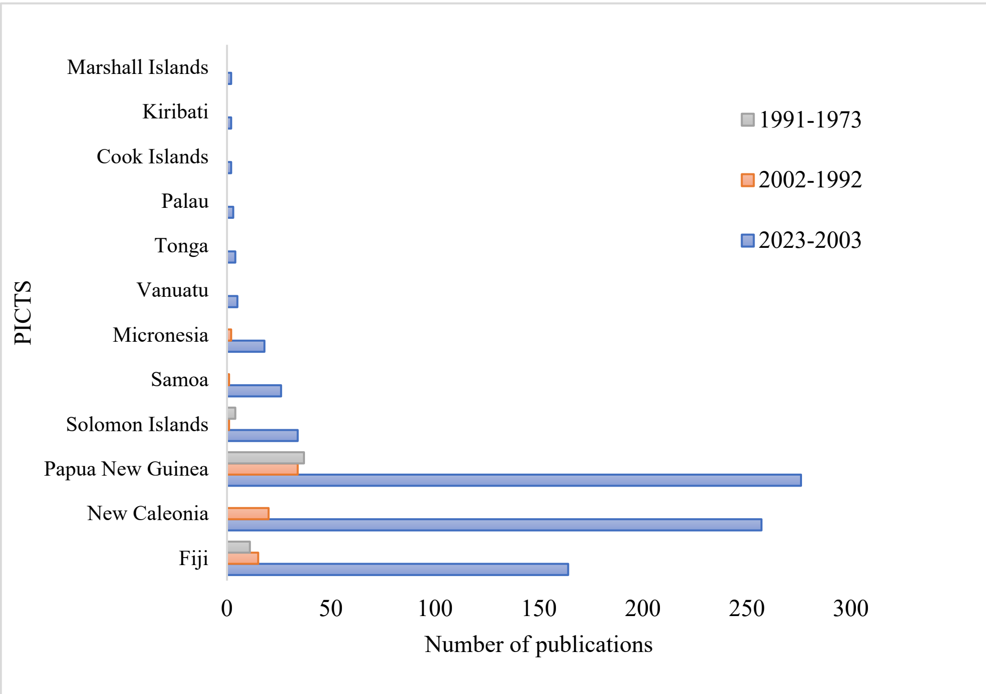

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Figure 2. FGR studies across the PICTs between 1973-2023.

This gap is particularly troubling given the heightened vulnerability of these regions to climate change, demographic pressures, and unsustainable resource extraction [32]. Addressing this imbalance is critical to ensuring that FGR research and policy frameworks are inclusive, contextually relevant, and responsive to the unique challenges faced by the Pacific region.

Figure 2 shows the distribution of FGR studies across PICTs between 1973 and 2023. New Caledonia and Papua New Guinea have received relatively more attention, while countries like Samoa, Vanuatu, and Micronesia remain underrepresented. The scarcity of FGR studies in the Pacific is attributed to a range of challenges, including insufficient funding, limited technical expertise, logistical constraints, and ongoing habitat degradation [25,42,43].

Despite these limitations, notable initiatives have emerged in biodiversity hotspots such as New Caledonia, Samoa and Vanuatu [44]. Several studies have successfully integrated molecular genetics with ecological and spatial analyses to guide both *in situ* and *ex situ* conservation strategies. These efforts demonstrate the potential of FGR research to navigate systemic challenges, yet a deeper understanding of biological foundations underpinning FGR conservation remains essential [45–48].

A significant gap lies in limited knowledge of long-term ecological dynamics and biological traits of key native species. For example, reproductive biology, regeneration mechanisms, and ecological interactions of species such as *Manilkara samoensis* and *Terminalia richii*, and *Santalum austrocaledonicum* in New Caledonia [46,48] are poorly documented. Similarly, the reproductive variability of *Araucaria nemorosa* and the pollination biology of *Carpoxylum macrospermum* remain underexplored [47,49]. These knowledge gaps pose substantial barriers to the designing of robust conservation and restoration programs, particularly in the context of accelerating climate change.

Table 1. Studies on FGR monitoring in at least one of the PICTs.

PICTs	FGR studied	Habitat	Results	Reference
Fiji	*Cycas seemannii*	Native forests	Starch-gel electrophoresis revealed low intra- population diversity and high inter-population differentiation	[45]
	Santulum yasi	Native forests	Despite low diversity in remnant stands, the species retains substantial genetic variation	[50]
Micronesia	*Campnosperma brevipetiolata*	Native forests	Enzyme assay protocols revealed a west to east decline in genetic variation across the Indo-Malayan source region	[51]
New Caledonia	*Diospros spp.*	Native forests	Genetic diversity in *Diospyros* stems from gradual accumulation and rapid radiations into four lineages	[44]
	Santalum austrocaledonicum	Native forests	Chloroplast microsatellite analyses revealed overall heterozygosity, with variation among islands	[48]
	Pycnandra spp.			
	Coffea spp.	Native forests		[52]
		Plantations	Three new species were described using nuclear DNA data from ETS, ITS, and RPB2 regions	[53]
	Araucaria nemorosa	Plantation forests	Inter-specific hybridization was detected, with one population showing high genetic diversity based on 26 microsatellites markers using multi-locus approach Nuclear microsatellite (nSSR) analysis revealed genetic bottle neck and elevated inbreeding in nursery stock compared to seedlings and adult populations	[49]

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Papua New Guinea	*Ixora margaretae*	Native forests	Assisted regeneration with controlled variability will be critical to conserving species biodiversity, as indicated by SSR fingerprinting	[54]
	Ficus spp.	Native forests	Restricted elevation ranges in multiple *Ficus* species constrain gene flow	[55]
	Eucalyptus pellita	Plantation forests	SNP analysis indicates Queensland as the origin of *E. pellita*, with high genetic diversity	[56]
Samoa	*Terminalia richii and Manilkara samoensis*	Native forests	Complimentary *in situ* and *ex situ* conservation strategies are essential for the species	[46]
Vanuatu	*Carpoxylum macrospermum*	Native forests	RAPD analysis revealed low genetic variation within the existing population	[47]
Hawaiian Islands, Marquesas Islands, Society Islands, and New Caledonia	*Miconia calvescens*	Tropical islands	Microsatellites and inter-simple sequence repeat (ISSR) markers revealed genetic variation within and among populations	[57]
Fiji, Samoa, and Hawaiian Islands	*Cyrtandra spp*	Native forests	Co-existing *Cyrtandra* species show closer phylogenetic and phenotypic clustering within island and site communities	[58]

3.3. Temporal Gap

The distribution and frequency of FGR-related studies across PICTs between 1973 to 2023 reflect a gradual expansion of the research landscape (Figure 2). Early studies addressed diverse species such as Campnosperma brevipetiolata [51], Carpoxylon macrospermum [47], the endangered Pacific Cycad [45], and the invasive Miconia calvescens [57]. More recent assessments have examined the genetic diversity of Eucalyptus pellita [56], Cyrtandra spp. [58], and Xylocarpus granatum [59], emphasizing the importance of both in situ and ex situ conservation, tree improvement programs, and institutional capacity-building.

However, historical biogeographic uncertainties complicate conservation planning in insular systems (Whittaker et al. 2023). Phylogenetic studies on Diospyros [44] and Carpoxylon macrospermum [47] underscore the need to integrate fossil records, paleogeographic data, and molecular clock dating to better understand evolutionary processes shaping current genetic diversity.

Despite these efforts, forests in PICTs face escalating threats from unsustainable land-use practices. A regional workshop on FGR convened by the Secretariat of the Pacific Community [60] highlighted biodiversity loss due to mining, agriculture and logging. In Papua New Guinea, between 2000 and 2015, over 253,000 hectares of forest were cleared for agriculture, while 2.37 million hectares were degraded by logging [61]. In New South Wales, Australia, industrial–scale logging has degraded 9 million hectares of woodland, affecting 244 forest-dependent threatened species [62]. These ecological pressures are compounded by socio-economic drivers such as population growth, extractive industries, and conservation incentives [63–66].

International research partnerships, particularly North–South collaborations, have been instrumental in advancing FGR research. Notable initiatives include the Australian Centre for International Agricultural Research (ACIAR) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) partnership, which built on the SPRIG program to conserve Santulum yasi in Fiji and Tonga [50]. In Australia, large-scale screening for myrtle rust resistance in Eucalytptus species, and in New Zealand, advanced genomics research on Pinus radiata led by Scion, have significantly contributed to FGR in Oceania.

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Recently, biodiversity valuation has shifted toward holistic, interdisciplinary approaches. Frameworks like those promoted by the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) and citation analysis tools offer promising avenues for evaluating research impact and guiding policy [67]. While North-South collaborations have enhanced infrastructure and knowledge exchange [68], long-term success depends on addressing persistent knowledge gaps and integrating indigenous knowledge systems [69–71]. [72] advocate for incorporating indicators of societal use, ecosystem functions, and genetic resilience into forest management assessments.

4. Conclusions

Forest genetic resources (FGRs) are essential to the environmental resilience, cultural continuity, and sustainable development of Pacific Island Countries and Territories (PICTs), particularly in the face of climate change and limited land availability. Despite their significance, persistent gaps in research leadership, institutional capacity, and equitable access to data and funding continue to hinder effective conservation and management. Addressing these challenges required renewed investment in community-based stewardship, scientific infrastructure, and inclusive governance. Strengthening local research capacity, fostering equitable international collaboration, and enhancing centralized repositories–like the Centre for Pacific Crops and Trees (CePaCT)–are critical steps toward informed decision-making and adaptive FGR management. By empowering Pacific communities to conserve and sustainably utilize their forest genetic resources (FGR), FGRs can serve as strategic foundations for ecological integrity, cultural preservation, and long-term sustainability.

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Abbreviations

The following abbreviations are used in this manuscript:

FGR	Forest Genetic Resources
ACIAR	Australian Centre for International Agricultural Research
CePaCT	Centre for the Pacific Crops and Trees
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DNA	Deoxyribonucleic acid
FAO	UN's Food and Agriculture Organization
ETS	E26 transformation-specific family of transcription factors
IPBES	Intergovernmental Platform on Biodiversity and Ecosystem Services
ISSR	Inter-simple sequence repeat
ITS	Internal Transcribed Spacer
nSSR	Nuclear microsatellite
PICTs	Pacific Island Countries and Territories
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analysis
RAPD	Random Amplified Polymorphic DNA
RPB2	RNA polymerase II subunit B
SPRIG	South Pacific Regional Initiative on Forest genetic resources
SSR	Simple Sequence Repeat
WoS	ISI Web of Science

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