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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

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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

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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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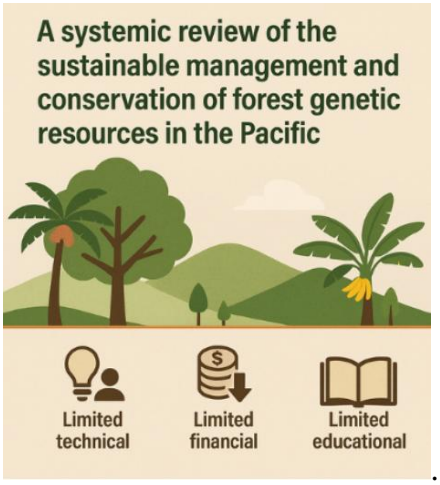

1. Introduction

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].

Global momentum for conserving tree genetic diversity gained traction following the Earth Summit and Rio Convention [25]. 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 [26-29], significant gaps remain in regional monitoring and capacity building [30, 31]. Comparative analysis with other tropical regions such as Southeast Asia and the Caribbean reveals both shared challenges and unique vulnerabilities. While the Pacific lacks large-scale

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commercial forestry operations, it faces greater constraints in terms of geographic isolation, limited economies of scale, and dependence on external technical expertise [32]. Lessons from other regions-such as regional seed networks, and disaster-resilient agroforestry offer promising models for adaptation [33].

The policy and institutional landscape for FGR conservation in the Pacific is shaped by national forest policies, regional frameworks (eg. PIRT-Pacific Islands Roundtable for Nature Conservation), and international agreements such as the Convention on Biological Diversity (CBD) and the Nagoya Protocol [16]. Despite these efforts, institutional mandates often overlap, and implementation remains uneven. National forestry departments frequently operate with limited technical capacity and funding, while regional organizations such as the Secretariat of the Pacific Community (SPC) and South Pacific Regional Environmental Programme (SPREP) provide coordination but lack enforcement mechanisms [7, 34]. Stakeholder engagement is also variable with indigenous communities, who are primary custodians and owners of forest lands, are often excluded from formal decision-making processes, while NGOs and academic institutions play critical roles in research, advocacy, and community-based conservation [28, 35].

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 [34].

Technological advances are beginning to reshape conservation strategies. Genetic mapping is being used to identify resilience genotypes of culturally and ecologically important species, while remote sensing and participatory GIS tools are enhancing forest monitoring [36]. Community-based monitoring initiatives, such as those piloted in Vanuatu and the Solomon Islands, are empowering local stakeholders to collect and manage data, bridging gaps between traditional knowledge and scientific research [37].

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 [38, 39].

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:

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

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

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collaboration networks within a field [40, 41]. Unlike traditional literature narrative reviews, bibliometric techniques offer a systematic and quantitative framework to organizing and visualizing bibliographic data [42].

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 [41]. 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 [41]. This approach enabled a structured, reproducible, and data-driven synthesis of the FGR research landscape in the Pacific region.

3. Results and Discussions

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

(iv) Quantitative gap – There is a limited volume of published research on FGR in the region, reflecting an overall scarcity of scholarly attention.

(v) Geographic gap – Existing studies are unevenly distributed across PICTs, with certain countries and subregions significantly underrepresented in the literature.

(vi) Temporal gap – Few studies have focussed on long-term monitoring of FGR, highlighting the need for sustained research efforts to inform comprehensive conservation and management strategies.

3.1. Bibliometric Insights into FGR Research in PICTs

A bibliometric analysis of forest genetic resources (FGR) research reveals a stark underrepresentation of Pacific Island Countries and Territories (PICTs) in global scientific databases. 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 PICTs. In contrast, broader Oceania representation was notably higher, with 46,612 records (5.85%) in WoS and 1,598 records (6.59%) in Scopus featuring at least one country from the 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.

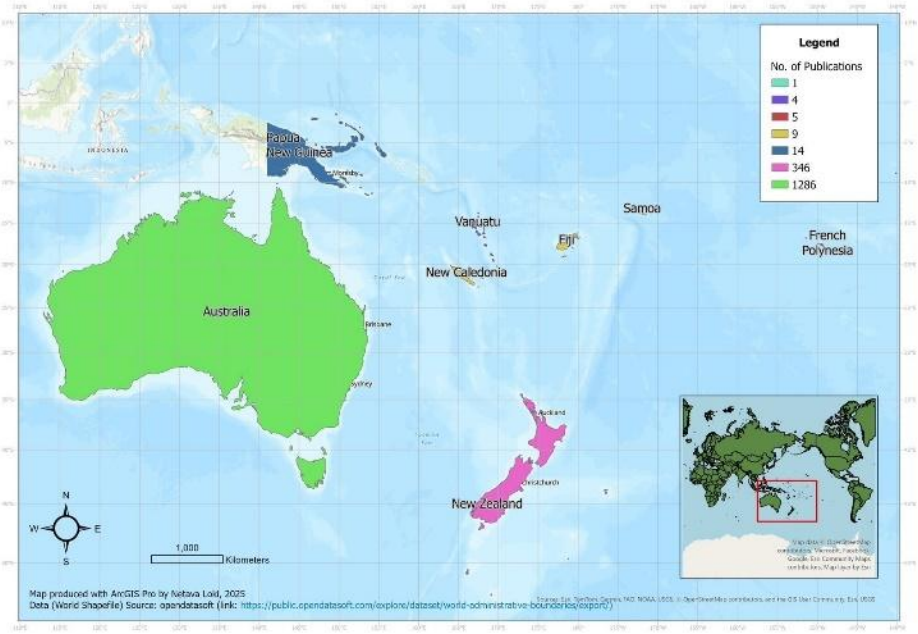

Figure 1. Percentage of studies that satisfied the search criteria for the Oceania region.

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Despite the ecological and cultural significance of forests in the Pacific, fewer than 1% of the indexed studies from both the databases explicitly addressed (FGR) diversity or its implications for sustainable conservation and management (Table 1). This gap is particularly concerning given the region's rich biodiversity and the reliance of many communities of forest resources for food security, traditional medicine, and cultural practices [34, 43].

These findings align with previous studies highlighting the marginalization of small island developing states in global environmental research [44, 45]. However, the reasons for this underrepresentation are multifaceted. Limited research infrastructure, constrained funding, and fragmented data-sharing mechanisms across PICTs contribute to the low visibility of Pacific-based forest science [31, 46]. Additionally, the linguistic diversity and absence of centralized research institutions may hinder regional collaboration and publication output [47].

Importantly, this review contributes to the broader understanding of FGR research by identifying systemic gaps and emphasize the need for inclusive scientific practices. While some Oceania countries (e.g., Australia and New Zealand) are well-represented in forest science literature, their dominance may obscure the unique challenges and priorities of smaller island nations. Addressing this imbalance requires a shift toward participatory research models that empower local communities and integrate indigenous knowledge systems [48].

However, this review is not without limitations. The reliance on ISI WoS and Scopus may exclude regionally published or non-English literature, potentially underestimating local research efforts. Moreover, bibliometric methods cannot fully capture the depth or quality of individual studies. Future research should explore alternative databases, incorporate grey literature, and engage with local information holders to build a more comprehensive picture of FGR research in the Pacific.

To address these gaps, future studies could focus on mapping indigenous FGR knowledge and practices across PICTs, develop region-specific conservation strategies informed by genetic data; enhance regional research capacity through training, funding and infrastructure; and promote open-access publishing and data-sharing platforms tailored to Pacific contexts. By acknowledging these limitations and proposing realistic, actionable steps, this review aims to catalyse a more equitable and inclusive approach to FGR research in Oceania.

3.1. Geographical representation of FGR studies

Forest genetic resource (FGR) research continues to exhibit a pronounced geographic imbalance, with strong concentration in developed nations–particularly Australia, the United States, and several European countries [49]. Systematic reviews and bibliometric analyses consistently highlight the limited scholarly output from Pacific Island Countries and Territories (PICTs) and Southeast Asian nations [50]. This disparity is especially concerning given the ecological richness and vulnerability of these regions.

Emerging research themes including genetic diversity, forest productivity, resistance, and resilience have gained traction globally, yet their application within the Asia-Pacific contexts remains uneven [28, 51]. Figures 1 and 2 illustrate this imbalance, with New Caledonia and Papua New Guinea receiving relatively more attention, while some countries like Samoa, Vanuatu, and Micronesia remain significantly underrepresented.

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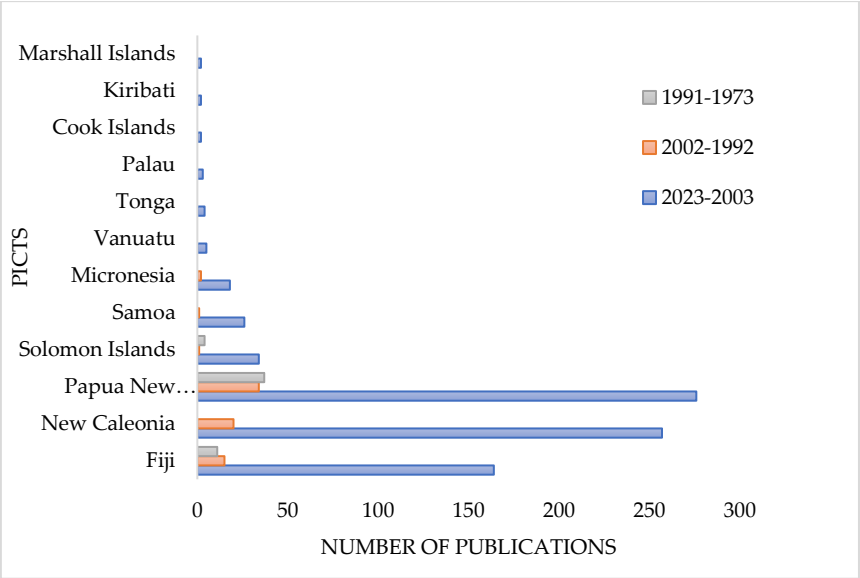

Figure 2. FGR studies across the PICTs between 1973-2023.

This underrepresentation is not merely a reflection of academic trends–it has real world implications. PICTs face heightened exposure to climate change, demographic pressures, and unsustainable resource extraction, making the need for robust FGR research all the more urgent [31]. Without inclusive, context-sensitive research frameworks, policy responses risk being misaligned with local ecological and cultural realities.

The scarcity of FGR studies in the Pacific can be attributed to several systemic challenges: limited funding, technical expertise, logistical constraints, and ongoing habitat degradation [34, 52, 53]. These barriers are compounded by the absence of coordinated regional research networks and the underutilization of indigenous knowledge systems in scientific discourse.

Despite these constraints, promising initiatives have emerged in biodiversity hotspots such as New Caledonia, Samoa and Vanuatu [54]. Several studies have successfully integrated molecular genetics with ecological and spatial analyses to inform both *in situ* and *ex situ* conservation strategies [55, 56]. These efforts highlight the potential of FGR research to overcome systemic limitations and contribute meaningfully to conservation planning [57-60].

However, significant knowledge gap persists–particularly in understanding the long-term ecological dynamics and biological traits of key native species. For example, the reproductive biology, regeneration mechanisms, and ecological interactions of species such as *Manilkara samoensis* and *Terminalia richii*, and *Santalum austrocaledonicum* in New Caledonia [58, 60] remain poorly documented. Similarly, the reproductive variability of *Araucaria nemorosa* and the pollination biology of *Carpoxylum macrospermum* are underexplored [59, 61]. These gaps hinder the development of robust conservation and restoration programs, especially in the face of accelerating climate change.

To address these challenges, future research should prioritize more species-specific ecological studies to inform conservation strategies, the integration of traditional ecological knowledge with scientific methods, capacity building initiatives to support local researchers and institutions, and regional collaboration platforms to facilitate data sharing and joint research efforts. Taking ownership of these gaps and proposing actionable solutions, this review advocates for a more geographically inclusive and ecologically grounded approach to FGR research in the Pacific.

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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	[57]
	Santulum yasi	Native forests	Despite low diversity in remnant stands, the species retains substantial genetic variation	[62]
Micronesia	*Campnosperma brevipetiolata*	Native forests	Enzyme assay protocols revealed a west to east decline in genetic variation across the Indo-Malayan source region	[63]
New Caledonia	*Diospros spp.*	Native forests	Genetic diversity in *Diospyros* stems from gradual accumulation and rapid radiations into four lineages	[54]
	Santalum austrocaledonicum	Native forests	Chloroplast microsatellite analyses revealed overall heterozygosity, with variation among islands	[60]
	Pycnandra spp.	Native forests	Three new species were described using nuclear DNA data from ETS, ITS, and RPB2 regions	[64]
	Coffea spp.	Plantations	Inter-specific hybridization was detected, with one population showing high genetic diversity based on 26 microsatellites markers using multi-locus approach	[65]
	Araucaria nemorosa	Plantations	Nuclear microsatellite (nSSR) analysis revealed genetic bottle neck and elevated inbreeding in nursery stock compared to seedlings and adult populations	[61]
Papua New Guinea	*Ixora margaretae*	Native forests	Assisted regeneration with controlled variability will be critical to conserving species biodiversity, as indicated by SSR fingerprinting	[66]
	Ficus spp.	Native forests	Restricted elevation ranges in multiple *Ficus* species constrain gene flow	[67]
	Eucalyptus pellita	Plantations	SNP analysis indicates Queensland as the origin of *E. pellita*, with high genetic diversity	[68]
Samoa	*Terminalia richii and Manilkara samoensis*	Native forests	Complimentary *in situ* and *ex situ* conservation strategies are essential for the species	[58]
Vanuatu	*Carpoxylum macrospermum*	Native forests	RAPD analysis revealed low genetic variation within the existing population	[59]
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	[69]
Fiji, Samoa, and Hawaiian Islands	*Cyrtandra* spp.	Native forests	Co-existing *Cyrtandra* species show closer phylogenetic and phenotypic clustering within island and site communities	[70]

3.3. *Temporal Gap in FGR Research Across PICTs*

The temporal distribution of FGR-related studies across PICTs from 1973 to 2023 reflect a gradual yet uneven expansion of the research landscape (Figure 2). Early investigations focused on species such as *Campnosperma brevipetiolata* [63], *Carpoxylon macrospermum* [59], the endangered Pacific *Cycad* [57], and the invasive *Miconia calvescens* [69]. These foundational studies laid the groundwork for understanding species-specific threats and conservation needs.

In recent decades, research has shifted toward more integrative approaches, examining the genetic diversity of Eucalyptus pellita [68], *Cyrtandra* spp. [70], and *Xylocarpus granatum* [71]. The

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studies emphasize the growing importance of both in situ and ex situ conservation, tree improvement programs, and institutional capacity-building. This evolution reflects a broader trend in forest science toward interdisciplinary and applied research, particularly in biodiversity-rich but data-poor regions.

However, onservation planning in insular systems remains complicated by historical biogeographic uncertainties [4]. Phylogenetic studies on genera such as *Diospyros* [54] and *Carpoxylon macrospermum* [59] highlight the need to integrate fossil records, paleogeographic reconstructions, and molecular clock dating to better understand the evolutionary processes shaping current genetic diversity. Without this historical context, conservation strategies risk overlooking deep-time ecological dynamics that influence species resilience.

Despite growing research interest, forests in PICTs face escalating threats from unsustainable land-use practices. A regional workshop convened by the Secretariat of the Pacific Community (SPC) underscored biodiversity loss driven by mining, agriculture and logging [72]. In Papua New Guinea alone, over 253,000 hectares of forest were cleared for agriculture between 2000 and 2015, while 2.37 million hectares were degraded by logging [73]. In New South Wales, Australia, industrial–scale logging has impacted 9 million hectares of woodland, threatening 244 forest-dependent species [74]. These ecological pressures are compounded by socio-economic drivers such as population growth, extractive industries, and uneven conservation incentives [75-78].

International research partnerships have played a critical role in advancing FGR research in Oceania. North–South collaborations, such as thoes led by the Australian Centre for International Agricultural Research (ACIAR) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO), have built on initiatives like the SPRIG program to conserve Santulum yasi in Fiji and Tonga [62]. 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 regional FGR knowledge.

More recently, biodiversity valuation has embraced holistic, interdisciplinary approaches. The Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) promotes approaches that integrate ecological, cultural, and economic dimesions. Citation analysis tools and impact metrics offer promising avenues for evaluating research influence and guiding policy [79]. While North-South collaborations have enhanced infrastructure and knowledge exchange [80], long-term success depends on addressing persistent knowledge gaps and integrating indigenous knowledge systems [81-83].

To strengthen FGR research in PICTs, research efforts should incorporate historical biogeogphy into conseervation planning, expand long-term ecological monitoring of native species, support coomunity-led research that values traditional ecological knoledge, and develop regional biodiversity indicators that reflect genetic resilience, societal use, and ecosystem function [84]. By bridging temporal gaps and aligning research with regional priorities, the Pacific can move toward a more resilience and inclusive FGR management framework.

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
GIS	Geographic Information System
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
PIRT	Pacific Islands Roundtable for Nature Conservation
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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