A Global Strategy
for the conservation and use of Coconut Genetic Resources
2018-2028

Compiled by R. Bourdeix and A. Prades

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LA RECHERCHE AGRONOMIQUE POUR LE DÉVELOPPEMENT

COGENT
Coconut genetic resources for enhanced livelihoods

Bioversity International

COGENT is the International Coconut Genetic Resources Network, an independant network with representatives of national institutions from 39 coconut-producing countries, representing more than 98% of the global production COGENT aims to strengthen international collaboration in conservation and use of coconut genetic resources; to promote improving coconut production on a sustainable basis, and to boost livelihoods and incomes of coconut stakeholders in developing countries. www.cogentnetwork.org

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Disclaimer

This document has been developed by experts both in coconut genetics and breeding, as well as other experts from along the coconut value chain. COGENT considers that it provides an informed and realistic foundation for prioritising coconut research and development. The goal is to use this strategy to envigorate the commercial coconut sector in a sustained manner, while protecting food security, by encouraging partnerships that increase the impact of research and adoption of technological innovations. COGENT encourages international, regional and national public research organizations, development agencies, NGOs, the private sector and other stakeholders to use the priorities set out herein to guide their activities and investment decisions. This strategy document should continue evolving as information becomes available. All views and opinions expressed herein are those of the contributors but do not necessarily reflect the views and opinions of their individual institutes. In case of specific questions and/or comments, please direct them to the COGENT Secretariat at Bioversity International.

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Acknowledgements

Cultivated in very diverse geographical areas and physical environments, the coconut palm is a species with a huge morphological and genetic diversity, grown by widely diverse communities and people for scores of different uses. It has indeed proved highly challenging and totally absorbing to gather all this diversity into a common Strategy.

This document, coordinated by COGENT, is the product of expert opinion and direct participation of more than 90 key stakeholders in the conservation and use of coconut genetic resources. COGENT would like to thank all those who contributed to developing this Global Strategy. Each of the 132 sections of this strategy is authored by 2 to 5 contributors often located in different regions of the world. More than 400 contributions were received from international, regional and national institutions, private companies, NGOs and a range of experts. It is not possible to individually cite all these participants here, but a detailed list of contributors, their parent institutions, and the sections they contributed are provided at the end of this document. The document was submitted to six international reviewers, namely Jan Engels, Mike Foale, Vincent Johnson, Jean-Pierre Labouisse, Nicolas Roux and Dietmar Stoian, who have significantly contributed to the improvement of this document. The numerous and useful advices provided by Brigitte Laliberté, in the light of her recent experience in compiling the Cacao Strategy, were also particularly helpful. COGENT would also like to acknowledge Claudine Picq, Vincent Johnson, Ane de la Presa, Alvaro Ullivari and Diversiflora International for their editorial, design and layout support in preparing the document for publication.

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Preface

Vincent Johnson*

Grown on more than 12 million hectares, the coconut palm (*Cocos nucifera* L.) is a culturally and economically important livelihood crop for millions across Southeast Asia, the Asia-Pacific, Africa and Latin America. Fully developed and strategically used, coconuts could help increase food production, improve nutrition, create employment opportunities, enhance equity and help conserve the environment. The future of global coconut production and livelihoods critically depends on the availability of genetic diversity and the sustainable use of this broad genetic base to breed improved varieties. Harnessing and conserving agrobiodiversity are critical to sustainably boosting productivity and livelihoods, and addressing important challenges including those posed by climate change or pest and disease epidemics.

More than 95% of coconut farmers are resource-poor smallholders lacking the voice needed to influence government policy or private sector practices. In support of these smallholders, the CGIAR agreed to include coconut in its research portfolio in 1991. Bioversity International's parent organization[1] organized the International Coconut Genetic Resources Network (COGENT) to promote global collaboration for the effective conservation and use of coconut genetic resources. COGENT began in 1992 with 15 coconut-growing countries as members, and has subsequently expanded to 39 member-countries representing more than 98% of global production, with two further potential members for 2018.

Over many years, and with the support of Bioversity International and latterly the CGIAR research program Forests, Trees and Agroforestry (FTA), COGENT has continued to coordinate the refinement of this progressive global strategy for conserving and harnessing coconut germplasm (the Strategy), aiming to cost-effectively optimize the conservation and use of as much representative diversity as possible. During the 2012, 2014 and 2017 COGENT Steering Committee meetings, agreements were made on finalizing this updated Strategy, and designing further related research in terms of: conservation in national field collections; conservation in the multisite International Coconut Genebank (ICG); *in vitro* embryo culture, somatic embryogenesis and cryopreservation; in situ and on-farm conservation; promoting conservation through use, and *'Polymotu'* - a concept employing geographic isolation to avoid costly controlled pollination.

COGENT would like to acknowledge the work and support of those many stakeholders, including the CGIAR, the Global Crop Diversity Trust, and the more than one hundred contributors who have been instrumental in developing and refining this important Strategy. It is hoped that, as an evolving document, it will provide the benchmark for effectively implementing the comprehensive conservation and research agenda proposed by the international coconut research community, as a route to the enhanced wellbeing of the millions of coconut smallholders across the globe.

* Bioversity International/COGENT coordinator, Montpellier, France

[1] The International Board for Plant Genetic Resources (IBPGR) –then becoming the International Plant Genetic Resources Institute (IPGRI), which finally became Bioversity International in 2006.

Foreword

Prof Gabrielle J. Persley AM*

Coconut is indeed the "Tree of Life". More than 100 million people living in fragile coastal areas of the Indo Pacific region, including the coastal lands bordering South and Southeast Asia, the islands of the Pacific Ocean and the coastal areas of Africa and Latin America, depend on coconut for their livelihoods. Coconut provides food and water, timber and leaves to build homes, and oil and copra for fuel and as a source of income. In times of environmental disasters, such as cyclones and tsumanis, coconut is often the last tree standing, able to protect and sustain communities in the immediate aftermath of the disaster, providing food, water and shelter while people rebuild their lives.

Globally, the demand for coconut products is growing exponentially. The estimated global market for coconut water alone is predicted to be in the order of USD 10 billion by 2030. This growing export market for a wider range and higher value of coconut products offers new opportunities for increasing incomes for millions of small- scale coconut producers. Increasing productivity and profitability of coconut as both an essential "tree of life" to sustain livelihoods in fragile environments and as a source of increasing income through the sale of coconut for higher value products is now feasible.

At a time when the demand for coconut and coconut products is growing worldwide, it is important to conserve and utilize the rich biological diversity of the crop. The International Coconut Genetic Resources Network (COGENT) took up this challenge in 1992, over 25 years ago, with the leadership and support of CGIAR, Bioversity International and its predecessor, amongst the international agricultural research centres. The Australian Government, through the Australian Centre for International Agricultural Research (ACIAR) was an early and ardent supporter for the inclusion of coconut within the portfolio of CGIAR crops, as an important but orphan crop whose biological diversity needed to be conserved and whose challenges, particularly in the areas of crop improvement and crop protection needed to be addressed.

It is timely now for Bioversity to be launching a new Global Strategy for Coconut Genetic Resources for the next ten years and beyond. It is also pleasing to learn that the Asia-Pacific Coconut Community (APCC) will be joining with Bioversity, the South Pacific Commission, ACIAR and the Australian Department of Foreign Affairs and Trade (DFAT) in support for this new strategy and its implementation through COGENT and its partners across the coconut producing world.

May I commend this strategy to the readers, congratulate the many people who developed this impressive document and wish those responsible for it successful implementation every success in their important endeavours.

Brisbane, August 2018

* ACIAR Commissioner, University of Queensland, St Lucia, Brisbane, Australia.

Outline

Chapter 1 introduces the background context and rationale for this new Global Strategy for the Conservation and Use of Coconut Genetic Resources. It articulates the origin, history and dynamics of coconut cultivation, particularly emphasising the importance of coconut genetic diversity and outlining the threats it faces. It then highlights the role of the International Coconut Genetic Resources Network (COGENT), and urgent need for this revised Global Strategy. The chapter then outlines the Strategy's vision, goal, objectives, outputs and outcomes, and how these link with the CGIAR system-level outcomes (SLOs), and concludes with describing the participatory approach to developing the Strategy.

Chapter 2 provides a global analysis of the present status of coconut genetic resources conservation and use. It begins by describing coconut genetic diversity in terms of its genepools, domestication, and nomenclature. It goes on to outline the current *ex* and *in situ* conservation methodologies, and associated *in vitro* culture and cryopreservation methodologies. The third section examines the current global *ex situ* conservation system in greater detail, in terms of the collections' content, management and costs, as well as current approaches to germplasm collecting, identification, characterization, evaluation and safety duplication. The fourth section on genetic resources information management then covers local genebank management systems, and managing international coconut databases and geographic information systems. Section five describes how coconut genetic resources are currently used, including: planting material for farmers; farmers in breeding and seednut production; past and current coconut breeding efforts in terms of breeding for improved yield; pest and disease resistance; quality; and drought- and other abiotic stress-resistance or tolerance. The role of genomics and DNA markers is also explored. The use of coconut to mitigate effects of climate change, and for ecotourism are then discussed. Section six embraces the important area of coconut germplasm exchange, including the benefits of sharing coconut genetic resources; Safe safe movement of germplasm and international germplasm transfers. Coconut partnerships and networking are then briefly discussed, before a closing section provides an overview of the emergency situation which coconut conservation is facing.

Chapter 3 focuses on prioritizing the actions and research needed to effectively secure coconut diversity and enhance its use, and proposes plans to develop concrete mechanisms, skills and research that will permit the global coconut community to achieve the Strategy's objectives. The chapter is laid out according to following sequence of these objectives: 1) strengthening commitment and communication; 2) ensuring *ex* and *in situ* conservation; 3) addressing diversity gaps, 4) developing mechanisms for effective international germplasm movements; 5) comprehensively characterizing and evaluating coconut germplasm, and 6) reinforcing COGENT. Section 2 revisits the concept of a Global coconut collection (including a "networked" or "virtual" collection), stressing the importance of field genebanks and their diversification and duplication, as well as that of sharing genetic resources. Section 3 focuses on securing existing *ex situ* coconut genetic resources, in terms of business planning; extending accessions' duration; triplication; and cryobanking.

Section 4 covers the *in situ* areas of conservation through use; multifunctional landscape management, and ethnobotanical and reproductive considerations. Collecting and filling gaps in *ex situ* collections is covered in the next section, including a particular focus on compact dwarfs Dwarfs and other special varieties, as well as collecting for pest and disease tolerance, filling geographical gaps, and prospecting in islands most isolated and/or endangered by climate change. Section 6 offers recommendations for strengthening the distribution and safe movement of germplasm in the areas of policy; germplasm transfer protocols, including for embryos pollen, and disease indexing and quarantine centres. Section 7 explores ways to promote using coconut genetic resources. It explores: global objectives in terms of planting material; promoting farmer-produced planting material; germplasm characterization and evaluation; international breeding trials, and finally how coconut clones may offer an innovative means to increased use. Section 8 articulates ways of improving databases and sharing technical information. Section 9 looks at genome studies for effective management and utilization of coconut genetic resources, including genome sequencing, preparing for marker-assisted breeding, and DNA analysis for more effective conservation. The chapter concludes with recommendations for enhancing networking and partnerships for global collaboration.

Coconut glossary

Accession: a collection of plant material from a particular location, received by a genebank to ensure sustainable conservation of a single specific cultivar, landrace or population.

Allogamous: naturally fertilized by pollen from another individual. Most of Tall-type coconut cultivars are preferentially but not exclusively allogamous. Opposite: autogamous

Allele: different partner version of the same gene (found at the same locus but in homologous chromosomes or in different individuals.

Autogamous: reproducing naturally by self-fertilization. Many Dwarf-type coconut cultivars are preferentially but not exclusively autogamous. Opposite: allogamous.

Axis: part of the coconut inflorescence following the peduncle and where the spikelets are attached (except for the Spicata varieties).

Coconut water: the natural liquid endosperm that fills the cavity of a developing coconut fruit (sometimes incorrectly called "milk" when used for *in vitro* tissue culture).

Coconut milk: the liquid white emulsion extracted from the grated meat/kernel of a coconut, used in food preparation and also sometimes called "coconut cream".

Coconut oil: the primary product of coconut cultivation with many diverse uses. obtained from copra or fresh kernel (called virgin coconut in the last case).

Coir: natural fibre extracted from coconut husks. Used in products such as floor mats, doormats, brushes, mattresses, geotextiles, etc.

Copra: the dried meat (kernel) of coconut, generally with 6% moisture. Once important for storage and shipment, it yields coconut oil and the residual coconut cake which is mainly used as fodder.

Cryoconservation: frozen in liquid nitrogen for purpose of conservation (at -196°C).

Cultivar: cultivated variety.

***Ex situ*:** when a species is conserved outside of its usual location, such as in field genebanks as living trees or in *in vitro* collections of tissues and embryos.

Genebank: type of biorepository which preserves genetic material. In the case of coconut palm, all are presently field genebanks conserving accessions of living coconut palms.

Genotype: the hereditary constitution of an individual.

Hybrid: In the case of the coconut palm, the term "hybrid" is defined in its widest sense as the result of a cross between population, families, or individual palms belonging to different varieties.

Impact pathways: build on logical models by giving more detail on the contribution of each activity on its path to impact. Impact pathways unpack the links between outcome and impact. Impact pathways are commonly presented graphically.

Inflorescence: the part of the plant that bears the flowers, including all its bracts, branches and flowers, but excluding unmodified leaves. Coconut inflorescences have both male and female flowers.

Inbreeding: producing offspring by self-fertilization or by crossing of parents that are very close genetically. Opposite: outbreeding.

***In situ*:** when a species is located/conserved in its usual situation,-in farmers' fields or in protected areas.

***In vitro*:** when a species is located/conserved in a glass receptacle such as test-tubes, as a part of *ex situ* conservation.

Landrace: traditional palms specifically adapted to the environmental conditions from their region.

Makapuno or **Macapuno: :** in the Philippines, Makapuno designates a particular type of coconut palm producing some of their coconuts with thick and soft meat, which are not able to germinate except by embryo culture.The spelling Macapuno was adopted in the USA and similar types in other countries have other names.

Monoecious: having both the male and female reproductive organs in the same individual; hermaphrodite. Opposite Dioecious.

Motu: small island. Scientists generally use mainly this term for small coral islands, while Polynesians apply it to any small islands were plants are growing.

Peduncle: the lower unbranched part of the coconut inflorescence.

Phenotype: appearance of an organism with respect to a particular character or group of characters (physical, biochemical or physiological), as a result of the interaction of its genotype and its environment.

Pollen competition: applies when female flowers pollinated with an equal mix of pollen of two varieties do not give seednuts resulting from an equal mix of these two parental varieties.

Polymotu: the Polynesian-based Polymotu concept (poly=many, motu=island) is to use the geographical isolation of dedicated sites for conservation and reproduction of individual varieties of plants, trees and even animals.

Progeny: the subsequent generation following a mating or crossing of parents.

Seednut: the entire fruit, with the husk arount the nut, when ripe.

Seed-garden: Areas (often up to 200 hectares) planted with one or several coconut varieties for producing coconut seednuts.

Selfing: Self-pollination and fertilization of an organism, is possible for coconut palms because inflorescences have both female and male flowers.

Spicata: rare forms of coconut palms where most of the flowers, instead on being attached to the spikelets, are attached directly to the axis of the inflorescence.

Spikelet: the part of the coconut inflorescence which is attached to peduncle and may bear female and male flowers. A coconut spikelet usually bears 0-6 large female flowers and 10-200 smaller male flowers.

Variety: a distinct, often intentionally bred subset of a species that will behave uniformly and predictably when grown in an environment to which it is adapted. Widest sense includes cultivar, ecotype, landrace, etc.

Theory of Change: presents an explicit identification of the ways by which change is expected to occur from output to outcome and impact.

Acronyms

ACIAR	Australian Centre for International Agricultural Research
ADB	Asian Development Bank
APCC	Asian and Pacific Coconut Community
CBD	Convention on Biological Diversity
CDM	Coconut Data Management sofware
CDC	Coconut Genetic resources Database
CPCRI	Central Plantation Crop Research Institute (India)
CFDV	Coconut foliar decay virus
CGIAR	Consultative Group on International Agricultural Research
CIRAD	Centre international de recherche en agriculture pour le Développement
CNRA	Centre national de recherche agronomique de Côte d'Ivoire
COGENT	International Coconut Genetic Resources Network
CRP	CGIAR research programme
DFID	Department for International Development
FAO	Food and Agriculture Organization of the United Nations
FTA	Forests, Trees and Agroforestry (CRP)
GCDT	Global Crop Diversity Trust
ICG	COGENT International Coconut genebanksGenebanks
IDEFOR-DPO	Former name of CNRA
IDOs	Intermediate Development Outcomes
IFAD	International Fund for Agricultural Development
IPRs	Intellectual property rights
IRHO	Institut de recherche sur les huiles et oléagineux
ITPGRFA	International Treaty on Plant Genetic Resources for Food and Agriculture
ITAG	COGENT International Thematic Action Groups (7 groups were created in 2012)
KCTA	Knowledge and commitment of targeted audience
LYD	Lethal yellowing disease
MLS	Multilateral system
MoA	Memorandum of Agreement
SC	Steering Committee
SMTA	Standard Material Transfer Agreement
SPC	Secretariat of the Pacific Community

1. Introduction to the Global Coconut Strategy

1.1 The coconut, a tree of many lives

Emblematic, aesthetic and strange, the coconut palm (*Cocos nucifera* L.) has long been valued by many civilizations, and has been endowed with multifaceted symbolisms and positive cultural references, reflecting its great genetic diversity and multiple uses. A global strategy to conserve such diversity can therefore serve as a basis for its sustainable use. However, coconut's complex biology poses particular challenges for researchers and curators working in both conserving and using coconut genetic resources.

Polynesian tradition tells us that coconut palms only grow well when they can hear the sea or human voices. However, recent agronomic progress has boosted palm yields even when they are a long way from beaches and houses.

Street sellers of the famous coconut variety named « King Coconut » or « Rath Thembili » in Sri Lanka. This variety is mainly used for tender nuts for drinking.

At the global level, coconut research remains insufficient with regard to the social, economic and cultural importance of the plant. Coconut is cultivated globally on about 12 million hectares, but countless home gardens also grow a few coconut palms each, to provide food; water and sap to drink; oil for culinary and non-edible uses; leaves for thatching and fencing; sugar, vinegar and alcoholic beverages from sap; timber and wood for construction; fuel from the husk, leaves and shells; materials for artefacts, traditional medicine and ritual purposes; attractive landscaping and shade, both for people and inter-crops. The custodial role of farmers, together with these hundreds of millions of gardeners, was and remains crucial for creating new varieties and transmitting seednuts through their social networks.

The coconut industry is now experiencing an important revival. Although the price of coconut oil and copra remains highly volatile and subject to much speculation, the price of fresh coconuts has greatly increased during recent years. Many farmers want to replant, preferably with high-yielding varieties bred for production of high-value products. Some countries have recently begun to increase their investment in coconut research, although this will take time to produce substantial results. Due to the lack of investment in coconut research over the last 20 years, many farmers continue to plant varieties with lower yield potential than those alternatively available. Higher-yielding planting material is not available in sufficient quantities or at an affordable price. The technical protocols and field management promoting best growth and higher yield are not adequately disseminated among farmers. The case for coconut research needs to be more assiduously made.

Created in 1991, the International Coconut Genetic Resources Network (COGENT) gathers 39 countries producing more than 98% of coconuts worldwide and hosting 24 *ex situ* coconut genebanks. COGENT's overall goal is to optimize the conservation and use of coconut genetic resources, as the foundation of a sustainable coconut economy (from farmers through research to consumers), by coordinating and strengthening such conservation and related research efforts of a worldwide network of stakeholders.

COGENT has played – and continues to play – a crucial role in developing international projects and in organizing the global coconut conservation system which is presently based on 5 international genebanks collaborating with the 19 national genebanks and other coconut stakeholders worldwide.

The previous version of this Strategy[2] was released by COGENT in January 2008, after an international consultation process which required four years[3]. The need to update this Strategy was highlighted as early as 2009, during a COGENT meeting held in Korea. One of the main limiting factors of global coordination was identified as "*making decisions with incomplete or obsolete information*".

With funding support by the Global Crop Diversity Trust (the 'Trust' hereafter), COGENT's major achievements for 2012 included: an update of the data regarding global *ex situ* coconut conservation (Bourdeix et al. 2012a) and holding the 16th COGENT Steering Committee meeting (Bourdeix et al. 2012b). In October 2012, another important meeting was also organized in Samoa by the Pacific Community (SPC) and the Australian Centre for International Agricultural Research (ACIAR), with participation of COGENT, the Asian and Pacific Coconut Community (APCC) and many country representatives. This meeting contributed to addressing priorities in coconut research and development. Thanks to CGIAR Research Program on Forests, Trees and Agroforestry (CRP-FTA), to Bioversity International, to CIRAD and to all COGENT country-members, this has led to the development of this new Strategy. Coconut is one of the priority crops listed in the Annex 1[4] of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA - 'the Treaty' hereafter). Reasons why coconut research remains insufficient and the possible remedies to improve this situation are comprehensively discussed in this strategy document, with a special emphasis on the conservation and use of coconut genetic resources.

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[2] "A framework for promoting the effective conservation and use of coconut genetic resources developed in consultation with COGENT members and partners". Available at the URL: http://www.cogentnetwork.org/images/publications/Coconut-Strategy-FINAL-28Jan2008.pdf

[3] In November 2004, the Global Crop Diversity Trust supported a meeting of the major coconut producing countries to review and update the Strategy and identify priority conservation activities. The updated Strategy was referred to the COGENT Steering Committee (SC), to representatives of coconut growing countries and COGENT partner research organizations, and based on their feedback, a revised draft was produced. The COGENT SC approved the revised Strategy during its meeting in India in November 2005. In December 2007, participants in the International Coconut Genebank (ICG) and National Genebank Curators Workshop/COGENT SC meeting reviewed the Strategy to further rationalize the collections.

[4] Available at the URL: http://www.planttreaty.org/content/article-xiv

1.1.1 Origin, history and dynamics of coconut cultivation

Evidence suggests that the coconut and its related species already had a wide distribution during the Eocene to Oligocene eras (28-44 million years ago). At the dawn of agriculture (around 10,000 years ago), it appears to have been restricted to a region extending from South-east Asia to near Oceania and to the south of the Indian sub-continent. It is feasible that when humans started to harvest coconuts for consumption and multiplication, this initiated a long and progressive domestication process.

Diversity of coconut fruits.

It is likely that within archipelagos and on islands, the spread of coconuts was based on a very small initial sample size, considering the bulk of the seed material and that the coconut reproduces by seed. The natural adaptation of coconuts to a dispersal mode by flotation means that sample size may have been limited to only a few nuts being the founders of populations on small islands and atolls. During this worldwide dissemination, these continued 'bottleneck events' have resulted in enormous genetic drifts in the founding populations. This process, facilitating a fragmentation of coconut genetic diversity, was overlain by ritual and commercial exchanges of seeds, which tended to homogenize populations at a regional scale. The results of these partially opposed tendencies need to be analysed further because they have significant implications regarding the current genetic distribution of coconuts, in particular when being collected for conservation and multiple uses.

Optimizing conservation requires a better understanding of the biological, social and historical dynamics shaping coconut genetic diversity and its uses. The current pan-tropical coconut distribution was attained only relatively recently from 3,400 to 100 years ago, involving Austronesian seafarers from Malaysia and Pacific, Arab traders in the Indian Ocean, and Europeans exploring the Atlantic and the Pacific coasts of the Americas.

South-east Asia comprising Cambodia, Hainan Island, Indonesia, Malaysia, the Philippines, Thailand, and Vietnam, is undoubtedly one of the most diverse regions for coconut cultivation. This is the region where the highly domesticated Dwarf[5] coconuts are likely to have originated.

Archaeological evidence suggests that the coconut was present in the Pacific prior to human arrival. Early human settlers occupied the Sahul region about 45,000 years ago

5 "Dwarf" and "Dwarf-types" designate 'Malayan-Type Dwarfs' and 'Compact Dwarfs' in the Strategy (see Plate 1.1).

settling in New Guinea Island and Australia. These first settlers were not cultivators, but may have used coconuts as floatation aids to reach New Guinea and Australia.

The coconut was associated with the "portmanteau biota" of the Austronesian peoples emanating from Taiwan (Kirsch 2002), whose navigational skills enabled colonization of the Pacific starting around 3,400 years ago. They travelled via South-east Asia islands, the Bismarck Archipelago and via outlying islands of Solomon and Vanuatu. Coconut fruit provided portable water and food for their rapid migration across Pacific Ocean.

Coconut palm and children in Funafuti, Tuvalu Islands. (R. Bourdeix)

In the 1800s, in most of the Pacific islands, each of the various clans had probably a limited number of coconut palms. However, they distinguished many coconut landraces which served many different purposes[6]. From 1870, coconut became a major colonial business and copra an international commodity. Commercial plantations of various sizes run by European settlers or companies had a ripple effect on the establishment of small plantations by Pacific islanders, geared to copra production. The number of coconut palms in the Pacific region greatly increased (probably 50 to 100-fold). In most cases planting techniques on the atolls consisted of clearing all the natural vegetation, letting it dry for a month, burning everything and importing coconut seednuts from another bigger island. These planting techniques were indeed harmful to the biodiversity of endemic species. They were also damaging from the perspective of conserving coconut genetic diversity. Agricultural landscapes and practices were brutally modified.

In many islands, the human population was decimated by diseases brought by infected European mariners and traders, such as measles and influenza. These cataclysmic events changed the social representations of the coconut palm for the Pacific islanders, and exacerbated the erosion of traditional knowledge and the mix of biological resources. It has been estimated that more than half of the coconut landraces that had been developed by the islanders over several millennia were lost by dilution in the mass of coconut palms selected purely to produce copra.

On the Pacific coast of the Americas, coconuts were present in Panama before the Spanish arrived during the 16th century, and recent studies have shown that they are closely related to those from the Philippines. Pre-Columbian cultivation of the coconut was unknown; it only became a plantation crop after European settlement. Further exploration in northwest South America may reveal untapped diversity from pre-historical introductions to this understudied part of the Neotropics.

[6] Purposes as listed in the introduction of this Strategy, plus coconut shells used as containers and husk fibre to make ropes.

Hindu scriptural references indicate that the coconut was cultivated in the southern Indian subcontinent even earlier than other recorded cultivations of around 2,500 to 3,000 years ago. Coconuts from the Laccadives, Maldives and Lakshadweep archipelagos to the south-west of India in the sea of Oman were highly valued for production of coir[7]. Landraces in the Andaman and Nicobar Islands are also highly diverse and include rare morphologies such as horned coconuts (Rajesh et al. 2008). The earliest known record of coconuts in Sri Lanka was in the "Mahawansa" historic chronicle from 101-77 BC; ancient accounts from pre-Portuguese travellers during the 6th century AD further support its antiquity in Sri Lanka, in India and in the Maldives. The periphery of southern India including Sri Lanka and the island archipelagos represents one of the two centres of coconut diversity (see Section 2.1.2 on domestication of the coconut palm).

By the end of the first century AD the Indian Ocean embraced a network of trade routes and coconut fruit became a popular trade commodity where exchanges were made between northern Africa, South-west Asia and the east coast of Africa (Cappers 2003). The main hubs were the Maldives and the Laccadives Islands. In Tumbe village, Pemba, Tanzania, archaeobotanical data suggest that coconuts and rice were already under cultivation from the 7th to the 10th centuries. In South Oman, the tradition of using coconut fibre (*kambar*) to construct dhows and cordage is attested in the 9th century and has persisted among local fishermen and transoceanic traders (Pereira et al. 2011) until recently. Coconut is still cultivated in Oman under irrigation. The Comoros Islands and Madagascar also formed an integral part of this trade route and show evidence of Bantu and Middle Eastern cultures. Molecular evidence has shown that a proportion of coconuts from Comoros and Madagascar were admixed with those from the Pacific and may be traced to earlier migrations around 1,500 years ago by Austronesians from eastern Kalimantan in South-east Asia. Soon after the opening of the navigation route to India by Vasco da Gama, coconut was introduced to the Cape Verde islands and from there to West Africa and to the Caribbean.

Historical and pre-historical knowledge about the dynamics of coconut cultivation and trade is still incomplete. During the 18th, 19th and even the 20th century[8], full boats loaded with coconut seeds were sent between continents, from Asia to the Pacific region and Indian Ocean, and vice versa. Therefore, it is imperative to establish and understand how traditional knowledge of diverse coconut germplasm might be of service to current agricultural and economic developments. In order to do this, coconut conservationists and agronomists should collaborate more closely with archaeologists and historians[9]. Genetic diversity measures from the interface between the landraces and cultivars have already provided crucial information concerning agricultural development.

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[7] The Laccadives were known as Diva-kanbar (Coir Islands) by Arab geographers and writers from the 10th century.

[8] For instance, according to Hugh Harries (personal communication) in 1962 a boatload reputed to be 1 million coconut seednuts, was shipped from Sri Lanka to Cuba.

[9] At least two PhD students are needed: one archaeologist compiling data regarding coconut prehistory, the other analysing the numerous international germplasm transfers conducted during the colonial period by private companies.

Plate 1.1

Malayan Dwarf-type Coconut varieties

Care for your coconut!

1. Malayan Red Dwarf (MRD) young palm in Vanuatu.
2. MRD, adult palm in Côte d'Ivoire.
3 Samoan Yellow Dwarf young palm in Vanuatu.
4. Malayan Yellow Dwarf (MYD) young palm in Vanuatu.
5. MYD, adult palm in Côte d'Ivoire.
6. Madang Brown Dwarf (MBD) from Papua New Guinea planted in sandy soil in Africa and producing elongated fruits.
7. MBD, planted in volcanic soil in Vanuatu and giving rounder fruits.
8. MBD, adult palm in Côte d'Ivoire.
9. Catigan Green Dwarf from the Philippines in Côte d'Ivoire.
10. Pilipog Green Dwarf from the Philippines in Côte d'Ivoire.
11. Brazilian Green Dwarf in Côte d'Ivoire.
12. A mutant form of the Brazilian Green Dwarf producing hundreds of small fruits in Sococo plantation, Brazil.
13. Pemba Orange Dwarf in a garden of Tanzania.

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The systematic documentation and collecting of coconut landraces needs to continue with respect to intellectual property of farmers and countries. This should be implemented in conjunction with applying a genomics approach.

1.1.2 Cultivation and current production of coconut

The coconut palm is cultivated in at least 94 countries worldwide, in all the tropical zones of Asia, Oceania, Africa and the Americas (FAO 2014). The coconut has traditionally been integral to the lives of the coastal people, even in West Africa, the Caribbean and the Atlantic and Pacific coasts of South and Central America where it was introduced only around 500 years ago.

To re-iterate, coconut is planted on approximately 12 million hectares worldwide, and provides the major source of livelihoods for more than 11 million farmers, mostly smallholders with low income (Adkins et al. 2006). Plantings are predominantly on smallholdings using traditional cultural practices. These farms and gardens cater mostly for local markets, where nuts are sold for domestic consumption.

Split coconuts.

The main cash products are *copra* (the dried kernel) for oil, *husk* for fibre, and *tendernut* for drinking the water. Whole mature nuts are also sold to factories producing desiccated coconut, coconut milk and very recently virgin coconut oil. Some fresh mature nuts may be sold for jelly and candy manufacture. Coconut water, delivered in whole fruit or in containers, feeds a very buoyant market in Brazil, India and Thailand, as well as in most areas close to large urban centres throughout the coconut zone. Husk is processed into fibres and then geotextiles and coco-peat used for greenhouses substrates. Shells are used to produce artefacts and activated charcoal.

Throughout the tropics, hundreds of millions are each growing a few coconut palms in their home gardens. An important part of the genetic diversity is conserved in this way. People take more care of the few palms providing daily food and drink than of those planted for commercial production. The role of these millions of “gardeners” remains crucial for creating new varieties. Coconut is a strategic commodity not only because of its economic value but also in terms of its social, cultural and religious importance.

According to FAO 2017, in 2014, the 12 million hectares of coconut plantations produced about 60 million tonnes of coconut (whole fruit). This suggests a world average of about 4,300 nuts per hectare per year, or about 900kg of copra equivalent per hectare per year[10]. If an average density of 120 adult palms per hectare is considered, the average production per palm is about 36 fruits or 7.5 kg of copra equivalent per palm per year.[11]

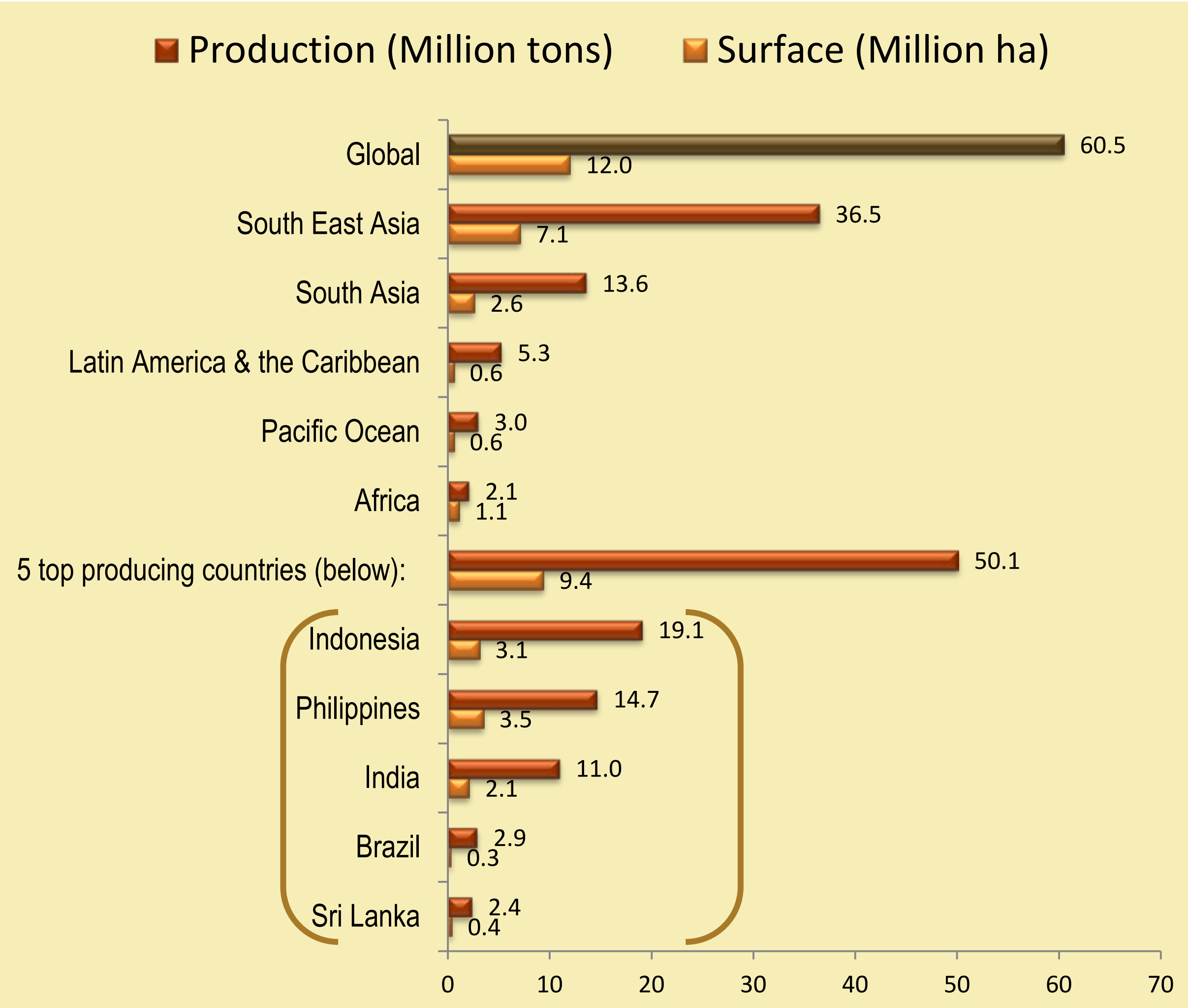

Figure 1.1. Global coconut production and surface in 2014 (Source: FAOSTAT 2017).

The diversity of markets in some of the major producing countries is illustrated by the following examples.

About 64 out of 72 provinces of the **Philippines** have coconut as a major crop. The livelihoods of more than 20 million Filipinos (about one-quarter of the country's population) are directly influenced by coconut that is processed into market

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[10] Taking into account an average proportion of husk in the fruit of 40% and 900g as the weight of the nut (including shell, kernel and water).

[11] To be compared with yields obtained by some private companies (keeping in mind that it is at industrial scale): About 180 coconuts and 45 kg of copra per palm per year for Dwarf x Tall hybrids in Malaysia (more details at the URL: http://www.unitedplantations.com/Products/documents/coconutbrochure161008.pdf); and 250 tender coconuts per palm per year obtained by Brazilian companies with Dwarf varieties (see URL above).

derivatives of all the major components of the fruit. There are 1.6 million farmers and around 1.9 million farm workers. The area devoted to coconut increased by about 16% between 2000 and 2012.

In 2012, the coconut acreage of **Indonesia** amounted to more than one-quarter of the world's total, with about 98% in the hands of 3.2 million small-scale farming families. The FAO data regarding yield per hectare is probably overestimated because actual cultivated area is probably larger. Most plantations, intercropped for subsistence, are adversely affected by soil nutrient deficiencies.

The states of Kerala, Tamil Nadu, Andhra Pradesh and Karnataka account for about 90% of the coconut industry of **India** (Thomas 2012). The shipment of tender nuts to markets in the large Indian cities is becoming an important part of the market. Irrigated coconut gardens in India, especially in the state of Tamil Nadu, are regularly harvesting an average of 250 mature coconuts per palm per year. In case of tender nuts the average is more than 300 nuts per palm per year.

Tanzania has the fourth largest area devoted to coconut cultivation but yields are low, partly due to loss from Lethal Yellowing disease (Eden-Green 1997), but also related to the severity of the dry season. In spite of this, new planting continues.

A significant part of the coconut area in **Brazil** is under intensive management mainly for the coconut water trade. Some of these plantations are highly profitable having adopted drip irrigation and high levels of fertilization. By planting common Dwarf varieties at industrial scale, such as Brazil Green, Malayan Yellow or Cameroon Red at 200 palms per hectare, a yearly average of 250 nuts per palm can be produced, giving a total of 50,000 fruits per hectare per year. Each nut yields an average of 400 ml of water, so that 100 L of water/tree and 20,000 L/ha can be harvested. The area devoted to coconut cultivation has increased by about 39% over the past 30 years (FAOSTAT 2017)

1.1.3 Importance of coconut genetic diversity

Over millennia, humanity has slowly selected and maintained hundreds of coconut varieties used for many purposes. It has resulted in an extraordinary morphological diversity which is expressed by the range of colours, shapes and sizes of the fruit, as shown in Plate 1.2. Better communication is urgently needed to make this diversity known at the global level. When looking at the central picture of Plate 1.2, many people from tropical countries are astonished to discover such an unimaginable diversity. Most 'Westerners' are unable to identify which species are illustrated in this picture. Furthermore, the huge breeding work conducted by coconut farmers and scientists remains greatly under-valued.

Coconut genetic resources cover all material from very rare self-sown populations in some isolated islands to palms growing in farmers' fields, plantations and gardens, including also accessions held in national and international genebanks and progenies tested in breeders' experiments.

Nursery of coconut seedlings from the variety "Brazil Green Dwarf" used for production on coconut water in Brazil. (R. Bourdeix)

Coconut germplasm can be conserved in two contexts:

- *In situ*, i.e. in farmers' fields, in nature or in protected areas. The 12 million hectares where coconut is grown as a crop and the hundreds of millions of coconut palms kept by gardeners in home-gardens are the main places where coconut diversity is conserved. However, many people owning or cultivating coconut palms are still not aware of the crucial importance of maintaining coconut genetic diversity in the production system. Better communication is urgently needed to increase their commitment to conservation.
- *Ex situ*, i.e. comprising all coconut germplasm currently maintained in field genebanks and screenhouses as living trees. *Ex situ* collections play a crucial role in the conservation of many varieties, particularly those that are disappearing from farmers' fields and home gardens. Presently, the 24 coconut field genebanks located in 23 countries (as detailed in Table 1.1) and referenced in the International Coconut Genetic resources database comprises about 90,000 living palms, equivalent to 530 hectares of coconut plantations.

Plate 1.2

Fruit diversity of the coconut palm

Wider future diversity

Oval picture: Mature and immature fruits of various coconut varieties: From left to right, then top to bottom: first rank **(a)** Papua Yellow Dwarf (PNG), **(b)** Rotuman Tall (Fiji), **(c)** Spicata Tall Samoa (Western Samoa), **(d)** Rennell Tall (Solomon Islands), **(e)** Cameroon Red Dwarf (Cameroon), **(f)** Madang Brown Dwarf (PNG), **(g)** Tahiti Red Dwarf (French Polynesia); second rank **(h)** Kappadam Tall (India), **(i)** Tagnanan Tall (Philippines), **(j)** Vanuatu Tall (Vanuatu), **(k)** Malayan Yellow Dwarf (Malaysia), **(l)** Malayan Tall (Malaysia), **(m)** Tampakan Tall (Philippines); third rank **(n)** Micro Laccadives Tall (India), **(o)** West African Tall Mensah (Côte d'Ivoire), **(p)** West African Tall Akabo (Côte d'Ivoire), **(q)** Sri Lanka Tall Ambakelle (Sri Lanka), **(r)** Comoro Moheli Tall (Comoro Islands), **(s)** Niu afa Tall (Western Samoa), **(t)** Tuvalu Tall Fuafatu (Tuvalu Island). **Top left:** Husked coconut **Top right:** Immature fruits **Bottom left:** Split fruits **Bottom right:** Husked coconut and immature fruits. The longest fruit is called "Banana nut" and results from a husk developing without pollination (no kernel inside, only husk and shell).

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New germplasm is introduced into field genebanks as seednuts. *In vitro* culture has more recently been given significant attention in coconut as well as in many other crops. One of its greatest successes has been using an embryo rescue technique for germinating and producing homozygous Makapuno plants (Sisunandar et al. 2010).

About Makapuno

Makapuno refers to a special form described first in the Philippines. A few of the fruits produced by these palms have soft and thick kernel but cannot germinate naturally. There are many kinds of Makapuno differing in the way the nuts are partially or fully filled by soft kernel, by the degree of kernel adherence to shells, and by textures and tastes of the soft kernel. Makapuno nuts are appreciated as delicacies and are sold at 5 to 10 times the price of a normal nut, in markets where the demand still strongly outstrips supply.

Makapuno coconuts in Thailand. (R. Bourdeix)

"Aromatic" varieties (mainly Dwarf-types) produce coconut water with special, attractive fragrances. The most famous variety is the Aromatic Green Dwarf from Thailand. There is no evidence that all the Aromatic varieties have the same taste, as no systematic comparison has been conducted at the global level. In the case of the Thai Dwarf, the Aromatic characteristic is recessive, where fruit from the aromatic variety pollinated by another variety will generally not express the aroma. In 2007, Thai researchers crossed Makapuno with Aromatic varieties. Using *in vitro* culture of excised embryos, they succeeded in obtaining a few autogamous Makapuno Aromatic homozygous Dwarfs. These new varieties will naturally produce 90 to 95% Makapuno Aromatic fruits (Nguyen Q.T. et al. 2016).

Many traditional varieties, endangered and sometimes not yet collected and described, have considerable economic potential for developing new products using a local branding approach. For instance, a project was recently conducted in Samoa for conserving the *Niu afa* variety, possessing the longest coconut fruit in the world. This special variety could generate and service a lucrative niche market. Samoan communities in Australia and elsewhere would prefer to buy products made from this special tasty variety bred by their Samoan ancestors. Making better use of their heritage varieties, farmers and small producers of virgin coconut oil will increase their incomes and improve their livelihoods. Respect for tradition can sometimes foster economic competitiveness.

On many Pacific islands and in some other places, rare coconut palms are reported where the husk of the normally tough and astringent young fruit is tender, edible and sweet. On ripening, the husk fibres are much finer and paler than normal.

Great variability exists amongst individuals and landraces, with some fruits being more or less tender, and more or less sweet. In the best palms, ripe fruit can be de-husked with bare hands, which is impossible with an ordinary coconut. These coconut palms are usually called 'sweet husk' (SWH). Various surveys have shown that such palms are becoming scarce (Bourdeix et al. 2013). It is currently very difficult to obtain any of their seednuts, as the young fruits are generally all harvested and eaten by children.

Husk of "Sweet husk" variety (right) compared to common varieties (left). (R. Bourdeix)

The benefits of conserving and utilizing coconut genetic diversity will only be realized if such diversity gains the attention of farmers and researchers engaged in breeding programmes. Scientists worldwide have been working for years towards producing coconut palms that can resist evolving pests and diseases, tolerate drought, strong winds and other environmental stresses, and can produce higher yields of copra. Their progress will be accelerated if they are provided with more information on the germplasm available, including agronomic traits, pest and disease resistance, and quality characteristics such as flavour, to help them prioritize materials for evaluation in breeding trials.

Coconut genetic resources are an essential element in the development of new and improved varieties to achieve a more sustainable and cost-effective foundation for coconut production (see Figure 1.2). The three coconut hybrids[12] with the widest global diffusion use a Malayan Dwarf as the female parent and cultivars from Africa and Solomon Islands as male parents. The famous "Brazilian Green Dwarf", widely cultivated in Latin America for production of coconut water, initially came from South-east Asia.

Although the safe movement of germplasm, including the necessary virus, viroid and phytoplasma indexing, has yet to be organized at the global level, coconut genetic resources conservation and exchange play a crucial role as part of the strategy for the biological control of pests and diseases. Genetic disease resistance

12 Malayan Yellow Dwarf x West African Tall (PB121 or Mawa hybrid from Côte d'Ivoire); Malayan Red Dwarf x Rennell Island Tall (MAREN Hybrid, from Solomon Islands and Côte d'Ivoire); Malayan Yellow or Red Dwarf x Panama Tall (MAYPAN hybrid from Jamaica).

factors are often found in introduced varieties. This was the case in Jamaica and Ghana for varieties tolerant to lethal diseases caused by phytoplasmas. Genetic resistance may be overcome due to evolution of the pathogen, as occurred recently in Jamaica. Introduction of new germplasm from safe sources should be encouraged and rationalized, even though the recrudescence of disease sometimes makes governmental authorities reluctant.

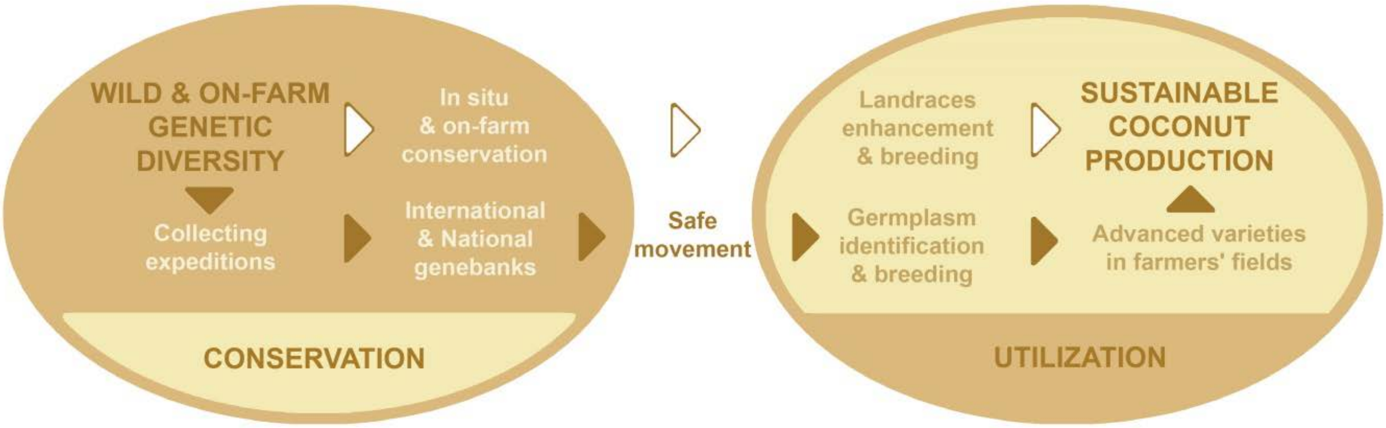

Figure 1.2. Links between coconut genetic diversity and sustainable coconut production (modified from C. Turnbull, Reading University, 2012)

It is however acknowledged that the Strategy will encourage both strong coconut breeding programmes at the regional or national level and a better understanding of why it has proved so difficult to realize a greater yield potential of coconut.

1.1.4 Constraints linked to the biology of the plant

Large palm and seed sizes

The bulky coconut palm requires a lot of space and time. Planting densities generally range between 80 and 250 trees per hectare, according to varieties and cultural practices. The time between planting and flowering varies from one year, for most precocious Dwarf-types such as the *Salak Green Dwarf* (Indonesia), to seven years for certain Tall-types with a thick stem bole, for instance from Comoro and Cook islands.

After pollination, the female flowers take 10 to 12 months to mature as a viable seednuts. Six to 12 months more are needed for raising the seedlings in the nursery before planting. The fruit has no dormancy, preventing storage of seednuts. The large size of both seednuts and seedlings makes their transportation expensive, both for farmers (from seed gardens to their fields) and for genebanks (international movements of germplasm). Their large size also increases the risk of disease or insect transmission, where smaller seeds are easier to disinfect. Only about 65% of seednuts are generally selected as seedlings for field transfer.

Palm height imposes an important constraint. For the purpose of conserving coconut genetic resources, the required palm-climbing has a significant human and economic impact. Tall-types reach a height of about 15 meters (from the ground to the bases of the crown) 25 to 30 years after planting. However, the real limiting factor is not the height of the palm but the method to climb it for making controlled hand-pollinations.

Bee flying to drink the nectar from female coconut flowers.

Two ants from different species drinking the nectar of female coconut flower.

Climbing the palm trunk and staying under the leaf crown is quite simple, and harvesting the ripe fruits from there is not difficult. The many existing remarkably inventive techniques, are described in several videos on COGENT's website[13]. However, the real challenge is to climb into the coconut leaf crown to reach the young inflorescences for making the controlled hand-pollinations.

Low multiplication rate

The low multiplication rate[14] is the main limiting factor both for regeneration and breeding purposes. Under average agricultural conditions, most cultivars annually produce less than 100 nuts per palm, making seednut production relatively expensive.

Controlled hand-pollination requires bagging the inflorescence with an expensive bag impermeable to pollen but permeable to air. Palms generally produce 12 to 16 inflorescences per year, each bearing only 2 to 3 nuts when

A bee harvesting pollen of male coconut flowers.

[13] See URL: http://www.cogentnetwork.org/climbing-the-coconut-palm

[14] Number of seeds produced per year.

bagged. In this case, the annual yield falls to 20 to 30 fruits per palm. To make only one controlled cross, for instance using a Dwarf as female and a Tall as male, it is necessary to climb the palms seven or eight times[15]. Thus, the average cost for producing one seedling from controlled hand-pollination is US$8-10. Such factors considerably limit the choice between crossing systems and the number of palms per accession to be conserved in the genebanks.

Size and heterogeneity of accessions

In classical coconut *ex situ* genebanks, coconut cultivars are conserved as accessions, generally planted close together. Each accession normally comprises 45 to 96 palms. Tall-type allogamous varieties need to be regenerated using the controlled hand-pollination technique. This is the only way to ensure that these varieties are conserved true-to-type during successive regenerations and that no genetic drift occurs.

Complexity of the natural breeding mode

Coconut inflorescences, borne on the axils of each frond, have both male and female flowers which, may or may not be mature at the same time, depending on the variety. The male flowers, located on the top portion of spikelets attached to the peduncle, are more numerous than the female ones which occupy the base of the spikelets. Two mating systems coexist in coconut: the largest group (Tall-type and a very special type of compact Dwarf) is predominantly cross-pollinating, where the female flowers become receptive after the male flowers in the same inflorescence have stopped shedding pollen. Self-pollination is however possible by pollen from the next succeeding inflorescence. A coconut palm mostly finds a way to reproduce, even if arriving alone on a new island.

Above are two pictures of the same palm taken with a ten days interval.

(a) the left-hand inflorescence has mature male flowers but female flowers are not yet mature; the right-hand inflorescence is not yet open.

(b) ten days later, the left-hand inflorescence has lost all its male flowers but the female flowers are now mature; the right-hand inflorescence is now open and has mature male flowers. The pollen of the right-hand inflorescence can pollinate the female flowers of the left-hand inflorescence.

This palm belongs to the West African Tall variety, and is planted in the Koral beach resort garden, Grand Bassam, Côte d'Ivoire.

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15 Climbing the tree is needed to install and remove the bag for collecting the pollen on the male parent, check the status of the inflorescence to be pollinated, install the bag on the female parent and make emasculation, make three successive pollinations and remove the bag after the last pollination; assess the level of fruit set at three months. Depending on the countries, harvest of the seednuts is made from the ground (for instance in Côte d'Ivoire) or by climbing the palm again (India).

Plate 1.3

Reproductive biology of the coconut palm

Care for your coconut!

1. Spikelets of a Tahitian Red Dwarf from the opening of the inflorescence to three months-old.

2. Coconut inflorescences.

3 & 4. Receptive female flowers with nectar drops pollinated by bees and ants.

5. A bee harvesting coconut pollen from male flowers.

6 to **11.** Reproductive biology of a young West African Tall.

6 & 7. Inflorescence (left side) is open but only maleflowers are receptive.

8 & 9. Nine days later than in **6 & 7**, female flowers (left side) are receptive, but no male flowers remain so cross-pollination occurs with pollen from another palm.

10 & 11. Three days later than in **8 & 9**, some female flowers (left side) are still receptive and the male flowers from the next inflorescence (right side) are now producing pollen so self-pollination can occur between successive inflorescences from the same palm.

12 to **15.** Inflorescences of Malayan Red, Niu Leka and Tacunan Green Dwarfs, Rennell Island Tall.

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A smaller group comprises self-pollinating types: all Dwarfs except from the above-mentioned Compact Dwarfs and a few "semi-Talls" such as the famous "King coconut" of Sri Lanka. The female and male flowers of these varieties mature at the same time. Ninety to 95% of all coconut palms worldwide are Talls, whilst Dwarfs are mainly found in gardens, and are increasingly widely cultivated, especially for coconut water production.

The complexity of the natural breeding mode of the coconut palm remains a challenge which needs to be better addressed by scientists. Further research is required to assess the rate of inbreeding in Talls which probably varies according to the varieties, the season, the climate and the conditions of cultivation[16]. The average pollination distance, which is a crucial issue for both seed production and *in situ* conservation, is also not sufficiently assessed. In the case of Dwarf seed-gardens, it was estimated that a 300-meter forest barrier was sufficient to guarantee the necessary isolation (De Nucé de Lamothe and Rognon 1975). In the case of Tall varieties, the average number of male parents naturally contributing to a coconut bunch has not yet been assessed.

In most scientific publications, it is indicated that coconut palms cannot be vegetatively propagated. Whilst this is true for most coconut varieties, surveys conducted by COGENT indicate that such propagation is possible for at least some. Coconuts able to both produce suckers and fruits have been described in Indonesia (Novarianto and Miftahorrachman 2000), and a young coconut able to produce suckers was recently seen (R. Bourdeix, personal communication)[17] during a survey conducted by the COGENT secretariat in the Fakarava Atoll, Tuamotu Archipelago, in French Polynesia[18]. None of these special coconut palms have been transferred to an *ex situ* coconut collection.

Long duration of experiments…

A field experiment in coconut breeding frequently covers an area of 1 hectare per cultivar under evaluation for a minimum period of 12 years. In many past cases, coconut experimental results have been lost even before their completion, due to research station fires or floods destroying data, computer damage, and high staff turnover. Consequently, coconut research not only needs high investments but also a greater functional stability. For obtaining convincing results in the field of coconut breeding, a research station should be operational for at least 20 years. Scientists sometimes prefer to work on crops with shorter production cycles and obtain rapidly

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[16] Although Tall varieties are predominantly allogamous, self-pollination may occur via pollination of female flowers from an inflorescence by the pollen of the following inflorescence of the same palm. The probability of such an overlap increases with the rate of inflorescence production, which responds to individual vigour of the tree, growing conditions and climatic variations. When selecting well-performing Talls it is possible to inadvertently select trees with a higher tendency for selfing causing a strong inbreeding handicap.

[17] See also suckering coconut at the URL: http://www.ikisan.com/tg-Coconut-abnormalities.html#Suckering

[18] This last survey indicated that farmers do not value and, being superstitious of strange growth, even sometimes destroy such clonable coconut palms. Planting coconut suckers is much more complicated than planting for instance banana suckers. The coconut suckers are rare, heavy to carry, and strongly attached to main stem, usually resulting in damage and death when removed.

publishable results. Donors and ministries often seem to prefer funding projects that give substantial results in 3 to 5 years, instead of funding coconut experiments that need 12 years to give complete results. A longer-term vision, a sense of general interest and working for the future generations need to be vigorously promoted.

... but some pleasant characteristics!

On the other hand, the plant has some advantageous characteristics. Its year-round production allows for a balanced planning of any breeding programme. No inter- or intra-varietal sterility has ever been observed, although pollen competition may occur (Sangare 1981). Its perennial nature allows for long-term conservation over successive generations and within living collections as well of multiple uses in experiment over a long period of time. Last but not least, coconut grows mainly in attractive coastal tropical locations, mostly close to the sea, and many coconut research centres can be regarded as small paradises from aesthetic, environmental and human perspectives.

1.1.5 Major threats to coconut genetic resources

Despite the existence of more than 1500 live coconut accessions in 24 *ex situ* collections worldwide, including 730 accessions that are held in 5 international genebanks, much of this germplasm remains greatly underused, or indeed at risk, due to the lack of adequate long-term funding to ensure that it can be conserved and utilized safely and effectively. Main threats to coconut genetic resources include:

- Social dynamics linked to coconut symbolism and inducing low commitment to conservation and use of genetic resources;
- Emerging diseases and pests;
- The environmental and social consequences of climate change and extremes;
- Economic aspects;
- Lack of capacity and other resources.

Social dynamics linked to coconut symbolism

The lack of adequate long-term funding for coconut research and *ex situ* genebanks is part of the social dynamics threatening coconut genetic resources. The ambivalent and multifaceted symbolisms associated with the coconut palm sometimes make stakeholders and even decision-makers forget that coconut cultivation strongly influences the livelihoods of millions of poor farmers. An ethnological approach of coconut symbolisms and their consequences was recently developed for the Pacific region. The modern representation of the Pacific islanders' coconut palm often appears as ambivalent. Caillon (2008) described the coconut palm's modern change of status in Vanuatu: the coconut is perceived by local people as the tree "of the Whites" mainly for its relation to the place. Quite similar representations are found in Polynesia, although the expression "plant of the Whites" was not encountered. If this "relation to the place" is indeed significant, these ambiguous representations also come from memories of the gruelling colonial times, from "westernization" and, as explained hereunder, from the simplistic coconut symbolism conveyed by globalization (Bourdeix et al. 2013).

In the past, many islanders were forced to work in coconut plantations or at smoky copra drying ovens, during a period when many died from imported diseases. In the collective Western imagination, the coconut palm has become a symbol of exoticism and tropical beaches. It is well-known that the image of the coconut palm is widely used to promote tourism and numerous associated products ranging from fashion accessories to financial investments. The combination of coconut with "hammocks" or "monkeys" sometimes reinforces the stereotype of peaceful paradise, far from the stresses of everyday life, an image which does not reflect the true situation of Pacific islands. Islanders become disengaged when confronted with such counterfeit representations that standardize the tropics and diminish their cultural identities.

For reasons linked to both colonization and globalization, many Pacific islanders simultaneously "love" and "hate" this emblematic palm. Their attitude towards the coconut is often a mixture of reverence and contempt. Nevertheless, in short discussions with local people elsewhere in the Pacific, they rapidly change their mind and acknowledge coconut palm as an integral part of their traditional cultures.

In other tropical regions, symbolisms associated with the coconut palm appear to be less ambivalent than in the Pacific. For instance, Balinese women were traditionally forbidden to even touch the coconut tree: females and coconut trees both share the ability to reproduce and men fear that a woman's touch may drain the fertility of the coconut tree into her own fertility. Another surprising example of social representation linked to coconut palm came a few years ago from the Philippines (L. Sebastien, personal communication): a Bioversity International research manager was told that: "when you see coconut palms in the landscape, you know that rebels are living there". Coconut palms and the poorest people are located in the same places. Because of these ambivalent representations, the value of implementing and funding research projects on coconut is sometimes questioned by stakeholders and decision-makers.

Emerging diseases and pests

In many countries, diseases and pests seriously threaten coconut cultivation and conservation of genetic resources. The main diseases are caused by a group of phytoplasmas[19]. Often but not always they are called "Lethal Yellowing diseases" or "Lethal Yellowing like syndromes". Phytoplasmas cause highly destructive, fast spreading diseases in coconuts and many other palm species. In Papua New Guinea, Bogia disease was identified in 2012 at 15 km from the International Coconut Genebank for the Pacific Region. This disease, also destroying betel nut and even some varieties of

Coconut grove devastated by Bogia disease near Madang in Papua New Guinea. (R. Bourdeix)

[19] Phytoplasmas are obligate bacterial parasites spread by insect vectors.

banana, has forced researchers to relocate the genebank to a disease-free area. In Côte d'Ivoire, a phytoplasma disease discovered in 2012 is now spreading in the Grand-Lahou region within 120 km of the International Coconut Genebank which has been involved in almost half of the international germplasm movements during the last 20 years. A duplication of this genebank is also envisioned to ensure the survival of the accessions.

Other most important diseases are the Cadang-Cadang viroid in the Philippines, the Foliar Decay virus in Vanuatu, and various forms of *Phytophthora* killing the palms and/or causing massive premature fall of immature fruits. The most important pests are: the beetles *Oryctes rhinoceros* and *Scapanes australis*, which eat young leaves and facilitate infestation by other insects (red palm weevil *Rynchophorus* sp.) which penetrate the heart and kill the palm; Red Ring disease caused by xylophageous nematodes in Latin America; the coconut eriophyid mite (*Aceria guerreronis* Keifer) which attacks the surface of fruit and strongly reduces their size, leaf-eating caterpillars; the white grub (*Leucopholis coneophora*), whitefly (*Aleurodicus* and *Aleurotrachelus* spp.), and the hispine beetle (*Brontispa longissima*) that cause considerable damage in numerous locations. Leaf hopper insects are known to be vectors of lethal diseases.

Climate change and hazards

Climate change, drastic changes in land use and progressive replacement of traditional coconut varieties with modern ones causes irreversible genetic erosion unless further steps are taken to conserve materials *in situ*, or to collect and conserve them *ex situ*. Traditional varieties growing on low atolls in the Pacific region and on low river deltas in all regions are especially endangered by rising sea-levels and flooding. Resistance to strong winds and cyclones is also an important consideration in many islands.

Genetic studies suggest that the material held in *ex situ* genebanks does not adequately represent the known range of diversity. More genetic variation remains to be described and collected in farmers' fields and in some remote locations where coconut palms may grow beyond human influence. Much of the germplasm in *ex situ* collections is inadequately duplicated outside of the host collection, mainly due to lack of funding.

National laws that restrict access to plant genetic resources have emerged in many countries. The introduction of Intellectual Property Rights (IPRs, e.g. UPOV variety protection) for new varieties and their genetic components in developed countries, the recognition of national sovereignty and restrictions to access genetic resources have made the availability of genetic diversity in recent years much more difficult. Insufficient communication and dissemination of reliable information on coconut accessions held in genebanks hinders efficient management and thus, significantly reduces their value to breeders, farmers and other investors.

Economic aspects

During the last 20 years, many countries have not invested sufficiently in coconut breeding, and seednut production, and interactions with coconut farmers have been inadequate. This was mainly caused by unacceptably low farm-gate prices reflecting market conditions. Low prices for copra and oil, and their high market volatility, led to lower interest in replanting coconut even in places where local consumption was crucial for livelihood. The intense development of oil palm plantations has also caused a certain loss of interest in coconut, from both farmers and researchers. Many researchers working on coconut shifted to oil palm, coffee or cocoa. Big companies planting crops on an agro-industrial scale can afford to support larger research budgets unlike the millions of small coconut farmers.

Tender Coconut street seller in Tonga. (R. Bourdeix)

Coconut cultivation is actually undergoing a strong revival. In November 2013, delegates from the governments of 13 Asia-Pacific countries, including eight Ministers of Agriculture, participated in a FAO Regional Consultation on Coconut Sector Development in Asia and the Pacific. They concluded that replanting of coconut trees on a massive scale is required if the coconut producing countries of Asia and the Pacific are to meet the world's rapidly growing demand for coconut products. According to Hiroyuki Konuma, the FAO Regional Representative: "Asia and the Pacific's aging coconut trees simply can't keep up with the growing demand…/… Indonesia, the top producer, would need to replant some 450,000 hectares". For instance, Thailand, who has diversified into a variety of export products such as virgin coconut oil and aromatic coconut water, is presently importing coconuts from Indonesia and Vietnam to feed its industry. Thus, the global economic situation seems now more favourable to coconut cultivation.

1.1.6 The International Coconut Genetic Resources Network – COGENT

In 2017, COGENT gathers 39 country-members and is organized into 5 regional sub-networks: Africa and the Indian Ocean; Latin America and the Caribbean; South Asia and Middle East; Southeast and East Asia; and the South Pacific. Table 1.1 provides a list of the member countries. COGENT brings together national and international players in both public and private sectors and promotes funding opportunities for conserving and utilizing coconut genetic resources.

Coordinating the global conservation of coconut genetic resources relies largely on COGENT, with support from ACIAR, Bioversity International, CGIAR and CIRAD. The other main institutions which coordinate international coconut research projects are APCC, SPC and ACIAR.

Table 1.1. Composition (membership) of COGENT by regional networks in 2017.

South Asia and Middle East	Southeast East Asia	South Pacific	Africa and Indian Ocean	Latin America and Caribbean
Bangladesh	China	Cook Islands	Benin	*Brazil*
India	*Indonesia*	Fiji	*Côte d'Ivoire*	Colombia
Pakistan	Malaysia	Kiribati	Ghana	Costa Rica
Sri Lanka	Myanmar	*Papua New Guinea*[20]	Kenya	Cuba
Sultanate of Oman	Philippines	Samoa	Madagascar	Guyana
	Thailand	Solomon Islands	Mozambique	Haiti
	Vietnam	Tonga	Nigeria	Honduras
		Vanuatu	Seychelles	Jamaica
			Tanzania	Mexico
				Trinidad & Tobago

In ***Italic***: International Genebanks.
In **Bold**: country members of the COGENT Steering Committee in 2014.

APCC and SPC are mainly involved in research in coconut processing and socio-economics; although SPC has recently tested a new conservation approach in Samoa, based on the *Polymotu* concept, with funding from the Trust, and in collaboration with COGENT, Bioversity International and CIRAD[21]. ACIAR focuses on socio-economics, plant pathology and *in vitro* culture. CIRAD is involved in providing contribution from its researchers to COGENT coordination and in participating in numerous international research projects. CIRAD researchers are working on the whole supply chain, from the production to the consumption or uses of the final coconut products.

COGENT programme priorities and activities are decided by its Steering Committee and reviewed by Bioversity International to enhance complementarity and effectiveness. The COGENT Coordinator and Secretariat coordinate the planning, implementation, monitoring and evaluation of COGENT's programme, projects and activities, and establish linkages with collaborating institutions, programmes and donors.

[20] The ICG in PNG is currently being relocated, and with support from the UK Darwin Initiative is being upgraded and expanded to include new collected material, with satellite genebank sites in Fiji and Samoa. See: http://www.spc.int/blog/new-project-to-save-diversity-of-coconuts-in-the-pacific-islands/

[21] See URL: https://lrd.spc.int/our-work/genetic-resources/centre-for-pacific-crops-and-trees/polymotu-conserves-special-coconut-varieties-in-the-pacific.

Upgrading COGENT's organization was initiated in 2012 by conducting two organizational assessments and two participative meetings. The composition and the role of the Steering Committee (SC) was modified in order both to increase its stability and to allow other member-countries to fully participate to decision making. The venue of COGENT meetings was fixed as biennial and linked with the COCOTECH meetings of APCC, in order to reduce costs and increase interactions with stakeholders from the coconut value chain. Other innovations are the creation of six permanent International Thematic Action Groups (ITAGS)[22], and the possibility of making decision at distance using two distinct processes, remote consensus and remote voting. Further details on COGENT and its recent reorganization, including a study to explore alternative hosting arrangements for the Secretariat are provided in Annex 4 of this document.

COGENT is currently not funded on a sustainable basis, although Bioversity International and CGIAR were until recently allocating a restricted executive budget to support the activities of the COGENT Secretariat. For more information on COGENT, see the website: www.cogentnetwork.org.

1.1.7 The urgent need for a revised Global Strategy

Since 1991 COGENT has played a crucial role in developing the present global coconut conservation system, which is based on 5 international genebanks collaborating with the 24 national genebanks and other coconut stakeholders worldwide.

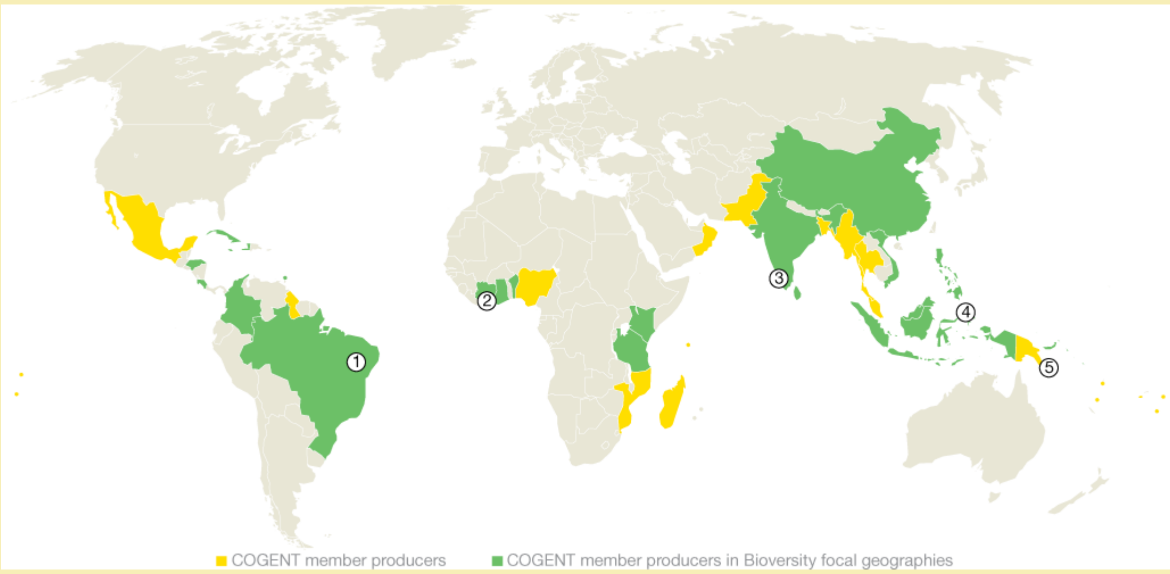

Figure 1.3. COGENT coconut producing countries.

[22] See URL: http://www.cogentnetwork.org/action-groups

One of the first internationally agreed priorities for COGENT was the development of a Global Strategy for the Conservation and Use of Coconut Resources.

Nevertheless, from a pragmatic standpoint, the 2008 version of the Strategy for *ex situ* conservation did not ensure sufficient sustainability to the global coconut conservation system. A COGENT project funded in 2012[23] by the Trust has shown that, among the 24 coconut genebanks participating in the network, 18 do not have the capability for true-to-type regeneration of the germplasm they are conserving. This includes three of the five international genebanks. Coconut *ex situ* conservation is thus facing an emergency situation. As articulated in section 2.3, about half of the many coconut varieties collected in the 1980s are becoming very tall. If nothing is done within a few years, their regeneration will prove impossible using currently available techniques.

Despite the recent coconut industry revival many coconut plantations are senile and unproductive. Most producing-countries cannot meet stakeholder demand for material for replanting programmes. The two-decade lack of investment has resulted in widespread planting of low yielding varieties by farmers, mainly due to the following factors:

- Lack of communication and commitment to conservation and use of coconut genetic resources at local, national and international levels;
- Under-resourced genebanks are lacking budget, manpower, equipment, laboratories and technical training to conduct the controlled hand-pollinations requested for regenerating the germplasm and to implement other activities such as collecting, characterization and breeding. The constraints linked to the biology of the plant make coconut conservation and use challenging and expensive using currently available techniques;
- The safe movement of coconut germplasm remains limited at the global level because of risks of disease transmissions, insufficient funding, lack of quarantine laboratories using efficient and affordable techniques for disease indexing; lack of capacities and the reluctance to share germplasm;
- Lethal phytoplasma diseases are expanding, threatening many farms and genebanks and destroying coconut genetics resources. In 2012, the rapid expansion of these diseases has threatened two international genebanks in terms of releasing germplasm at international level;
- Although the reorganization of the CGIAR system has had strong positive effects, COGENT is still working without long-term, stable and sufficient funding and is having thus a limited action. The current CGIAR conservation system still favours international genebanks directly placed under its authority, as opposed to a networking approach such as COGENT, which gathers 24 national and international genebanks in a global system.

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[23] See URL: http://www.cogentnetwork.org/network-projects/past-projects/upgrading-genebanks

The numerous coconut international projects launched by COGENT from 1992[24] demonstrate how multi-sector collaboration and shared priorities can help to set the agenda at national and international levels, aiming at more efficient use of coconut genetic resources to achieve common goals. Nevertheless, project-based activities, together with the past project-based COGENT organization have not been sufficient to ensure a sustainable global coconut conservation system.

Many crop species already benefit from a coordinated approach to the conservation of their germplasm supported by the Trust. This was established under international law in 2004, and was founded by FAO and Bioversity International, acting on behalf of CGIAR[25]. The Trust has established an endowment fund to safeguard *ex situ* collections of unique and valuable plant genetic resources for food and agriculture (PGRFA), with priority being given to those that are included in Annex 1 to the Treaty or referred to in its Article 15.1(b). Coconut is one of the crops listed in Annex 1. Therefore the Trust may offer a route to manage funds designated for coconut conservation.

Funding decisions by the Trust are based on priorities identified and agreed by internationally recognised networks of experts and key stakeholders, which need to be defined in global crop strategies. The Trust has developed priorities and guiding principles for the allocation of funds[26] and a set of specific criteria to be met before a collection will be considered for long-term funding support. These include:

1. the genetic resources are judged to be important within the context of an agreed global conservation strategy, and
2. the collection has effective links to users and is willing to act in partnership with others to achieve a rational system for conserving plant genetic resources and making them available.

Most nations and regions involved in coconut improvement and production are highly dependent on genes and varieties developed and conserved *in situ* and often also *ex situ* in countries or regions other than their own. Most of the efforts needed to manage these resources can therefore only be carried out through international collaboration and the participation of all partners. There is an urgent need for a revision of the former global strategy for the conservation and use of coconut genetic diversity and the dissemination of related information within and beyond the coconut community.

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[24] See the list of projects in Annex 5 and in COGENT website at the URL: http://www.cogentnetwork.org/past-projects/upgrading-genebanks

[25] International frameworks such as both FAO and its Global Plan of Action (GPA) for the Conservation and Sustainable Use of Plant Genetic Resources for Food and Agriculture (PGRFA) and the Treaty also call for a more efficient and effective global conservation and use system. This should be based on better planning and more coordination and cooperation, to reduce costs and build conservation and management work on crop diversity on a more scientifically sound and financially sustainable foundation.

[26] See URL: https://cdn.croptrust.org/wp-content/uploads/2017/03/The-Role-of-the-Crop-Trust.pdf

1.2 Global Strategy vision, goal, objectives, outputs and outcomes

1.2.1 Vision and goal

The Global Strategy for the Conservation and Use of Coconut Genetic Resources envisions all coconut farmers, consumers and other associated stakeholders significantly benefiting from a wider diversity of coconut varieties that fulfils their current and future needs. Comprehensively conserved coconut diversity will be readily accessible while respecting countries' and farmers' rights. It envisions substantial improvements to the resilience, livelihoods, food security and wealth status of more than 11 million farmers in developing countries across Asia, the Pacific region, Africa, and Latin America and the Caribbean, and of the many more million people who depend upon coconut for their livelihoods.

The overall goal of the Strategy is to optimize the conservation and facilitate the use of coconut genetic resources, as the foundation of a sustainable coconut economy (from farmers, through research, to consumers) by bringing together national and international players in both public and private sectors.

The Strategy promotes the rationalization of conservation efforts at national, regional and global levels through encouraging partnerships and sharing facilities and tasks.

The Strategy is intended to be used as a roadmap towards building a more efficient and effective global system that focuses mainly on the needs of small-scale coconut producers. The Strategy aims to be an important guiding document for donors, international and national research organizations and the private sector. It will thus facilitate raising support by identifying funding priorities to ensure comprehensively conserved, readily available and optimally used improved coconut genetic diversity worldwide.

1.2.2 Objectives

The SMARTER (Specific, Measurable, Achievable, Realistic, Timebound, Evaluable and Re-evaluable [Yemm 2013]) objectives of the Strategy must be simple, comprehensive and limited in number. Thus the Strategy focuses on seven main objectives:

1. **Strengthen** local, national and international **commitment** to identify, collect, conserve, document and better utilize coconut genetic resources;
2. **Ensure** the sustainable, long-term, efficient and effective **conservation of *ex situ*** coconut genetic resources;
3. Assess the global range of coconut genetic diversity, identify critical gaps in existing *ex situ* collections, **prioritize and build up missions** aiming both to **collect germplasm** and to **secure local conservation**;
4. **Promote**, strengthen and consolidate ***in situ* and on farm conservation of landraces** and dissemination by **local** stakeholders of high quality **planting**

material in a sustainable and equitable manner appropriately integrating gender consideration;

5. **Develop** the policies, mechanisms, skills, knowledge, capacity and other resources required for effective, efficient, safe and easier **international germplasm movements**;
6. Strengthen the use of the coconut genetic resources by **enhancing characterization and evaluation of germplasm**, by dissemination of breeding results as well as **marketing of improved varieties**. This will include exploring the potential use of molecular tools and genomics information for pre-breeding, and establish links between breeding programmes;
7. **Reinforce COGENT** as a sustainable, powerful and effective platform for the **collaborative** conception, coordination and implementation of **priority projects** in the field of coconut genetic resources conservation, improvement and use.

These seven objectives are fully articulated in the third chapter this Strategy. The second chapter aims to provide a global analysis of present status of coconut genetic resources conservation and use. The third chapter focuses on prioritizing the actions and research needed to effectively secure coconut diversity and enhance its use.

1.2.3 Outputs

The expected outputs of the Strategy are the following:

- **Output 1:** the coconut genepool is comprehensively and sustainably conserved *in situ* and *ex situ* for the long term by a global network of partners maintaining the representative diversity of coconut genetic resources;
- **Output 2:** the use of coconut genetic diversity is comprehensively documented, valued and strengthened;
- **Output 3:** an efficient global system for the safe and effective exchange of coconut germplasm is created;
- **Output 4:** the sustainability and effectiveness of global efforts to conserve and use coconut genetic resources is assured.

1.2.4 Expected outcomes

As articulated above, the key outcome of the Strategy will be many coconut farmers, consumers and other stakeholders significantly benefiting from a wider diversity of coconut varieties that responds to their current and future needs. There will be substantial improvements to the resilience, livelihoods, food security and wealth status of millions in developing countries across Asia, the Pacific region, Latin America and the Caribbean, and Africa who produce and depend upon coconut for their livelihoods.

Applying fertilizers in a coconut plantation in Côte d'Ivoire. (R. Bourdeix, CIRAD)

Effectively conserved coconut germplasm will also allow for more effective climate change mitigation in coastal areas, reducing the vulnerability of coconut communities.

Outcomes are associated with changes in behaviour. It is expected that the implementation of a communication strategy will increase commitment to conserve, use and enjoy coconut genetic resources. There will be more effective national and international collaboration in both public and private sectors. This will partly be brought about by reviewing and optimizing partnerships in a more actor-oriented approach, to clearly understand roles and responsibilities of all stakeholders involved in further developing and implementing the Strategy.

The Strategy will guide donors, international and national research organizations and the private sector. It will thus facilitate raising support by identifying funding priorities to ensure comprehensively conserved, readily available and optimally used improved coconut genetic diversity worldwide.

1.2.5 Link with outcomes of CGIAR research programs

The revision and development of this Strategy was funded by CGIAR together with a significant contribution of researchers' time from COGENT member countries and CIRAD staff. CGIAR gathers 15 research centres which are independent, non-profit research organizations. These centres are home to almost 10,000 scientists, researchers, technicians, and staff. Only one CGIAR centre is presently involved in coconut research. Bioversity International hosts the COGENT secretariat, although due to funding cuts, hosting alternatives are being considered.

Since early 2011, CGIAR has been developing and begun implementing 16 global agricultural research programs (CRPs). In January 2017 the CGIAR Centres and their partners began implementing phase 2 of a rationalized CRP portfolio including seven Agri-Food Systems research programs[27]; four cross-cutting Global Integrating Programs[28] and three research support platforms[29].

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[27] i) Fish; ii) Forests, Trees and Agroforestry; iii) Livestock; iv) Maize; v) Rice; vi) Roots, Tubers and Bananas; and vii) Wheat;

[28] i) Agriculture for Nutrition and Health; ii) Climate Change, Agriculture and Food Security; iii) Policies, Institutions, and Markets; and iv) Water, Land and Ecosystems;

[29] i)Platform for Big Data in Agriculture; ii) Excellence in Breeding Platform; iii) Genebank Platform

As one of the retained CRPs, "Forest, Trees and Agroforestry" (FTA) aims to enhance the management and use of forests, agroforestry and tree genetic resources across the landscape, from farms to forests. Coconut research is included in its portfolio[30] and implementing this Strategy should fall within its *Flagship 1: Tree genetic resources to bridge production gaps and promote resilience.* Clearly COGENT would benefit from increased FTA support in implementing its Strategy.

The CGIAR has adopted a strategy and results framework (SRF)[31] which outlines three system-level outcomes (SLOs):

1. reduction in rural poverty;
2. increase in food and nutrition security;
3. more sustainable management of natural resources.

To support achieving these SLOs, a new results-based management (RBM) strategy will be implemented. Each CRP has articulated an impact pathway arising from its research activities via intermediate development outcomes (IDOs) to impact at scale. CGIAR has established several IDOs related to improvements in: productivity; food security; nutrition; income; gender equity and empowerment; capacity to innovate; adaptive capacity; policies ; environment; future options (for ecosystem services); and climate change mitigation. Each CRP has then identified those IDOs relevant to its research. CRP-FTA had identified the following IDOs relevant to its work programme:

1. Policies supporting improved livelihoods and sustainable and equitable resource management adopted;
2. Greater gender equity and women's empowerment in decision-making and control over forest, tree and agroforestry resource use;
3. Enhanced income from goods and services derived from forestry and agroforestry systems;
4. Increased and stable access to nutritious food by rural and urban poor;
5. Production of wood, food, fuel and other products from forestry and agroforestry systems increased;
6. Biodiversity and ecosystem services (including carbon sequestration) from forests, trees and agroforestry resources conserved or improved.

Implementing the Strategy could contribute to all of the above IDOs, although principally 3, 5 and possibly 6.

All coconut research activities are presently conducted under the CRP-FTA, although parts of coconut research conducted by COGENT country-members could be of great interest to other FTA flagships 2-5, operating further along the coconut value chains, and other CRPs/research support platforms, such as:

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[30]See URL: http://foreststreesagroforestry.org/about-us/

[31] See URL: http://www.cgiar.org/our-strategy/

- Managing and Sustaining Crop Collections (the 'Genebanks CRP');
- Excellence in Breeding;
- Water, Land and Ecosystems;
- Climate Change, Agriculture and Food Security.

This Strategy document also describes how links between coconut research, CRP-FTA and the other abovementioned CRPs and research platforms could be strengthened.

This Strategy also aligns with Bioversity International's delivery of scientific evidence, management practices and policy options to use and safeguard agricultural and tree biodiversity to attain sustainable global food and nutrition security. The scope of this Strategy falls within Bioversity's research initiative *Effective genetic resources conservation and use*.

1.3 Process for developing the Global Strategy

This Strategy is the result of a long process of consultations involving more than 100 genetic resource specialists, crop researchers and other coconut stakeholders. The Strategy was developed as a specific output for the CRP-FTA under the coordination of COGENT. The first draft document was progressively built on:

- the former Coconut Global Strategy published in 2008 and the Cocoa Strategy published in 2012 by CacaoNet and Bioversity International;
- the four international surveys targeting COGENT country-members; two of which conducted in 2012 prior to the 16th Steering Committee, the third held from May to August 2013, and the last one held from December 2014 to January 2015;
- the ten international recommendations emitted in 2012 by the COGENT Steering Committee[32];
- the numerous interviews conducted from 2011 to 2013 during visits of the COGENT secretariat to ten countries - namely Brazil, Côte d'Ivoire, Fiji, Italy (donors), Malaysia, India, Indonesia, Papua New Guinea, Samoa and Sri Lanka;
- the participation of the COGENT coordinator to the ACIAR meeting on Coconut Research and Development held in Samoa in November 2012;
- the recommendations arising from the APCC ministerial meeting held in Fiji in January 2013;
- meetings with Bioversity International and CIRAD researchers in March 2012;
- the available scientific documentation.

A new outline for the Strategy was drafted using inputs from the above consultations and the Cocoa Strategy. Based on this proposed outline, coconut scientists and

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[32] Available at the URL: http://www.cogentnetwork.org/53-news/149-10-rec-2012

stakeholders were contacted for technical documentation, advice, and direct contributions to the writing.

This consultation was conducted via:

- the 78 COGENT representatives and alternative representatives ;
- the members of the six COGENT International thematic action groups;
- the APCC and SPC;
- the 950 members of the Coconut Google Group;
- International experts, most of them members of the coconut Google Group.

For each section of the Strategy, three co-author-contributors were identified according to their expertise and their geographical location. Where possible, contributors for each section were chosen from three distinct regions of the world. As shown in Annex 2 and 3, 85 contributors from 38 countries were solicited in this writing process, and many others provided useful advice. Senior researchers were selected from different regions (Pacific, Americas, Asia and Africa) to read and edit one of the three main chapters of the Strategy.

Thus, the whole document was reviewed by a committee of three international experts, two of whom had little or no authorial involvement.

It is expected that the continuous review and updating of this Strategy will take place within the framework of COGENT and that this document will serve as the basis for the direction of the global system on the conservation and use of coconut genetic resources.

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2. Where we are today?

This chapter presents the status of coconut germplasm conservation and use. It first describes what scientists currently know about the genetic diversity of the coconut plant and how it is conserved. The aim of the existing conservation system is to use the genepool to develop breeding programmes and prepare the hybrids of the future. In order to implement such research programmes, COGENT members have already defined a germplasm exchange policy that will be described in this chapter. However, most recently threats have been emerging, further weakening coconut biodiversity's conservation system. The chapter thus also provides an overview of the current worrying situation.

2.1 The genetic diversity of coconut

This section reviews the status of coconut genetic diversity in the light of coconut genepools, domestication and nomenclature.

2.1.1 The coconut genepools

Coconut (*Cocos nucifera* L.) is the sole member of its genus *Cocos*. It belongs to the Cocoseae tribe from the Arecaceae family. Its closest genetic relative is the South-American genus *Syagrus*. No intergeneric hybrids have been reported. It is a pantropical species with a coastal natural habitat and seeds naturally adapted for dispersal water flotation. However, coconut cultivation and spread by human migrations have contributed greatly to its present distribution.

Microsatellite marker studies (Gunn et al. 2011) show the existence of two highly differentiated genepools, named after the oceans where they are found.

The Indo-Atlantic genepool originated in South Asia and consists only of Tall-type coconuts. Its presence in the Seychelles and in the western Indian Ocean can be explained by natural dissemination, although Indian and Arab travellers also may have played a role. The presence of this genepool in countries bordering the Atlantic Ocean dates from the Portuguese expeditions around the African continent. The areas of repartition of the Indo-Atlantic and Asia-Pacific coconuts remain distinct, except for the western Indian Ocean and East Africa where the populations are admixed.

In line with neutral genetic markers, genetic diversity in Tall-type coconut palms can be split into three components, of which:

- about a third is accounted for by the differentiation between the Indo-Atlantic and Pacific genepools, taken as a whole;
- a sixth by the differentiation among cultivars within these two genepools (and excluding the differences due to the genepools themselves);
- half by diversity within cultivars (excluding the differentiation between genepools).

This result shows that genetic diversity of neutral markers is mainly found within cultivars and between genepools (Gunn et al. 2011).

Niu Kafa Tall Tonga (NKF03), typical type from Indo-Atlantic genepool. (R. Bourdeix, CIRAD)

Phenotypic diversity is considerable in terms of fruit morphology, vegetative traits and disease resistance. Most (but not all) of the Pacific group coconuts are of the Niu Vai type, as described by Harries (1978). This type is characterized by round fruits with high water content and a low proportion of husk. In addition, they exhibit early germination and possess erect stems. Likewise, most of the varieties from the Indo-Atlantic group are of the Niu Kafa type as described by Harries, with sensitivity to lethal diseases caused by phytoplasmas, curved stems, and triangular fruits with thick husk, low water content (because the nut – and therefore its vacuole – is small), and slow germination. Correlations between microsatellite data and fruit morphology traits may indicate that at least some of the morphological differences between Indo-Atlantic and Pacific coconuts pre-existed human intervention.

2.1.2 Coconut domestication

The coconut palm is a coastal plant, naturally adapted to high insolation in tropical environments and sandy, saline soils. Protected by a thick husk and capable of retaining viability while floating for long periods in sea water, its fruit is well adapted for long-distance dispersal by oceanic currents. Natural inland propagation is restricted by its low competitive ability for light among rainforest plants, intense intraspecific competition due to its large seed mass, lack of dispersal agents and susceptibility to predation of its fruits and seedlings by mammals. Ethnobotanical and linguistic evidence suggests its domestication began in two different regions in the Pacific and Indian Ocean respectively.

Crop domestication is a co-evolutionary process triggered by a combination of conscious or unconscious selection and modification of the crop environment, resulting in reductions in the plant's capacity for autonomous reproduction and propagation. The particular traits associated with this loss of autonomy constitute the domestication syndrome. Different populations of the same species may present different syndromes and hence different degrees of domestication. In the case of coconut, only the Malayan Dwarf-types appear to be fully domesticated, while the Tall forms are highly variable in their domestication status, between the extremes of the "wild" populations bearing small fruit on some uninhabited atolls and the populations characterized by very large fruit associated with human habitats.

Considering the importance of oceanic dissemination for a strand plant, the coconuts' domestication syndrome has been associated with (1) thickness of the fruit's husk for flotation, seed protection and speed of germination, (2) fruit shape, and (3) the proportion of coconut water in the fruit, affecting flotation. Indeed, angular oblong fruits appear more stable than round fruits when deposited by the sea close to the high-tide line. Fruits with thick husks may have a natural advantage for being carried further, longer and faster on sea currents. As germinating seeds do not remain viable when floating in seawater, greater delayed germination seems a further advantage for long distance travel (Harries 1978). Thus, the coconut's range of natural dispersal has been estimated indirectly through flotation experiments, deducing maximum travel times from duration of retained seed viability, and computing maximal distances travelled from estimates of current velocity.

Bunches of the variety "Micro Laccadives Tall" originating from Laccadives Islands in India, conserved and photographed in Côte d'Ivoire.

A first shortcoming of this speculative approach is the lack of precise data on the main dispersal parameters. Their variation among wild populations is unknown, so the information is mostly based on cultivated materials. While seedling emergence may occur on the tree in some rare cases, germination can take from 1 to 19 months (Zizumbo-Villarreal and Arellano-Morin 1998). Furthermore, there are both advantages and disadvantages arising from slow germination. For example, very slow germination may be related to low vigour or potentially increase the risk of predator consumption of the young seednuts but is a useful trait for transporting nuts over long distances. Also, different properties can be related to different dispersal strategies. The particular properties of differently sized fruits – small versus large – growing on different bunches of the same palm have not been studied (Bourdeix et al. 2005b).

A second inadequacy is the assumption that dispersal is essentially mechanistic, rather than probabilistic, based on common variables for the species. It does not take into account the potential impacts of rare events such as tsunamis or more frequent events like hurricanes on long distance dispersals.

Thus, differentiating wild coconuts from Tall cultivars selected and propagated by humans is complex. A big rounded fruit with a thin husk, selected by seafarers as food and water reserves have been opposed to the supposedly wild type with an oblong angular fruit and small nut. However, large and long thick-husked fruits were also selected by Polynesians and Arabs to produce ropes from the husk fibres (coir). A round fruit may have resulted from long-term selection within seemingly wild populations (Leach et al. 2003).

All Malayan-type Dwarfs descend from the same ancestral population originating from South-east Asia. In spite of a low genetic diversity of neutral markers, they exhibit a high phenotypic polymorphism, resulting in a large number of Dwarf cultivars, which are closely related but can be quite easily distinguished due to discrete differences in colour and fruit shape and a relatively fragile trunk. Malayan Dwarf-types show different combinations of traits that are attractive for humans (short stature, precocity, sometimes sweet water) with traits that favour reliable reproduction of this desirable phenotype (such as colour of the germinating sprout-for orange and yellow forms). Its short stature and short leaves are suitable for the environment where it is usually found (close to human habitations), but make it a poor competitor in the wild, where it would soon disappear owing to its low vigour, low wind tolerance and comparatively short life span.

The origin of this phenotypic diversity of Malayan Dwarf-types is multiple:

- When the self-pollination syndrome was acquired, the ancestors were still heterozygotes and allelic segregation resulted in a number of distinct lines;
- In addition, mutation may have introduced new polymorphism;
- The above factors together with recombination among Dwarf coconuts contributed to the enhanced diversity;
- Dwarf x Tall recombination apparently occurred in Papua New Guinea (Ashburner et al. 2001). This would explain the larger diversity in this region compared to South-east Asia, and the existence of a number of semi-Tall cultivars. This is probably a rare event, because the Dwarf habit depends on several independent traits. Despite the advice of breeders, many farmers plant the progeny of Dwarf x Tall hybrids (from natural pollination or from advanced material) and this could result in new attractive Dwarf phenotypes being selected.

Domestication in Malayan Dwarf-types appears to be a rather recent event. The rate of meiotic abnormalities (during sexual cell division) in Malayan Dwarf-types is intermediate between that in cross-pollinated Tall-types and self-pollinated Semi-Tall types (Swaminathan and Nambiar 1961). This suggests that elimination of genetic load through selfing is still under way. Comparisons of the abnormality rates among allogamous and autogamous Tall and Dwarf coconuts could provide us with a means of evaluating the number of generations since acquisition of autogamy.

Other coconut populations might also be described as domesticated: in particular, the group of other short-statured coconut types called “Compact Dwarfs”. The first description of this type was the previously-mentioned variety “Niu Leka” in Fiji: a genetically dominant phenotype, cross-pollinating and similar to a Tall coconut except for the very short internodes, often short frond petioles and short fronds overall. Recent surveys conducted in Fiji and French Polynesia indicate that many “Compact Dwarf” cultivars are yet to be described and collected, some of them probably being advanced progenies of crosses between Malayan-Dwarf types and other Compact Dwarfs.

Domestication events can create population bottlenecks and cause a reduction in coconut genetic diversity, as “selective sweeps” of favourable alleles may occur. For both Dwarf-types, the genetic determinants of dwarfism are not yet fully understood. They appear to depend on several genetic factors. Understanding the genes underlying the phenotypic and structural changes as a result of past domestication is important for the future of coconut breeding and improvement.

2.1.3 International coconut nomenclature

Standardization of coconut cultivar names has been undertaken for decades. During the first COGENT meeting held in Montpellier, France in May 1992, representatives from national collections tried to clarify the status of existing collections and outlined what would become the Coconut Genetic Resources Database (CGRD).

Coconut nomenclature has been quite specific since 1992, when researchers were asked to systematically provide an international name to any accessions they collect. It is unclear why and by whom this requirement was established, although COGENT believes that this nomenclature rule has strongly influenced users' representations of coconut diversity and the conservation of coconut germplasm at the global level.

The guidelines "Useful definitions of terms and nomenclature" has been released as an annex in the book "Coconut genetic resources"[33] published in 2005 by Bioversity and available on the COGENT website. These guidelines were also more recently published in the "Catalogue of conserved germplasm"[34], together with an extensive list of international names of coconut cultivars.

The researchers in charge of the national coconut genetic resources programme are responsible for giving international names to the germplasm from their country. However, they are prompted to follow these specific guidelines in order to achieve international standardization.

Accessions are generally named just after the accession has been planted in the *ex situ* genebank. These names start to become "international" only when the passport data of the collected germplasm has been transmitted to the CGRD, serving *de facto* as an international reference. The COGENT secretariat, which has been acting as CGRD manager, has made sure that the new names meet the nomenclature rules and, if necessary interacts with national researchers to adjust the proposed name accordingly. For instance, a new international name must not duplicate any previously recorded name (including synonyms and abbreviations).

Once the first version of the CGRD was released, twenty COGENT member-countries were visited by CIRAD experts. National researchers were trained in generating and inputting data into the database. These visits offered many opportunities to interact with national researchers about the names of coconut germplasm.

Presently, the only names which have an international status are those of accessions that are conserved in *ex situ* genebanks and recorded in the CGRD. Lists of these names are released on the COGENT website as a FAQ (frequently asked question)[35]. Beyond that housed in the *ex situ* genebanks, coconut germplasm does not have registered international names.

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[33]See URL: http://www.cogentnetwork.org/images/publications/Coconut_genetic_resources.pdf

[34] See URL : http://www.cogentnetwork.org/conserved-germplasm-catalogue

[35] Which Coconut germplasm is presently conserved by COGENT country members?
See URL: http://www.cogentnetwork.org/faq/139-exsitu

In 1991, Dr Hugh Harries (1991) tried to develop a "Coconut Registration Authority", but this proposal was not further developed. A more complete list of coconut cultivars does exist and is based on this early initiative[36] and the subsequent work of some CIRAD researchers. This list has not yet been officially published or released, due to lack of time availability of the researchers involved in its maintenance, and lack of known formal procedures to ratify an official registration.

Each accession planted in a COGENT *ex situ* genebank has to be registered under at least a cultivar name and an abbreviation. National researchers were advised not to create a new cultivar name for each and every sample they collected in farmers' fields. For that purpose, the notion of population within a cultivar was introduced in the nomenclature as follows: "Populations could denote minor geographical and/or phenotypic differentiation within a cultivar". This helped limit the unwanted proliferation of cultivar names which could lead to unnecessary and costly conservation of the same germplasm accessions under different cultivar names.

Pool of coconut fruits collected from the same cultivar

There still remain differences between countries regarding the way they are naming the accessions. For instance, researchers in Bangladesh, Pakistan and Sri Lanka recently named many accessions as populations of already existing cultivars, whereas Indonesian researchers continue to give many new cultivar names to the accessions they collect. As for other crops, also a coconut cultivar should have characteristics that distinguish it from any other known cultivar. In reality, within a large network of 39 countries, this principle is sometimes difficult to meet and check. The standardized characterization and evaluation data existing in the CGRD help to compare accessions and cultivars conserved in different countries.

Using international names in scientific publications is highly recommended. Whilst there may be good reasons to use another name, it is good practice to include a list establishing links between the alternative names and the international names.

2.2 Methodologies for conserving coconut genetic resources

For many crop plants, germplasm can be stored as dried seeds and at low temperatures. Coconut seeds are recalcitrant: they germinate naturally using the free water available inside the coconut and germination can be prevented if the germ-pore cover remains dry due to dryness in the adjacent fibres of the husk (M. Foale, personal communication). Seednuts cannot normally survive the drying process, nor can they be stored below 8°C. Therefore, coconut germplasm can be maintained *in vivo* as living

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[36] COGENT and CIRAD take this opportunity to thank Dr Hugh Harries for having transmitted his huge compilation work of coconut cultivar names.

trees in field genebanks, in farmers' fields and gardens, and in some protected areas such as natural reserves and public places. Other technologies like *in vitro* plantlets or cryopreserved embryos, pollen or tissue could be used but are not yet available and need further refinement.

Emerging powerful new technologies such as molecular genetics, genomics, proteomics and eco-geographical remote-sensing techniques are greatly expanding the methodologies supporting the conservation, management and utilization of genetic resources. Advances in informatics and communication technologies have also markedly increased our capacity to use, analyse and communicate relevant data and information, but are not yet in use in the coconut genebanks.

2.2.1 *Ex situ* conservation methods

Ex situ conservation plays a crucial role in preserving many varieties, particularly those that are disappearing from farmers' fields. It forms an essential buffer between users and the fast evolving *in situ* genetic diversity in nature and farms.

Effective conservation and management of coconut genetic resources includes the following routine activities: targeted collecting actions; establishing and maintaining field collections; regenerating old accessions using controlled hand-pollination; effective characterization and identity verification studies; evaluation for important priority traits; information management; safe exchange of germplasm; and sometimes germplasm pre-breeding. Most of these methods have been described in the numerous books available on the COGENT website[37].

Presently, *ex situ* coconut conservation relies solely on the 24 field genebanks as described in Chapter 1, table 1.1. Conservation in the form of field collections has the advantage that the growing material can readily provide seednuts or pollen. The material remains available for distribution, characterization, evaluation, as well as training and demonstration. The field collections however, are highly vulnerable to pests and diseases, to other natural disasters such as floods, typhoons hurricanes and fires, and to land pressure.

The "Stantech Manual" was published in 1996 (Santos et al. 1996) after an extensive consultation involving researchers from COGENT and International institutions. It provides agreed standardized research techniques in coconut breeding and conservation. In coconut *ex situ* genebanks, the recommended sample size for an accession ranges from 72 to 96 palms for a heterogeneous allogamous Tall population. A lower sample size of 45 palms could be used for autogamous homogeneous dwarfs. These minimum numbers per accession were calculated to represent accurately the genetic diversity of the populations and to allow both consistent characterization and workable regeneration (Ramanatha 2005).

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[37] Available from the URL: http://www.cogentnetwork.org/manuals-and-handbooks

The use of standardized descriptors contributes to the development of consistent databases and increases the uniformity of documentation and the ability to work with other partners. It also enables greater efficiency in collection management by helping to identify and reduce duplication (Gotor et al. 2008). The last publication of the full list of the international coconut descriptors dates back to 1996 in the Stantech Manual. According to Laliberté et al. (1999) on average, each set of descriptors should be revised approximately every ten years. Some coconut researchers and curators believe that present standard descriptors for coconut do not allow comprehensively identifying most of the allogamous tall coconut cultivars. There are still no coconut descriptors for roots, inflorescence or pollen morphology, the upper part of the fruit, the three eyes of the nut, and the top of the canopy.

Diversity of coconut faces.

In 2007, a list of 17 minimum descriptors was extracted by COGENT from the previous document. This strategic set of descriptors, together with passport data, is the basis for the global accession-level information system being developed at international level (Yao et al. 2015).

About pollination

Making controlled hand-pollination (CHP) is costly, time-consuming and complex. The visits conducted in many countries by the COGENT Secretariat highlighted that existing written guidelines are not sufficient for a research centre to develop *de novo* the laboratories and skills needed for making CHPs. For the rejuvenation of a Tall-type accession, the CHPs are implemented over a four-month period; the mature seednuts are harvested one year later, also over four months; then the old accession is removed from the field and replaced by a new one. For regenerating an accession, or for creating a new hybrid between two accessions, researchers often use a minimum of 48 female parents crossed with 24 male parents. Each female parent is pollinated three times with pollen from three distinct male parents. A CHP gives only 1 to 2 seedlings, so this will allow the production of about 200 seednuts within a 4-month period. Production of the seednuts needed for the duplication of an accession will demand one and half years' preparation; and will cost more than US$2000. Only scientists with healthy research budgets can afford ordering varieties from coconut genebanks.


Emasculation is one of the steps of controlled hand pollination.
(R. Bourdeix, CIRAD)

It has long been recognized that sexual reproduction (in absence of vegetative propagation) in an allogamous species variety requires isolation to exclude other varieties. For regeneration of allogamous Tall-types, controlled hand-pollination with inflorescence-bagging is strongly recommended. Regenerating autogamous Dwarf-type is much easier: the stem is shorter and seeds can be produced by open pollination if the variety is sufficiently isolated, or with a simple bagging to isolate the whole inflorescence and ensure selfing.

The Stantech manual gives a detailed description of the controlled hand-pollination process. In 2008, the same subject was developed in a shorter version as a part of the regeneration guidelines for coconut (Konan et al. 2008).

A major constraint that the curators face is the accessibility of the inflorescence for safe and effective hand-pollination[38]. Until recently, the crucial techniques of climbing the palm crown were not discussed in COGENT documents. In 2013, a compilation of 23 videos on palm-climbing was released on the website[39].

'Friends of coconuts'

Coconut palm climbing mechanical device in India. (A. Prades, CIRAD)

One of the major problems experienced in the coconut sector of India particularly in the major producing states like Kerala is the critical shortage of palm climbers. The number of traditional palm climbers is consistently in decline due to the disinterest of the younger generation for this traditional profession. Consequently, the farmers experience difficulty in arranging timely harvesting and also plant protection. To overcome this problem, the Coconut Development Board initiated a novel scheme to provide intensive one-week training courses in palm climbing using a mechanical device, in nursery management and in the control measures for common pests and diseases to groups of educated but unemployed rural youth.

This scheme named 'Friends of Coconut' has already trained hundreds of young men and women, whose services are now available to the farmers for harvesting and plant protection.

Although palms can survive for more than 100 years, the average useful lifespan of coconut accessions in most of *ex situ* genebanks is only 25 to 30 years. For instance, for climbing the palms in Côte d'Ivoire, workers of the international coconut genebank[40]

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[38] Several climbing devices exist to reach the top of the stem and harvest the fruits but, for hand pollination, it is necessary to reach young inflorescences in the centre of the crown.

[39] Available at the URL: http://www.cogentnetwork.org/videos/climbing-the-coconut-palm

[40] International Coconut Collection for Africa and the Indian Ocean, located at the Marc Delorme Research Centre, National Centre for Agronomic Research (CNRA) in Côte d'Ivoire.

use large triple aluminium ladders which can reach a maximum height of 14 meters. Thus, palms must be regenerated within 25 to 30 years, before their stems extend beyond 14 meters. If taller, it will be impossible to conduct controlled hand-pollinations, unless new techniques are developed. A better, safer technique could enable casualty-free regeneration to be conducted only every 60 years.

DNA studies show that about 50% of total coconut genetic variation is presently found within heterozygous Tall-type cultivars. Whether the germplasm is transferred (or regenerated) by seednuts, by *in vitro* culture of zygotic embryos, or by any other means, the traceability of the planting material genealogy is crucial for three main reasons and thus, needs to be properly recorded. Such traceability allows:

- Curators to know the numbers of female and male parents used at each generation and to control the genetic drift;
- Checking the reliability of progenies by using DNA markers;
- Conducting genetic studies and comparing the progenies of different parents from the same variety. For instance, within a cultivar, the progeny of a given palm can be tolerant to a particular disease while the progenies of the other palms will die.

For each coconut palm conserved in a genebank, at least its mother palm needs to be known. Presently, less than 20% of accessions conserved at global level meet this requirement[41].

In vitro collections are not yet used for safety duplication of the field collections or for rapid multiplication and dissemination of disease-free planting material. A benefit of the approach is that it can act as a barrier to the transmission of many diseases. A drawback of *in vitro* conservation is that the material demands regular sub-culturing and might be subject to somaclonal variation. Therefore, rejuvenation and verification of the trueness-to-type of the conserved germplasm will have to be performed periodically. Another major drawback is that today, very few of the coconut *ex situ* genebanks are equipped to use this technique or have appropriately skilled staff..

Cryopreservation offers a complementary means to enhance the security of germplasm collections (Nguyen et al. 2015). Storage of frozen pollen samples may offer an additional way to conserve coconut, though the parent's genetic identity would not be maintained as a whole. Frozen pollen is already used in some of genebanks, such as in India.

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[41] Two different cases exist:

- Open-pollinated seednuts collected from farmers' fields: In this case, for allogamous varieties such as Tall-type coconuts, the father palm is unknown. A unique number must be allocated to each mother palm harvested in farmers' fields. Ideally maps of farmers' and genebanks' fields are documented, using a geographical system and/or satellite image. The unique number given to each harvested palm features on both types of map.

- Seednuts or embryos harvested in ex situ genebanks. In most of the cases, for allogamous varieties such as Tall-type coconut palms, both female parents and male parents are located in the genebank. The seednuts are obtained by controlled pollination. In this case, the female parent number and the male parent number must be kept carefully even after the progeny palms have been planted.

2.2.2 Conservation *in situ*, on-farm and beyond *ex situ* collections

In situ and on-farm conservation of coconut germplasm refers to the maintenance of coconut genetic diversity in its natural habitat or through the continued cultivation of landraces or traditional varieties in the agro-ecosystems where they have evolved. Therefore, it involves the protection of the areas, ecosystems and habitats in which the plants have developed their distinctive characteristics. This way of conserving genetic resources should be facilitated through legislative and policy measures as well as through the use of incentives.

The great advantage of *in situ* conservation is that it maintains the evolutionary processes of the species and its traditional varieties in a dynamic way. Its main drawback is its vulnerability to social and economic changes. Many factors contribute to the erosion of *in situ* genetic diversity: drastic changes in land use; adoption by farmers of high yielding varieties; lethal diseases; rural drift; development of urban areas, and anthropogenic or natural disasters.

Data from many countries shows that a great diversity of coconut is kept on farms, and that coconut farmers often prefer to plant their traditional Tall varieties instead of the recommended new ones. Genetic and agronomic criteria are insufficient to explain the distinction made by farmers between coconut varieties. From an anthropological perspective, varietal assessment is not a free or isolated process. Farmer evaluations are often based on their traditional varieties, which are already known and used as reference. This comparison has less to do with the biological characteristics of the plant than with its qualities as a cultural entity within a human community (Bourdeix et al. 2008).

Sustainable *in situ* conservation requires community participation, control of land rights in local communities, systematic documentation of farmers' knowledge of coconut diversity, a gendered approach, education, extension and development of environmental awareness. Of equal importance is the principle that any *in situ* conservation programme must also benefit local communities and promote gender equity. In coconut growing areas, evidence shows that the level of conservation of existing stands strongly correlates with the extent of profitable coconut-based farming systems/enterprises on farm (Sangalang 2004). This suggests that such coconut-based enterprises are critical to successful on-farm/*in situ* conservation of coconut genetic resources. Management by local communities can often develop effective links to national efforts concerning documentation, conservation and use. This attracts commercial and private agencies to be partners in on-farm conservation efforts and can lead to linkages between public, community and private sectors in plant genetic resources conservation.

Through the support of the Department for International Development (DFID), UK, the Asian Development Bank (ADB) and the International Fund for Agricultural Development (IFAD), a COGENT project testing *in situ* conservation strategies was implemented in 35 communities of 15 coconut-producing countries[42]. Working in poor coconut growing communities, this project assessed the technical feasibility, financial viability, social acceptability and environmental safety of coconut-based technologies and production systems, namely: (1) producing and marketing high-value products from all parts of the coconut – kernel, husk, shell, wood, water, leaves; (2) intercropping cash and food security crops/integrating livestock; and (3) propagating important local and introduced high-value coconut varieties in community-managed nurseries and conserving them *in situ* and on farm.

This project had a consistent impact on poverty alleviation in the targeted communities and on *ex situ* coconut conservation. Eighty-nine (89) farmers' coconut varieties were identified and a total of over 62,000 seedlings from these varieties were planted on community farms. Results of this project also outlined issues for optimizing the *in situ* conservation approach:

- The project was conducted in too many communities and countries with regards to the limited funds available. Not enough research time was devoted to specific genetic resources aspects, and especially the characterization of traditional varieties.
- From a communications and awareness perspective, farmers' involvement in conservation of genetic resources was insufficiently promoted, valued and secured for the long term. The publication of a "Catalogue of farmer's varieties", although initially planned, was cancelled. This was due to a lack of reliable data; the poor web visibility of these communities and supplies of their coconut products not being sufficiently assured for promoting community involvement, helping them to market their products, and serve as example and success story.
- In some communities, palms from traditional varieties chosen by farmers as seednut providers were located at less than 20 meters from Dwarf x Tall coconut hybrids. The cross/open pollinating habit of these Tall-types has certainly led to unwanted varietal mixing.

The results contributed to the formulation of an international recommendation[43] during the 2012 COGENT SC meeting. This recommendation invites researchers to develop alternative concepts of conservation.

2.2.3 Revisiting the classical delineation between *in situ* and *ex situ* conservation

Many different locations could integrate the conservation of coconut genetic resources and even seed production by using a multifunctional land management policy.

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[42] Bangladesh, India, Sri Lanka, China, Indonesia, Malaysia, the Philippines, Thailand, Vietnam, Fiji, Papua New Guinea, Ghana, Tanzania, Mexico and Jamaica. Report available at: http://www.cogentnetwork.org/images/publications/PRCGC_Vol1.pdf

[43] Assessment and improvement of farmers' technical and traditional knowledge regarding coconut biology, in order to increase farmers' autonomy for production of good planting material. Available at the URL: http://www.cogentnetwork.org/images/2012_sc_meeting/cogent_recommendation_3.pdf

The *Polymotu* concept (*poly*=many, *motu*=island), a concept derived from previous initiatives in conservation by ancient Polynesians, uses the geographical isolation of dedicated sites or designs for conservation and reproduction of individual varieties of plants, trees and even animals.

For instance, when a small isolated island is planted with a single Tall-type variety certified for its true-to-type integrity, breeding occurs only within this variety and "naturally certified" seednuts are produced. In this case, both the geographical isolation and the availability of certified seednuts secure conservation. Various kinds of inland sites can also be used for this purpose as long as they are protected from pollen contamination. More than one variety per crop species can be conserved in each location, if genetic markers are available to differentiate progenies at the nursery stage (Figure 2.1).

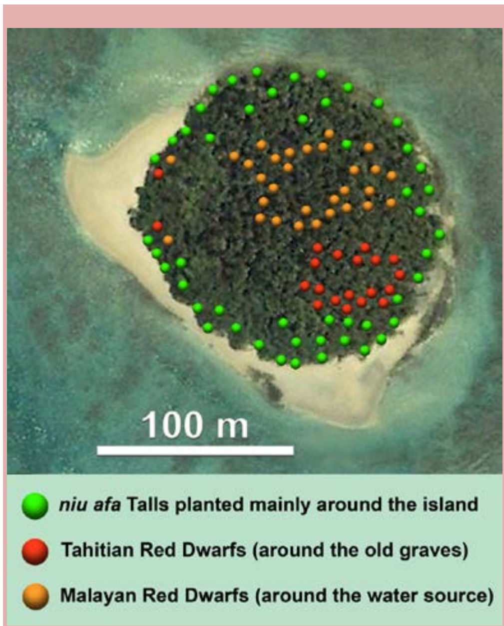


Figure 2.1. Schematic representation of the plantation of Nuusafe'e Island in Samoa using the Polymotu concept. (R. Bourdeix 2012)

The *Polymotu* conservation concept fits into a multifunctional land management policy. Many different locations can be used for conservation of genetic resources and even seed production so long as they meet the criteria required for biological and reproductive isolation. These dedicated sites can be small islands owned by communities or private individuals, public gardens, university campuses, golf courses, the backyards of resorts or research centres, or the bottom of small valleys. Even an entire small village may become an established place for conserving genetic resources and seed production, if all villagers agree to cultivate only a well-defined set of cultivars or populations. This kind of multifunctional land management strengthens the links between people, landscape and bio-diversity. It gives a special cachet to the sites, generates income and may enable related activities such as eco-tourism.

Using the *Polymotu* concept, some of the most important constraints encountered in *ex situ* collections are shifted. There would be no need for palm climbing and any accession's lifetime would be extended. Instead of climbing the palms for making controlled hand-pollination, people only have to wait for the fruits to fall naturally to the ground. Open-pollination provides true-to-type and cheap seednuts. Thus, the same accession can be kept as long as a sufficient number of palms remain alive in the field. In most cases, the duration of a coconut accession would then be extended from 25 – 30 years (current useful lifespan in *ex situ* collections) to 75 - 100 years. Even if some of the palms die, there is no need to remove the remainder, as is done presently in classical genebanks. Dead palms can be replaced by new ones, without removing the old palms still alive. Such lifespan extension represents a huge saving of resources.

Three possible applications of the *Polymotu* concept are currently being studied: "Ecotourism on Islands" (French Polynesia, Samoa), Inland (to be applied in Côte d'Ivoire) and "Urban" in Fiji and possibly in Brazil.

Case study 1: the *Polymotu* approach versus "ecotourism on islands"

Projects testing the *Polymotu* approach versus "ecotourism on islands" were recently implemented in Samoa and, to a lesser extent, in French Polynesia. In Samoa, a project funded by the Trust and leaded by SPC was implemented with collaboration of CIRAD and the COGENT Secretariat. Six small islands surrounding Upolu were surveyed, and two of them, namely Namu'a and Nuusafe'e were planted in 2012 with 50 seedlings of Niu afa, 20 seedlings of Malayan Red Dwarf (MRD) and 10 seedlings of Tahitian Red Dwarf (TRD). The aim of planting three coconut varieties is to produce both pure breeds of Niu afa, dwarf seedlings and natural hybrids between Dwarfs and Niu afa. As shown in Figure 2.2, the size of the fruits and the colour of coconut sprouts allows visually differentiating between pure strains of Niu afa (green sprouts), the Dwarfs (orange) and new hybrids produced (brown).

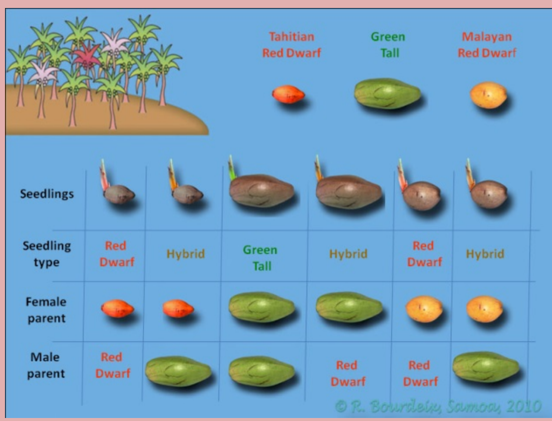


Figure 2.2. The three varieties planted in Nuusafe'e and Namu'a Islands, Samoa: Tahiti Red Dwarf, Niu Kafa Tall, Malayan Red Dwarf, and the way to identify progenies in the nursery by using the shapes of the fruit and the colors of the germinating sprouts. (Bourdeix et al. 2005b, 2014)

Thirty other tropical fruit trees (including rambutan, avocado, soursop, and mandarin) were also planted in each island. In French Polynesia, a *motu* from the Tetiaroa Atoll is little by little replanted with progenies of a few rare palms producing "horned coconut".

Case study 2: the *Polymotu* approach versus "inland"

A project testing the *Polymotu* approach versus "inland" has been launched in Africa. In Côte d'Ivoire, the Marc Delorme Research Centre houses the International Coconut Genebank for Africa and Indian Ocean. The collection is currently threatened by a Lethal Yellowing Disease (LYD) which is now at less than 150 km from the centre, on both sides of the coast (in Ghana and in Grand Lahou region). It is also threatened by intense land pressure due to the expansion of Abidjan (the capital city) and by a chronic budget deficit that could ultimately jeopardize the existence of the genebank. In order to address the two first constraints, the COGENT secretariat encouraged CNRA to duplicate about 50 coconut accessions on 5 of the 13 other experimental sites belonging to the institute and scattered across the country. Each accession of Tall varieties will be planted in geographical and reproductive isolation, in the middle of other tree crop plantations (Rubber, oil-palm, forest trees, coffee and cocoa). CNRA is presently slowly implementing this project with limited funding.

Plate 2.1.

Tall-type coconut varieties from the Pacific region

Coconut is much more than coconut!

1 & 2. One of the most famous coconut palms in the Pacific region, called "Seven in one" in Rarotonga, Cook Islands. The seven palms were grown from a single coconut planted in 1907. The second picture dates when the palms were young, probably around 1918.

3. Tall-type coconut varieties include palms with the thicker stems, here in a garden of Rarotonga, Cook Islands.

4. The famous "niu afa" in Samoa, Internationally known as Niu Kafa Tall, has the longest coconuts of any variety.

5. Harvesting a variety called "lady coconut" in Tuvalu. During weddings, when the guests are too numerous, and large fruits not available for all, such small elongated coconuts are distributed for drinking.

6 & 7. Vanuatu Tall and Rennell Island Tall

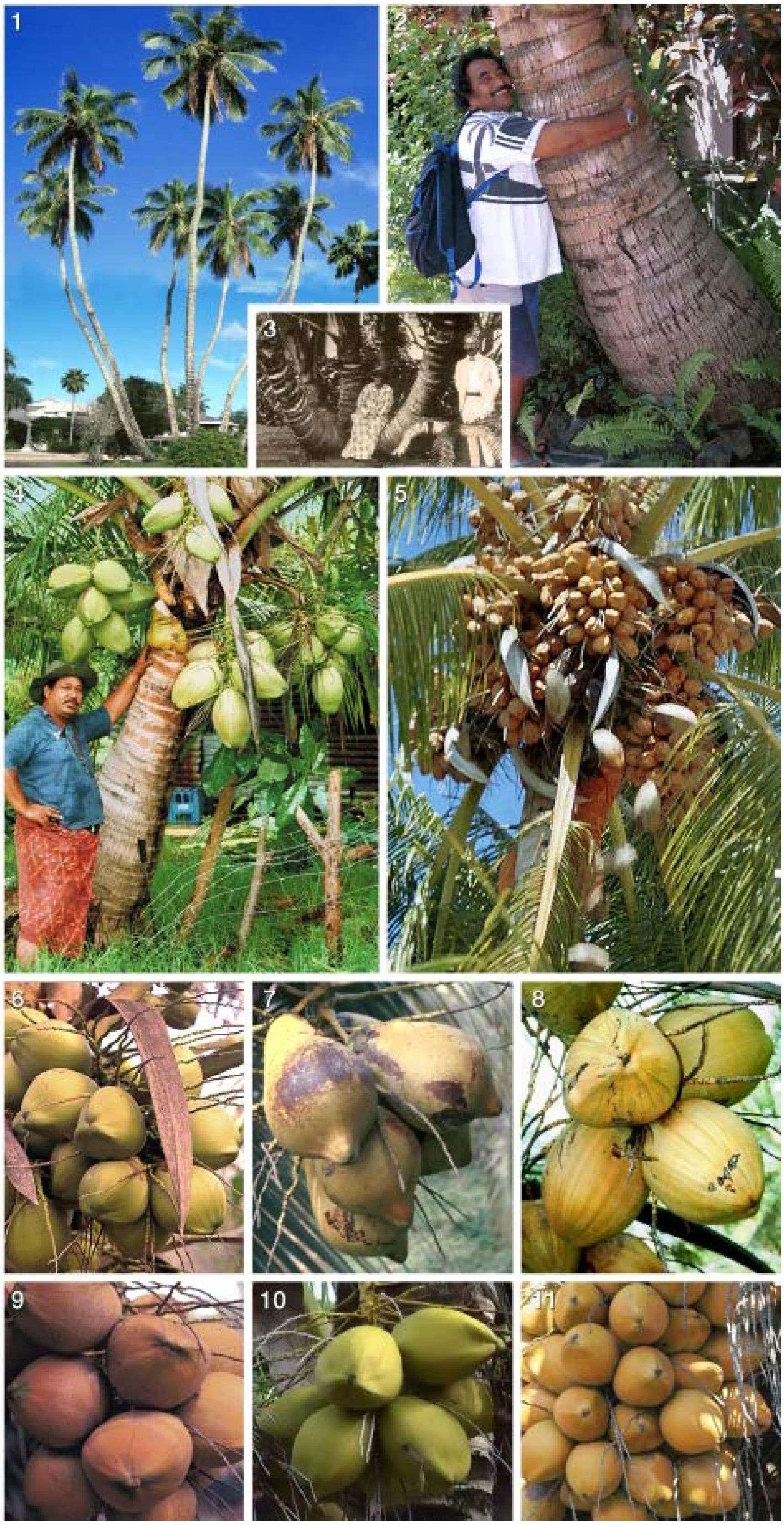
8. A rare Tongan Tall with striped fruits.

9. Karkar Tall from Papua New Guinea.

10. A variety from Tubuai Island, French Polynesia, with elongated fruits and very long bunch peduncles.

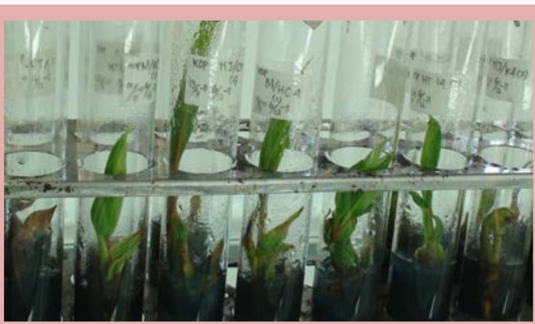
11. The variety "makire" with numerous small round fruits in Tahiti, French Polynesia.

R. Bourdeix and A. de la Presa



2.2.4 *In vitro* culture and cryopreservation

Currently, coconut-planting material is mainly distributed to farmers by using seednuts and seedlings. International exchanges of germplasm were tested via transfers of coconut embryos cultivated *in vitro* and are more often by seednuts (but their use is often restricted because of inherent phytosanitary risks).



Coconut cultivated *in vitro* from excised zygotic embryos. (V. Johnson, Bioversity International)

In vitro culture is being assessed by researchers as an alternative means for producing coconut clones as planting material for farmers, for securing germplasm and increasing its collecting and exchanges using excised embryo transfer, and for long-term conservation using cryopreservation of embryos, their plumules, or calluses. This section provides an overview of the research status for each of these objectives.

Ageing palms, declining productivity and emerging virulent diseases (such as those caused by phytoplasmas), prompt a growing demand for selected planting materials with high productivity and robust disease resistance. Such demand is hard to meet when palms individually produce few seednuts.

Coconut is one of the most recalcitrant plant species to regenerate *in vitro*. Numerous explant sources have been tested for micropropagation (or *in vitro* vegetative propagation) purposes including: leaves, immature inflorescences, embryo plumules, and unfertilized ovaries isolated from immature female flowers. Embryo plumules have initially provided the most reproducible somatic embryogenesis, although efficiency has initially been low (four to ten somatic embryos per plumule). In order to increase the multiplication rate, two different approaches have been evaluated: secondary somatic embryogenesis and multiplication of embryogenic calluses. Using the latter process, tens of thousands of somatic embryos can now be obtained from a single plumule, with a plantlet conversion-rate higher than twenty percent.

A similar process is being developed using explants from immature inflorescences, with very promising results. Anthers excised from male flowers of an adult palm have also been cultivated *in vitro* to produce plants via androgenesis (Perera 2010), which is the development of embryos containing only paternal chromosomes. Normal plants with a single shoot were observed in low frequencies while weak plantlets with multiple shoots were observed in abundance. Under similar culture conditions, some plantlets showed vigorous growth whereas the majority had a slow growth rate. Androgenesis will be useful to breeders for rapidly obtaining homozygous genotypes, for instance helping to select Dwarf genotypes within recombinant progenies between Dwarf and Tall-types.

Some micro-propagated coconut palms have been established successfully in the field with a true-to-type behaviour when compared with palms obtained from seednuts. Experience with oil palm suggests that an effective protocol for scaling-up such a technique from the laboratories to the full-scale development stage is yet to be developed. Breeding methods will also need to be specifically adapted to identify and select the best clones. This technique has not yet been applied on a large scale for producing planting material for farmers.

Methods for *in vitro* culture of coconut embryos started to be developed in 1950s (Cutter and Wilson 1954). Producing plantlets from mature embryos has been successfully achieved rather quickly. It has been more difficult to obtain plantlets with a balanced development of roots and aerial parts. In the laboratories, the best recovery rates (from tube to palms in the field) of embryos cultivated *in vitro* are about 50%. In traditional nurseries, only 65% of seednuts give rise to palms planted in field[44]. The main challenge is to obtain replicable results in a wide range of situations.

Coconut embryo extraction. (V. Johnson, Bioversity International)

As reported in the CGRD[45], among the 408 accessions transferred from one country to another, 68 accessions (17%) were transferred as embryos cultivated *in vitro*[46]. The CGRD allows comparing the average number of living palms for the 196 accessions planted in or before 1981, which were transferred from one country to another by using embryos versus using seednuts. These average numbers of palms per accession are 45 for accessions transferred via seednuts and 26 for accessions transferred via embryos[47].This last number is likely overestimated, because those attempts to import coconut embryos which completely failed have not been recorded in the CGRD. So the practical application of embryo culture to international germplasm transfers needs further review and refinement, because it generated a decrease of at least 42% in the accessions' sizes.

Funded by the Trust, a project was conducted from 2009 to 2012 to optimize, validate and apply a standard embryo culture protocol[48]. This project refined existing techniques and applied them to a range of genotypes and conditions, which then led to the publication of improved guidelines (Cueto et al. 2012) available on COGENT

[44] Some seednuts do not germinate; some seedlings are discarded at the nursery stage because of low growth or abnormalities.

[45] CGRD does not take into account germplasm transfers conducted during the recent embryo project funded by the Trust (it is necessary for the accessions to be planted in the field), and the material recently taken by Mexico and Brazil from Côte d'Ivoire (no data transmitted by countries to CGRD).

[46] The first accession transferred via embryo was planted in 1981 in Malaysia. Then Thailand (1991), India (1997) and Sri Lanka (2005) succeeded in introducing accessions using embryo transfer.

[47] Efficient sizes as defined in section 2.2.1 i.e. not null, limited to 45 palms for Dwarfs and 96 palms for other varieties. If real accession sizes are considered, average accession sizes are 152 for accessions transferred via seednuts and 32 for accessions transferred via embryos.

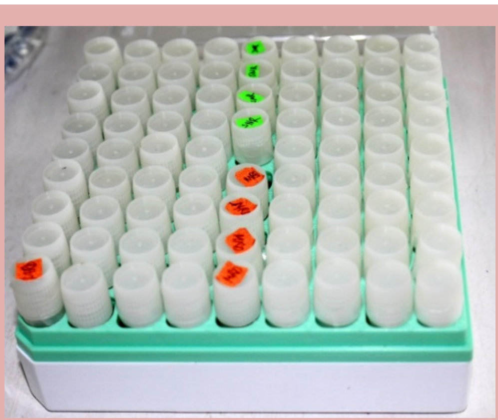
[48] See URL: http://www.cogentnetwork.org/past-projects/validation-of-a-coconut-embryo-culture-protocol

website. However, successful transfer will only be achieved if those involved have the necessary skills and resources to adhere to protocols such as this.

To ensure long-term conservation, accessions conserved *in vitro* can also be 'cryo-preserved'. Cryopreservation stops both the growth of plant cells and all processes of biological deterioration, so that the material can be preserved for an extended period (probably several hundreds of years) and regenerated into fully viable plants. The cost of cryopreserving accessions is expected to pay off against the recurrent costs of *in vitro* or in field maintenance over a number of years, at the exception of the material which needs to be regularly distributed.

Since 1992 (Assy-Bah and Engelman 1992), cryopreservation protocols for **zygotic embryos** have been developed and refined. A protocol based on dehydration of the embryos was recently applied to 10 accessions representative of coconut genetic diversity, with germination percentages of cryopreserved embryos between 13.7% and 74.7% (N´Nan et al. 2012). Research is pursued notably at least in Australia (Nguyen et al. 2015), Brazil, Colombia, France, India (Bhavyashree et al. 2016), Indonesia, South Korea and Mexico, with publications associating authors from more than one country (Sisunandar et al. 2010a, Sisunandar et al. 2012). Cryopreservation of coconut zygotic embryos does not induce morphological, cytological or molecular changes in recovered seedlings (Sisunandar et al. 2010b), thus suggesting that the method is appropriate to efficiently preserve coconut germplasm.

Cryopreservation of **plumules** from zygotic embryos and subsequent production of **somatic embryos** has also been developed[49]. Researchers are now working to optimize the techniques and to evolve from validated laboratory protocols to standardized methods giving regular and consistent results at a large scale and in a wide range of situations. Cryopreservation of the **embryogenic callus** obtained from plumules has likewise been studied. If successful this technique could allow conserving a piece of tissue with the potential to regenerate thousands of plants from it.


Storage of coconut embryos in cryotubes (PCA-ZRC)

Pollen, which can be easily obtained in large quantities, can also be cryopreserved. Exchange of germplasm through pollen poses fewer quarantine problems than is the case for seednuts or other propagules. Little additional research is required to further develop and refine this technique which is still not used by *ex situ* coconut collections. If a standard dose of desiccated pollen, such as that prepared in a glass tube for controlled hand-pollination, is kept for one hour in liquid nitrogen and then extracted, the pollen will germinate normally (R. Bourdeix personal communication). Most of the pollen used by genebanks is conserved at -18°C for only four to six months.

[49] http://www.cogentnetwork.org/network-projects/ongoing-projects/korean-cryopreservation-project

Using cryopreservation techniques based on embryos, plumules or pollen carries certain constraints. It does not allow reproducing and thus multiplying a genotype, but only the progeny of this genotype. Thus, some of the limitations linked to the reproduction mode of the coconut palm still apply, such as the requirement of costly controlled hand-pollinations to duplicate a Tall-type variety conserved in an *ex situ* collection. For most allogamous Tall-type varieties conserved *ex situ*, embryos will have to be obtained by controlled pollination with bagging.

Therefore, the main constraint to the development of a cryogenebank from *ex situ* field collections remains again the cost of controlled pollinations. However, in some cases, instead of using the palms conserved in *ex situ* collections, it will be possible to access the original source of particular genotypes in farmer's fields. But going back to these sites will also have a significant cost.

2.3 The current global *ex situ* conservation system

Currently, coconut germplasm is only conserved as accessions in one or more *ex situ* collections. Twenty-four of these field genebanks are located in 23 COGENT member-countries. Unique and valuable material is kept in these genebanks. They conserve local traditional varieties, introductions from other collections, and accessions collected directly abroad by institutions from Côte d'Ivoire, France, India and Jamaica.

Information regarding the content of these collections is gathered in the CGRD, managed by the COGENT secretariat. Available on the COGENT website, this database is of crucial importance. It provides the only global compilation of *ex situ* conserved coconut germplasm.

Three surveys aiming to collect information on *ex situ* collections were undertaken by COGENT in 2012 and 2013 to better understand the objectives of the collections, their content (in terms of diversity), the long-term security of the collection, the management of the information, the exchange of materials and the (urgent) needs and priorities to be addressed through a global collaborative Strategy. Annex 6 provides the template of the global survey conducted in 2013 and the list of institutions who responded.

In 2014, a last electronic survey was launched by the COGENT Secretariat to understand the perspectives of the genebank curators on (i) the optimization of the current areas of the 24 collections of the network, (ii) the policy regarding backup accessions, (iii) the support required from the multilateral system, (iv) the level of collecting in each country, and (iv) whether the collection of new cultivars should continue or not during the next 10 years.

The *ex situ* conservation management and activities are described in sections below, based on information from the surveys conducted in 2012, 2013 and 2014, from the content of CGRD and from direct interaction with curators.

2.3.1 Content of *ex situ* collections

Most coconut germplasm international movements before 1940 can be classified in two types:

- Introduction of very small amounts of seednuts, by farmers or scientists, for experimental purposes. Generally only one to ten seednuts were introduced for each cultivar for conservation;
- Introduction of many seednuts to create large plantations with varieties coming from other countries for commercialization.

Most genebanks started by collecting traditional varieties in their respective countries. Then, germplasm imports from abroad began.

The total number of registered accessions in collections reached 1760 in 2017. It is currently estimated that only 1607 accessions[50] are still alive. Detailed lists of the cultivars, populations and accessions, ranked either by site of conservation or alphabetic order, are available on the COGENT website[51].

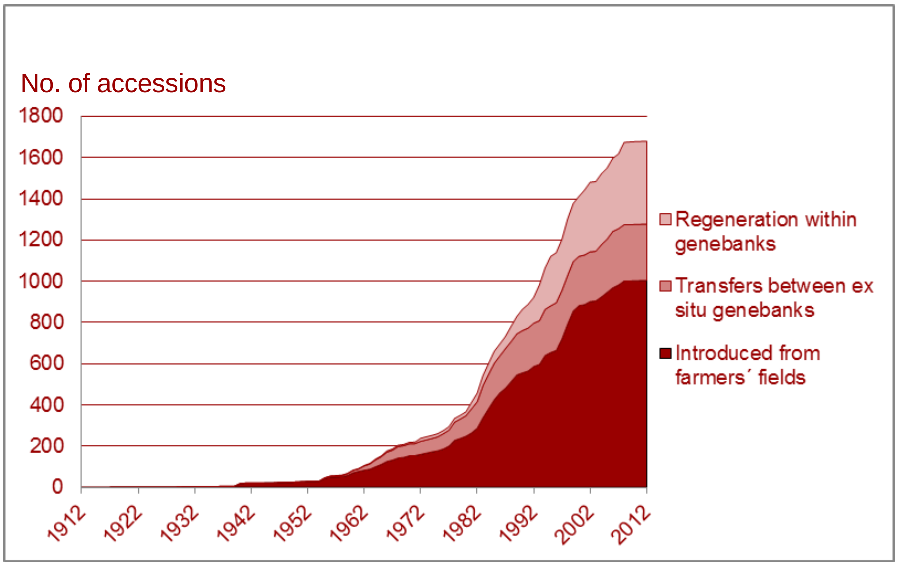


Figure 2.3. Evolution of accessions recorded in CGRD

Figure 2.3 gives the evolution of the number of accessions recorded in CGRD (Coconut Genetic Resources Database), ranked in three categories: introduction from farmers' fields, transfer between *ex situ* collections, and regeneration within these genebanks.

Regeneration within genebanks started in Indonesia in the 1950s and Jamaica in 1960s. In 1980, only 20 accessions had been rejuvenated; this number started to increase to

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50 Accessions recorded in the CGRD with an accession size superior to zero, but sometimes curators do not update this information even over a long time frame.

51 See URL: http://www.cogentnetwork.org/faq/139-exsitu

reach 103 in 1990. The following decade was the most active, with 188 accessions rejuvenated from 1991 to 2000. Then it decreased from 2000 to 2012, with only 111 accessions rejuvenated. However, since 2017 Vanuatu started to regenerate the national collection, showing a continuous interest in the conservation of coconuts varieties.

Most collections need to combat genetic erosion, where significant losses are often associated with poor practices in controlled hand pollination techniques. Deviations from the standard protocol of controlled hand-pollination may cause unwanted mixes between accessions, resulting in useless material being conserved and errors being propagated through germplasm transfers around the world. These deviations can appear when genebank staff are either not well trained or have been replaced. If any new employee is not trained by the departing staff, he/she will lack crucial information to perform tricky and demanding conservation processes. Finally, land-use/tenure issues also threaten the genebanks more often than expected.

Land pressure threats

Material has been lost over the past decade, such as that in the international genebank located in Indonesia, where 15 hectares of coconut accessions were destroyed. Land tenure problems and changes at research stations for coconut conservation have induced a global loss of 54 cultivars, representing 13% of the existing global holdings. In Côte d'Ivoire, about eight hectares of coconut palms were recently felled by the international genebank in order to replant with new accessions. Then, villagers from the neighbourhood came and claimed the land as their own, and preventing replanting. The problem was finally solved in favour of the international genebank, but it forced the curator to modify the design of the whole collection. In order to avoid similar problems in other fields, all the new accessions were planted between the rows of the old living ones. Once new accessions have established, after three to four years, old accessions can be removed.

Most of collections have not started removing duplicated accessions within the collection as part of a rationalization or conscious reduction of the collection at the global level. Although the constitution of international collections has been partially supported by public resources, this support has not yet been secured for the long term.

2.3.2 Mandate of institutes managing *ex situ* collections

All the institutes managing the 24 *ex situ* collections in COGENT member-countries have an official mandate from their government to carry out research on coconut and to conserve coconut at the national, regional or global level. The coconut genebanks mandate includes the following activities:

- Acting as national repository of coconut genetic resources;
- Targeting collecting actions;
- Maintaining field collections of living palms;
- Characterizing and evaluating for important traits;
- Disseminating information about conserved germplasm;

- Providing conserved germplasm to key users;
- Safely exchanging germplasm and all related information.

The prevailing notion that genetic resources are a common heritage for humanity has been replaced by the national sovereignty concept in the Convention on Biological Diversity (CBD) which entered into force in 1993. The implications for crop germplasm exchange were then articulated by FAO, leading to the negotiation of the International Treaty which came into force in 2004.

Coconut is one of the priority crops listed in Annex 1 of the Treaty, which lists the crop species that are subject to such facilitated access under the conditions defined in a Standard material transfer agreement (SMTA). Countries which have ratified the Treaty can access the coconut germplasm declared by hosting countries as being in the public domain and thus included in the multilateral system of the Treaty. For those which have not ratified the Treaty, access can be made through bilateral arrangements.

In order to foster a more efficient and effective system of germplasm conservation, evaluation and safe movement, the COGENT Steering Committee decided in 1995 to establish a multi-site International Coconut Genebank (ICG). The ICG today comprises five regional genebanks hosted by Brazil for Latin America and the Caribbean, Côte d'Ivoire for Africa and the Indian Ocean, India for South Asia and the Middle East, Indonesia for South-east and East Asia, and Papua New Guinea for the South Pacific. However, during the two last decades, most of the germplasm exchanges were done between national genebank without using the multilateral system.

The five ICG field collections are held in trust under the auspices of FAO through a formal agreement between Bioversity, the five countries and FAO (Table 2.1).

The designated germplasm is shared under the terms of the SMTA as part of the multilateral system of access and benefit sharing created by the Treaty or of the Material Transfer Agreement (MTA) specified in the Memorandum of Agreement (MOA) establishing the ICG in the case of India.

An important article of these MOA is related to emergency situations. For instance, in the MOA signed by Papua New Guinea, Article 2g of the agreement (Rights and obligations of the Parties) states that "*if the orderly maintenance of the ICG is impeded or threatened by whatever event, including* force majeure, *the Secretary of the Treaty and Bioversity International, with the approval of the Host Government, shall assist in its evacuation or transfer, to the extent possible*". Such emergency situations have recently occurred in Côte d'Ivoire and Papua New Guinea. These two international genebanks are the most active in providing germplasm, yet within the last few years, they have been threatened by urban pressure and emerging lethal diseases caused by phytoplasmas.

In April 2015, the Crop Trust with the help of COGENT and SPC organized a workshop in Papua New Guinea. The objective of the workshop was to design a project proposal to safely move the international genebank. The international experts gathered in Port-Moresby and Madang thanks to the financial support of ACIAR and prepared a five-year work plan to move the genebank to Punipuni, a safe location in the south of the country. The plan was presented to the Papua New Guinea

Government in 2016 and the implementation of this plan is currently under the responsibility of Indonesian department Kokonas Indastri Koporesen (KIK).

Table 2.1. Date and types of Memoranda of Agreement signed by the five countries hosting ICG.

Region	Country	Date of Signature	Signatory bodies of the Memoranda of Agreement	International convention
South Asia and Middle East	India	Oct. 1998	Government of India Bioversity International (IPGRI) FAO - Commission on Genetic resources for food and agriculture	CBD*
South-east and East Asia	Indonesia	May 1999	Government of Indonesia Bioversity International (IPGRI) FAO - Commission on Genetic resources for food and agriculture	CBD
Africa and the Indian Ocean	Côte d'Ivoire	Sept. 1999 (first MoA) Feb. 2007 (Final)	CNRA on behalf of Government of Côte d'Ivoire Bioversity International (IPGRI) FAO on behalf of the Governing Body of the Treaty.	ITPGRFA**
Latin America and the Caribbean	Brazil	June 2006	Brazilian Agricultural Research corporation (Embrapa) Bioversity International (IPGRI) FAO - Commission on Genetic resources for food and agriculture.	CBD
South Pacific	Papua New Guinea	May 2007	Ministry of Agriculture on behalf of Government of Papua New Guinea Bioversity International (IPGRI) FAO on behalf of the Governing Body of the Treaty.	ITPGRFA

* CBD: Convention on Biological Diversity
** International Treaty on Plant Genetic Resources for Food and Agriculture.

2.3.3 Cost of *ex situ* collections

Assessing the cost of coconut conservation was initiated in the framework for preparing this Strategy. A CGIAR costing study, published in 2011, represents the most comprehensive and recent costing study of *ex situ* collections managed under international standards (CGIAR 2011). This study started to be used as a model for costing *ex situ* coconut conservation, together with the strategy document published for Cacao in 2012.

During the 2013 COGENT survey, curators were questioned regarding the financial status of the coconut genebank they manage. Table 2.2 gives an overview of the 15 replies obtained. The current status of funding for routine operations and maintenance is mainly average or inadequate. The staff number is mostly satisfactory but the technical level of staff was not assessed. Some specific tasks, such as climbing palms and making controlled pollination, are limiting factors encountered in all collections conducting pollination programmes. The status of building, facilities and equipment is mainly average to inadequate: most genebanks do not have the facilities and laboratories requested for making controlled pollinations necessary for true-to-type regeneration of Tall-type accessions. The funding for characterizing and collecting germplasm is mostly inadequate. The level of germplasm use by breeders and researchers is good to average.

Table 2.2. Quality of the management of the genebanks (survey conducted in 2013 by the COGENT Secretariat).

Answer options	Very good	Good	Average	Poor	Very poor
Funding for maintenance	0	3	6	3	3
Number of staff	0	7	3	2	3
Status of buildings, facilities and equipment	0	2	9	2	2
Funding for collecting germplasm	0	2	3	6	4
Funding for research on the collection	0	2	4	7	2
Level of use by breeders, researchers	1	4	7	2	1

During the same survey, curators were asked to estimate the annual cost per accession of the activities conducted in the genebanks. The responses were extremely variable, as shown in table 2.3.

Table 2.3. Estimations on the annual cost per standard accession of activities conducted in *ex situ* coconut collections, and following estimation by the COGENT secretariat (check the detailed of calculation in Annex 7).

Activity	Average estimation by genebank curators (US$/accession/year)	Estimation by the COGENT Secretariat (US$/accession/year)	Difference
Field collection maintenance	927	150	+ 777
Morphological characterization	285	100	+ 185
Molecular characterization	775	12	+ 763
Agronomic evaluation	379	200	+ 179
Germplasm health (indexing & eradication)	267	100	+ 167
Information management	154	200	- 46
Total	2787	762	+2025

Estimations of average costs were calculated by the COGENT secretariat with the help of Dr Jean-Louis Konan, the curator of the ICG for Africa and Indian Ocean.

The online survey alone was not sufficient to gather comparable and standardized data; and so closer interactions with curators are needed. The huge difference between the estimation cost of the curators and the COGENT Secretariat could be due to several reasons. Firstly, researchers in charge of coconut conservation are often not only coconut researchers. They generally assume other tasks, such as conservation of other tree crops, breeding or other research activities. Thus, it is not always easy to differentiate what should and should not be included as conservation costs. As such, some staff cost could have been over-estimated by the curators.

The estimation of the manpower needed for characterizing accessions using standard international descriptors is indeed tricky. The total staff time needed ranges from 1,409 hours (Côte d'Ivoire) to 2,395 hours (Indonesia) per accession (see Annex 8). It requires collecting about 19,000 data per accession. As accessions are kept 30 years in the field, the time needed for characterization is 47-80 hours per accession per year. Labour cost varies widely between countries, so the cost will not be the same in all the genebanks.

The other big difference between the survey cost and the COGENT secretariat estimation (table 2.3) is the molecular analysis. For molecular characterization, a standardized kit of 15 molecular markers is presently used for assessing the allelic diversity of accessions. The recommended sampling sizes are 6 palms for Dwarf-type autogamous varieties and 12 palms for other types of varieties. The cost for analysing a Dwarf-type accession was estimated at US$204; the cost for analysing other types of accessions was estimated at US$408[52]. As an accession is kept in the field for 30 years, the annual costs are estimated at US$6.8 per Dwarf-type accession, and US$13.6 for other types of accessions. As a quarter of the accessions are autogamous Dwarf-types, the average cost of molecular characterization was estimated at US$11.9.

Finally, the average annual cost for conserving, characterizing and evaluating a standard coconut accession with the current standardized methods is presently estimated by the COGENT secretariat at US$762. This amount is provisional, has to be refined and will change as the methods and tools will quickly evolve during the next 10 years.

Within the coconut collections, the main expenses normally incurred are for planting, for characterization and evaluation during the first twelve years and for regeneration of the accessions by controlled pollination. As the useful lifespan of an accession is presently 30 years, the total cost has to be divided by 30 to get an average cost per year.

Except during the juvenile phase, which lasts from three to six years depending on the variety, the value of the production generally far exceeds the cost of maintaining the accessions in the fields. After 12 years in the field, the cost of conserving accessions is

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52 The cost of analysing a palm with a 15-marker kit is estimated at US$34: US$10 per palm for leaflet sampling, managing and/or sending samples and DNA extraction; US$1 per marker for DNA analysis, and US$0.6 per marker for managing and analysing the data.

considerably reduced. In some genebanks, management of these coconut fields is allotted to small private companies. These companies clean and fertilize the plantation; harvest the coconuts and buy them at a lower rate than the market price. This business model may not be suitable for every genebank and should be assessed, taking into account the context and legal environment of the collection.

In 2011 the COGENT secretariat launched a global-level initiative to standardize costs for preparing germplasm for international exchange. This allowed estimating the cost of controlled pollinations (CPs) which is one of the most costly operations needed for genebank management. This cost was estimated at US$8 per controlled pollination. In coconut *ex situ* collections, the recommended sample size ranges from 72 to 96 palms for a Tall-type accession. For regeneration purposes, curators plan making one CP for each palm to be planted in the field. Rejuvenating a Tall-type accession needs 72 to 96 CPs, so a budget of US$576 to $768 is needed just for CPs[53]. This is a one-off expense every 30 years, which is the present average useful lifespan of a Tall-type accession in the field. In order to obtain an annual cost, this budget needs to be divided by 30. So regeneration of a Tall-type accession by controlled pollination costs US$19 to US$26 per annum.

As a whole, COGENT country-members are spending more than US$1.1 million per year for conserving, characterizing and evaluating at least 1,500 coconut accessions in at least 24 *ex situ* collections. A substantial part of this budget is covered by genebanks' self-funding, including selling planting material, selling coconuts, and sometimes selling high-value coconut palm products. This self-funding amount is not currently known, but could achieve a gross annual income of US$4,000 per hectare.

Countries enjoy sustained benefits from the increase of national coconut production linked to the use of these genebanks: the conserved germplasm serves as a basis for breeding activities and allows dissemination of good planting material among farmers. The cost of conserving genetic diversity is high, but the cost of not taking action would be much higher.

2.3.4 Collecting germplasm

According to the information available in the CGRD, 1,005 accessions have been collected in farmers' fields and successfully transferred to *ex situ* collections. The three oldest recorded accessions were planted in the Solomon Islands, Indonesia and Jamaica respectively in 1912, 1927, and 1935. From 1935 to 1955, India played a leading role by starting its *ex situ* collection with 18 local varieties and 26 varieties introduced from abroad; except for dwarf varieties, which are easier to collect, the number of palms per accession was low (7 in average). The focus on collecting and exchanging coconut germplasm strongly increased after 1950. By the early 1960s, about 30 countries had begun to exchange seed or pollen[54].

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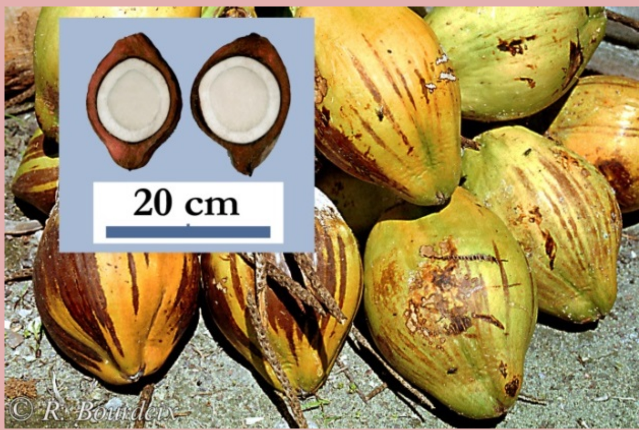
[53] Assuming a dedicated laboratory is already fully operational. If a country is just starting to make controlled pollinations, it will be more expensive as the lab needs to be established.

[54] FAO report. In: Batugal, P., Ramanatha Rao, V., Oliver, J. (eds). 1996. Coconut genetic resources. Available from the URL: https://bioversityinternational.org/uploads/tx_news/Coconut_genetic_resources_1112.pdf

A survivor of an old traditional landrace

In Tuvalu, a unique and remarkable genotype was discovered with striped fruits and almost no husk. Mature fruits had only 10% husk, whereas most coconut varieties possess 20 to 50% (35 % on average). Such a fruit quality is highly desirable for some coconut uses. This combination with striping may indicate that this unique palm might be a survivor of an old traditional landrace. A few other palms in the same field also had striped fruits, with good but less exceptional fruit quality. Embryos were taken from these palms and sent to the Papua New Guinea genebank via the Fiji SPC lab, but they all died due to high contamination and low rooting rates. Farmers and agricultural officers had been advised to multiply the best palm locally. As a result of both the cross-pollination habit of the palm and the short duration of the project, researchers do not know if the farmers succeeded in true-to-type reproduction.



"Lady coconut" variety in the Nui Island, Tuvalu archipelago, with stripped fruits and very low content of husk. (R. Bourdeix, CIRAD)

In the case of coconut, it is indeed challenging to collect and use individual palms having favourable traits. Twelve to 15 years are needed between discovering rare palms with favourable traits in farmers' fields and creating a population usable by breeders. When such palms are found, researchers generally succeed in collecting 2 to 20 seednuts or embryos and not all of these will germinate. As many coconut varieties are mainly cross-pollinated, hardly any of this progeny will reproduce the targeted characteristics. Those that do reproduce will come mainly from selfing, which generally induces a strong inbreeding depression on yields. If lucky, a few targeted progenies will be available in the *ex situ* collection six to seven years later. In this event, another generation will be needed to breed and multiply this progeny. Pollen can also be collected but this is rarely done by surveyors. The lifespan of pollen in natural conditions is no more than five days. Hence pollen collected in farmer's field would need to be immediately cryopreserved.

The early international surveys were based on rather specific objectives such as: tolerance to Lethal Yellowing Disease (LYD) conducted by Jamaica and Tanzania, or searching for varieties with large fruits conducted by Côte d'Ivoire, and so forth. Thereafter, more systematic surveys based on geographical grids and/or participative approaches were launched, including in the Philippines and in Vanuatu. According to Pernes (1984), the best germplasm collecting programmes are carried out in two stages: an initial exploration and preliminary survey is conducted and used for planning a second, more systematic campaign. Such a two-step programme was conducted in Mexico. Fruit analyses were first realized in 47 locations, and collecting was then carried out in only 19 locations, mainly on the Pacific coast, where the greatest fruit variability was found (Zizumbo-Villarreal et al. 1993). However, restricted budgets seldom permit conducting such two-step surveys.

COGENT recently analysed the extent of coconut conservation at country-level. Accessions conserved in *ex situ* collections come from 44 countries and territories. According the FAO, they are 92 coconut producing countries and territories (CPCT), so 47 CPCT (51%) are not yet represented[55] in the germplasm conserved in the 24 COGENT *ex situ* collections.

Ratios between the area under coconut and the number of accessions conserved *ex situ* were calculated. On average, this index is 84 accessions per million hectares, as shown in Table 2.4. At the regional level, this collecting index varies from 64 (in Africa) to 282 (in the Pacific Ocean) per million hectares of coconut plantation.

Table 2.4. Collecting index by region (number of accessions conserved in *ex situ* collections per million hectares).

Region	Harvested area* (Million hectares)	Number of accessions in *ex situ* collections	Collecting index (Using areas data from FAO*)
Asia	9.7	721	74
America and the Caribbean	0.6	45	75
Africa	1.1	70	64
Pacific Ocean	0.6	169	282
Global	12.0	1 005	84

* FAOSTAT data for year 2014.

The calculated index is based on the assumption that data is representative. Some countries with important coconut production have quite a low collecting index, such as Mozambique (12), Ghana (17), India (29) and The Philippines (37). On the contrary, those countries devoting more effort to coconut germplasm collecting have higher collecting indices: Bangladesh (977), Malaysia (626), Fiji (366) and Sri Lanka (306).

Most of the coconut genebanks have plans for collecting germplasm. They are mainly planning to collect materials from farmers' fields in their own countries. For instance, in Kenya some new high yielding accessions of Dwarf-type and Tall-type varieties have recently been collected from farmers' fields. But there is no information regularly collected and gathered at the COGENT Secretariat for the moment on this important activity.

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[55] This includes eight COGENT countries namely, by importance of cultivated surface: Myanmar, Venezuela, Colombia, Haiti, Costa Rica, Honduras, Cook Islands, and Oman.

Additional collecting is strongly encouraged and is still in demand by 87% of the network genebank curators (based on 2014 COGENT survey) since:

- Most COGENT experts and curators estimate that not more than a third of the existing useful diversity has been adequately transferred to *ex situ* collections;
- In some countries and regions, diversity is disappearing from farmers' fields as a result of drastic social changes, urban pressure, lethal diseases, rising sea-levels and other hazards linked to climate change;
- Diversity, such as that embracing Compact Dwarfs, is needed for immediate use and is not available from the existing collections.

2.3.5. *Ex situ* collection management

Coconut genebanks from COGENT member-countries, in addition to collecting and conserving genetic diversity within their jurisdiction, also have a responsibility to curate the collection to an internationally acceptable level. This entails maintaining the collection, safeguarding it from genetic erosion, regenerating accessions using controlled pollination or by re-collecting seeds from the original source (if that is cheaper and still feasible), characterizing the collection, documenting and sharing information so that the accessions can be utilized, and sharing the genetic resources to support coconut-breeding programmes worldwide.

Nut labelling. (RL Rivera, PCA)

All the institutions surveyed in 2013[56] reported that coconut accessions were maintained only in field collections. Within a country, all the locations devoted to coconut *ex situ* conservation are more frequently (72%) under the same national institution. The average number of conservation sites per country is 2.8 for the 14 countries which provided information.

Genebanks' teams do carry out field maintenance and labelling, although 40% of the collections reported inadequate financial resources to support routine operations and maintenance. The genebank survey demonstrated that the level of collection management varies widely depending on the country and the resources available. Excepting Brazil and India, it seems that genebanks do not use irrigation facilities. Many genebanks do not systematically fertilize the palms. Annual fruit yields per palm vary from 55 to 147 according to genebanks, with an average value of 80. India reports annual commercial nut yields as high as 400 per palm. Intercropping is practiced in only a third of *ex situ* coconut collections. For instance, in Papua New

[56] See Section 1.3 and Annex 6 for detailed information on the survey conducted in 2013 by COGENT Secretariat.

Guinea, at the Stewart research centre, the coconut genebank is intercropped with cocoa. The Stewart research centre also manages a cocoa field genebank but, although in the same plantation, this genebank is not located in the same fields as the coconut collection. In India, at CPCRI Kasaragod, some of the old coconut germplasm plantations are intercropped. Within the coconut genebanks, crops are generally intercropped for demonstration or research purposes, or for increasing income. Plantations are generally designed only for the conservation of coconut genetic resources and not for conservation of other crops.

Most of the collections do not have post-entry quarantine facilities and do not carry out systematic virus and phytoplasma indexing. There is no information on the business models of these structures so it is impossible to know today if they can be cost-effective or, at least, cost-efficient. Similarly, there are no studies on the social, cultural and environmental impacts and nor on the ecosystem services these collections account for.

2.3.6 Germplasm identification, characterization and evaluation

Characterization according to standard descriptors is carried out on a routine basis in about 60% of the collections and occasionally in most of them. All genebanks generate some degree of evaluation and/or characterization data for their accessions. Evaluation data comes primarily in the form of duration to planting and flowering, production of fruits and bunches, fruit component analysis and disease tolerance. In some genebanks, fruit theft disrupts yield evaluation.

Marc Delorme Coconut Research Centre, Côte d'Ivoire. (R. Bourdeix, CIRAD)

The coconut palm is a polymorphous plant whose appearance varies considerably depending on the soil, climate and time of year[57]. Genebanks differ widely regarding which data are regularly recorded, occasionally recorded or not recorded at all, and as to the duration of observation. For instance, in Côte d'Ivoire and Vanuatu, fruit analysis data available in the CGRD database are averaged over four years of observation. Most of data from the international genebank in India come from a unique harvest of fruits. In the Indian ICG, morphological growth characters are recorded annually on the juvenile palms as well as period to inflorescence initiation. The annual yield is computed from their fruit-harvest records

Misidentification of palms within a genebank arising from errors in establishment is a significant problem. In 2011, DNA fingerprinting using microsatellites or simple sequence repeats (SSR) markers was introduced for checking the pedigrees of

57 At the outset, a coconut palm often produces a few larger and rounder fruits than those it will produce later. Once mature, fruit production often follows discontinuous rythms, especially for dwarf cultivars cultivated under average management. A coconut loaded with more than 200 nuts may produce fewer than 10 nuts the following year.

accessions conserved *ex situ*[58]. The first studies were conducted on progenies obtained by using controlled hand-pollination in India and Côte d'Ivoire, countries which both are hosting international coconut collections. Such misidentifications are caused by deviations from the standard protocol of controlled hand-pollination. As well as inadequate isolation, other errors can occur at every stage, from pollen handling to nursery management and field establishment or recording planting data. Current practices therefore need to be reviewed and improved. Lack of fidelity within collections can result in conservation of useless material and errors being propagated through germplasm transfers around the world.

The majority of collections carry out screening for pest and disease resistance. This reflects the objectives of the collections and the key traits of interest for breeding. However systematic evaluation of *ex situ* collections for such important traits has only been partially achieved. Uptake of accessions in breeding programmes has been restricted. The main limiting factors mentioned by the collection curators for the germplasm to be used in breeding are: 1) constraints in accessing materials (quarantine and policies) 2) lack of precise information and knowledge (particularly evaluation) on the material, 3) death of breeding programmes and breeders and 4) lack of funding for research and breeding programmes.

Characterization using molecular markers is not routinely carried out. This may be due to inadequate resources and facilities, or to the fact that such an evaluation does not appear as a priority to curators.

2.3.7 Safety duplication of germplasm

When germplasm is not duplicated in a separate and distant location, accessions are further threatened by natural and anthropogenic disasters. Coconut genebanks do not have intentional safety-duplication through a formal agreement with another institute, outside of the country. Although this duplication is a key aspect in FAO genebank standards, carefully elaborated for international genebanks, the MOA signed with any coconut international genebank does not mention such duplication. The only case where duplication is considered in these documents is the clause relative to "emergency" cited in section 2.3.2.

For COGENT curators, the lack of safety-duplication agreements with other institutes is caused by limited funding and by a lack of international and national policies for the conservation of coconut genetic resources. Furthermore, pests/diseases are an increasingly serious impediment to the overall welfare of the collections, resulting in high levels of genetic erosion and severely constraining the ability to safely transfer germplasm.

The 24 COGENT genebanks referenced in CGRD conserve numerous accessions, which prove useful to their national programme. Genebanks will continue such vital

[58] Basically, this consists of selecting at random a subset of the female and male parents and of analysing DNA from parent palms and their progenies. This technique can be only used when the precise pedigree of each palm planted is safely recorded, and when the progenies are obtained by crossing parent palms one by one, and not by mixing pollen from several male parents. Less than 20% of COGENT genebanks presently meet these two conditions.

conservation work, although using a network approach is critical to such conservation at the global level.

At present, some cultivars are found only in 1 genebank while some other cultivars are conserved in more than 15 countries. According to the CGRD, among the 338 living cultivars conserved in COGENT *ex situ* genebanks, 269 are conserved in only 1 country. A further 25 cultivars are conserved in 2 genebanks. Another 44 cultivars are conserved in at least 3 genebanks.

The analysis presented hereunder aims to assess the *global* efficiency of the present *ex situ* conservation system (*sensu stricto*). The information in the CGRD provides a crucial global overview. As illustrated in Table 2.5, only a third of the palms referenced in CGRD can be considered as really effective for conservation of the species at the global level.

There are 1,760 coconut accessions registered in the CGRD, totalling 144,559 palms referenced as alive and covering about 900 ha. When removing the accessions which have been already cut (because already regenerated or for another reason), and those for which no number of palms have been reported[59], there remain 1,374 accessions with an average of 105 living palms per accession.

Table 2.5. Analysis of accessions for global efficiency of conservation (Analysis carried out in 2013).

Level of analysis	Description	Total number of "globally useful" accessions	Total number of "globally useful" palms	Palms per accessions
1	All living palms	1374	144,559	105
2	Excluding over representation due to excessive accession sizes: - over 96 palms for Tall-types - over 45 palms for Dwarf-types	1374	65,460	48
3	Excluding (2) and cultivars duplicated in the same genebank	987	53,647	54
4	Excluding (2),(3) and limiting the conservation of cultivars at no more than 3 replications worldwide	857	47,816	56

Some accessions registered in the CGRD have a number of living palms which is too large for conservation purposes. For instance, the highest accession size was recorded on an accession of Malayan Yellow Dwarf in Tanzania with 6,400 palms; this rather coincides with a full seed garden and not with an accession planted for conservation. So it is important to differentiate between the numbers of palms currently registered in the

[59] There are 153 old accessions removed from the fields with 0 as accession size; and more than 153 accessions do not have a recorded size (data not sent by curators).

database, and the numbers of palms really useful for conservation purposes. The recommended sample size for an accession ranges from 72 to 96[60] palms for heterogeneous, allogamous Tall populations, and 45 palms for autogamous, homogeneous Dwarfs.

A survey[61] conducted by the COGENT Secretariat in 2014 and 2015 among the 39 country members received a 49% response. Seventy-nine percent of the 24 genebanks (national + international) and 4 out of the 5 ICGs replied. This survey established that among the 19 genebanks which replied, 80% of survey respondents agreed that a backup should be applied to a selected set of priority cultivars, chosen to represent global diversity. Not every cultivar would be secured, although every existing cultivar would be represented in the priority set by at least one cultivar with a very similar gene pool.

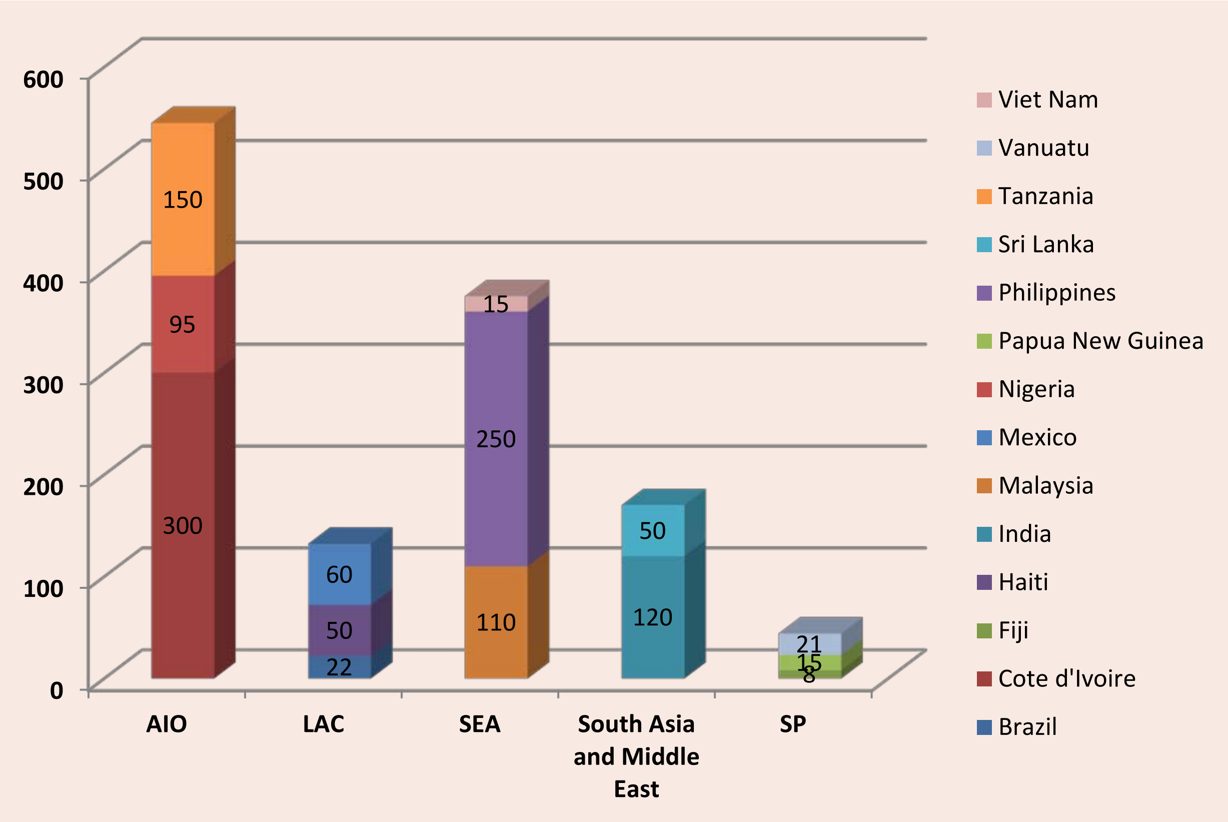

Figure 2.4. Hectares currently devoted to the genebanks (concerns 19 genebanks out of the 24)

Sixty percent of respondents estimate that support from the multilateral system should be provided for a priority subset of the extant accessions proven to be distinct, based on phenotypic observations. Due consideration should be given to the geographic repartition of the origins of priority accession (to maximize genetic diversity).

60 96 palms per accession of Tall-types were considered for the present calculations.

61 See the results of the survey at http://www.cogentnetwork.org/images/publications/StrategyCOGENT_MadangApr2015.pdf

Accessions of high agronomic or market quality values for the country would be funded, irrespective of whether they are sufficiently represented elsewhere or not.

Thus, it seems important to distinguish between what is needed at country level and what is needed *sensu stricto* for conservation of the species at global level. Most of the genebanks are interested in acquiring the same set of well-known, well-performing and representative varieties. Indeed, this is useful for their national breeders, as it serves as a core collection and basic material for breeding programmes. But when conservation is assessed at the global level, there is no need for the same germplasm to be conserved in more than two (according to FAO international standards) or three genebanks (according to some coconut genebank curators)[62].

2.4 Genetic resources information management

In a perennial plant such as the coconut palm, the constraints linked to its biology increase the cost of scientific progress and worsen the consequences of possible errors. Consequently, coconut research and conservation not only need high financial and human resource investments but also a secure and sustainable information management system[63].

2.4.1 Local genebank management systems

In various countries, many years of field observation data have been lost as a result of different types of calamities and constraints, such as fires, floods, revolutions, staff turnover or simply the lack of funds leading to termination of the breeding programme. In some cases, due to the very long period between the start and completion of a breeding project, the data from initial years of bearing have been lost even before full project completion. High staff turnover has fortunately now reduced with greater concomitant stability and sustainability.

Data on characterization of accessions can be lost. This was recently the case in some COGENT member-countries. Acting on the advice of the COGENT secretariat, in 2013 and 2014 CRP-FTA and Bioversity International funded three internships (two MScs and a PhD) to assist researchers in cleaning, reconciling, improving and analysing the available data on genebanks and genetic experiments.

Tagging palms. (R. Bourdeix, CIRAD)

Some genebank curators often use home-made software or Microsoft

[62] Except for some varieties serving as international reference controls. For Dwarf-types, the Malayan Yellow Dwarf; for Tall-types, there is no consensus yet.

[63] A coconut accession is presently kept in the field during 30 years, although most of the characterization is conducted during the first 12 years. A genetic experiment frequently covers an area of 8 hectares for a minimum period of at least 12 years. A coconut breeder often analyses the experiments established by his/her predecessor and establishes experiments for his/her successors.

Excel to store their data, which are generally scattered in many small files not all having the same structure. This put the data at further risk, because over time such bespoke software becomes obsolete, or it becomes difficult to understand the particular structure of the numerous small files used for storing the data.

The Coconut Data Management software (CDM) was created in 1996 by CIRAD for managing palm-by-palm data[64]. This software is presently used in only three COGENT member-countries. Its main advantage is an efficient graphic interface for managing the identity of the palms. The coconut database managed with CDM software in Côte d'Ivoire is the largest and most comprehensive existing database in any COGENT member-country. In October 2013, it contained 8.2 million observations of fruit and bunch harvests conducted on 90,500 palms during 47 years (from 1967 to 2013); and millions of other observations of standard descriptors and fruit component analysis.

2.4.2 Managing international coconut databases

Information on morphology, evaluation, origins and locations of accessions conserved *ex situ* is available in the CGRD[65] which was developed between 1994 and 2013 by CIRAD. Until 2002, the project was funded by the French Government via Bioversity International and implemented in collaboration with COGENT member-countries.

In 1999, the COGENT Steering Committee took the decision to release the CGRD into the public domain, in order to disseminate this useful information and create public awareness about coconut genetic resources[66]. Since 2002 no regular funding has been available to manage this database.

In the CGRD, data on coconut cultivars are divided in two main components: (1) passport data and (2) characterization and evaluation data. It takes into account the standardized descriptors for the coconut palms and the methods detailed in the STANTECH manual. As indicated elsewhere in this Strategy, the CGRD is a crucial strategic tool for three reasons:

- It provides the only means to assess coconut conservation at the global level. Most strategic analyses presented in this Strategy rely on the content of CGRD;
- It provides access to information on conserved germplasm for all users. Curators can be informed of what exists in other genebanks and request germplasm transfers. Breeders can search for and identify the accessions they would like to include in their plans;
- It serves as a data repository, to back up paper documents containing historical data of accessions in the event of loss.

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[64] Version 3 of CDM delivered in March 2000 is able to manage the palm identification traits along with data on observations during the vegetative phase, leaf morphology, stem measurements and state of the palms. It is possible to execute powerful queries on the database, to export data into external file, and to make statistical analysis of widely used experimental designs. The software was introduced in a COGENT training course held in Montpellier in 2002.

[65] Available from URL: http://www.cogentnetwork.org/cgrd-version-6-0-test-version

[66] Source: Minutes of the 8th COGENT Steering Committee held in Ho Chi Minh City, Vietnam, 20 -22 September 1999.

The CGRD software is too technical to be used by farmers and some other stakeholders from the coconut value chain. In order to make germplasm information available in the most user-friendly way, two initiatives were developed:

- A catalogue of conserved germplasm compiled and made available online. Coconut varieties and populations conserved *ex situ* are each described by a page of text and a page of standardized pictures[67];
- To aim at an online publication of the coconut data available in CGRD accessible in a wider database system to be developed by Bioversity International for three commodities - *Musa*, cocoa and coconut. This germplasm Information System, called COCOGIS[68] for coconut, could provide user-friendly access to coconut germplasm data, with the possibility of visualizing germplasm information (passport and characterization standard descriptors) on geo-referenced maps and satellite images. However, development has been suspended due to lack of resources.

The TropGENE database, created and hosted by CIRAD, manages genomic and phenotypic information about many tropical crops[69]. TropGENE contains coconut molecular markers and quality trait loci (QTL) data as well as genotyping studies. It is not envisioned to include other types of information (such as phenotypic data) because these are already available within CGRD. The data for genotyping studies included in TropGENE have been generated by CIRAD and by institutions from COGENT country-members, using 1,293 palms from 160 accessions collected in 34 countries.

Genesys is a global multicrop portal supported by the Secretariat of the Treaty. The Genesys portal aims to provide users with improved access to the millions of accessions held in genebanks worldwide. The only coconut accessions referenced in Genesys are 18 from the USA and 147 from Côte d'Ivoire. It is expected that COGENT data will be included at some point, but this operation requires the signature of bilateral data sharing agreements between each COGENT country member and the repository of the data in order to establish the intellectual property rights of each party.

Obtaining data from curators can be challenging. More than 80% of the data presently available on the CGRD database was obtained when COGENT experts went to the countries and worked directly with curators and their teams. Thanks to CIRAD (Chantal Hamelin, UMR AGAP) and to the three-month Bioversity/COGENT project "Upgrading international coconut genebanks and evaluating accessions" funded by the Trust, CGRD software has recently been updated and improved. Two upgraded versions were released in 2012 and 2013 respectively. More recently, in May 2016,

[67] See URL: http://www.cogentnetwork.org/conserved-germplasm-catalogue

[68] See URL: http://www.cogentnetwork.org/cocogis-version-1-0-test-version

[69] See URL: http://tropgenedb.cirad.fr/tropgene/JSP/interface.jsp?module=COCONUT

Version 6.1.2 was released on the COGENT website[70] along with an updated user manual in a downloadable pdf format.

At present, none of the COGENT databases available online includes the scientific literature relevant to coconut genetic resources. Such a database is maintained on a voluntary basis by Dr Hugh Harries as the Coconut Time line[71].

2.4.3 Geographic Information Systems.

A Geographic Information System (GIS) may be defined as "a database management system which can simultaneously handle spatial data in graphic form, i.e. maps, or the 'where', and related, logically-attached, non-spatial, attribute data, i.e. the labels and descriptions of the different areas within a map, or the 'what'."(Guarino et al. 2002). GIS technology has been increasingly used in genetic resources studies and conservation. For example, mapping collecting sites has allowed visualizing and extrapolating the distribution of targeted species, as well as locating areas of higher genetic diversity, and areas that are under-represented in conservation or threatened with genetic erosion or global change. Thus, in Vietnam, GIS technology has been used to manage a database of coconut palms selected in farmers' fields, for producing planting material, and to evaluate the effects of climate change in the Mekong Basin through the National Coconut Project led by the Institute for Oils and Oil Plants.

Between 1995 and 2012, coconut researchers from 13 COGENT countries were trained for inputting data into the CGRD, subsequently allowing geo-referencing 60% of the CGRD accessions. In 2013, CIRAD collaborated with COGENT and the CRP-FTA to assess this and other information, and to map global coconut distribution. The localization of all collection sites was systematically checked, significantly improving the quality of COGENT data. Coconut global distribution has been studied using Ecoclimatic Niche Modelling. The resulting maps provide a clearer picture of potential coconut cultivation areas (Figure 2.5), contribute to our understanding of coconut dispersal, and allow a better identification of collecting gaps (under-represented in international collections, see Figure 2.6). This new tool will also be useful for anticipating the effects of climate and sea-level changes. From this perspective, an effort has been recently undertaken to map regions of particular genetic diversity.

Figure 2.5 presents climate suitability for coconut. Dark green indicates marginal areas, while light green and warmer colours are used for increasingly favourable areas. Highly favourable climates are best represented in the Pacific and Indian oceanic regions (Southern Asia to Australia, Eastern Africa and Madagascar, and myriad small tropical islands), corresponding to the natural distribution of the species (Batugal et al. 2005b). Favourable climates are also found in the Gulf of Guinea, the coasts of eastern Brazil and the Guyanas, in all the Caribbean, (where the coconut was introduced in historic times), and in the Pacific coasts of Colombia and Panamá (where the coconut was introduced in Pre-Columbian times).

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70 See URL: http://www.cogentnetwork.org/cgrd-version-6-0-test-version

71 See URL : http://cocos.arecaceae.com/

The climatic model also suggests some inland areas, as in the basins of the Amazon and the Congo, where coconut is rare, or only recently introduced.

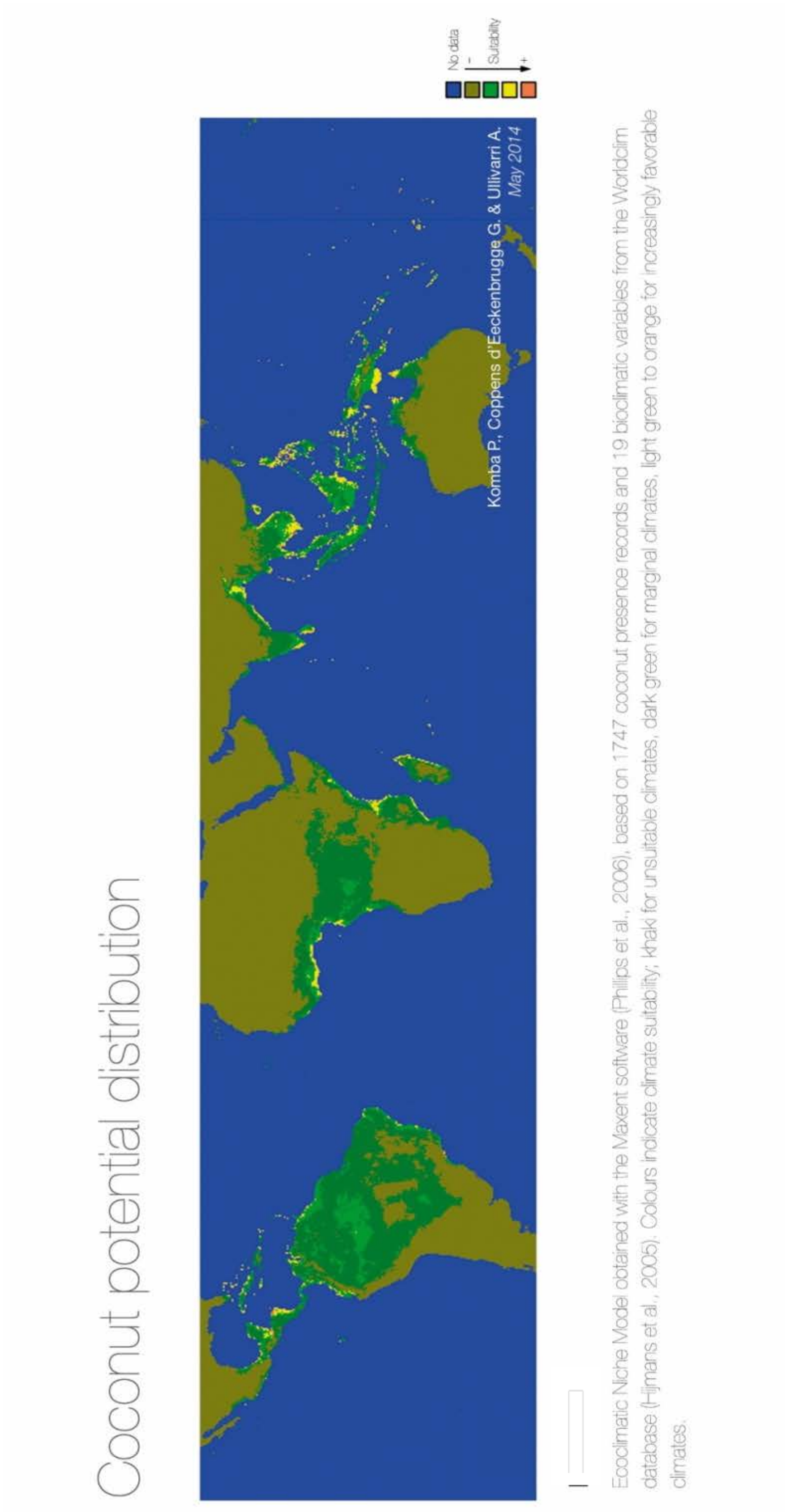

Figure 2.5. Ecoclimatic niche model for coconuts

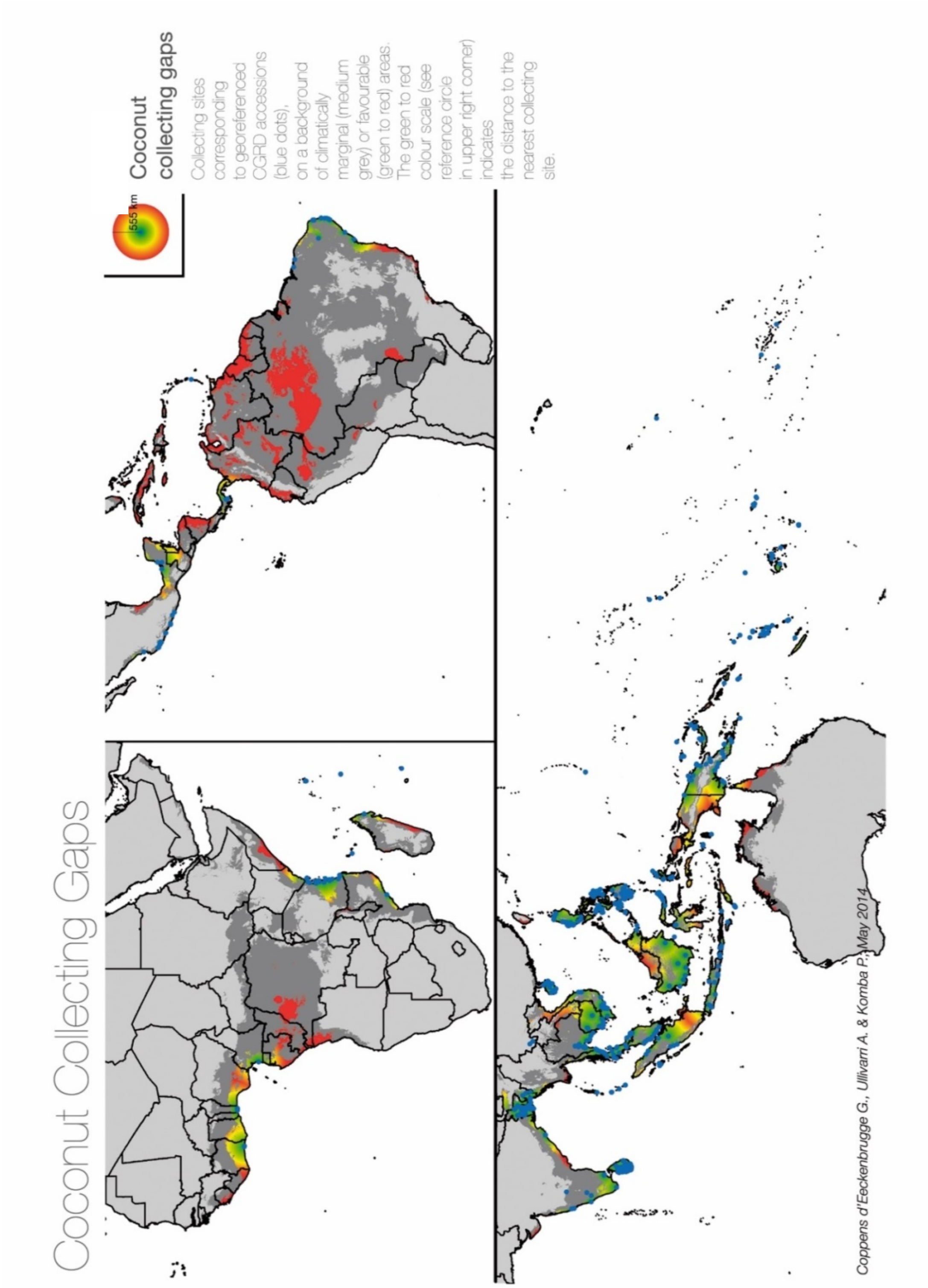

Figure 2.6. Coconut collecting gaps

Figure 2.6 (former page) presents the geographic origin of coconut germplasm held in the international collections under the aegis of COGENT. The Indo-Pacific region has been relatively densely sampled. However, there are important collecting gaps along the northern coasts of Australia, several areas in Indonesia, northern Viet Nam, the Indian coast, southern Somalia, and eastern Madagascar. Western Africa has been poorly explored, particularly south of the Gulf of Guinea. Similarly, in the neotropics, germplasm from the Caribbean coasts, Gulf of Mexico, northern South America and the equatorial Pacific are very poorly represented in the international collections.

Remote sensing analysis is the most cost-effective way to precisely map cultivated areas and inventory coconut resources. Coconut palms are easily recognisable in satellite images and can be counted with adapted field controls. Such an approach was developed in French Polynesia (Teina et al. 2008, Desmier et al. 2011) and in Kiribati (Forstreuter 2013). With the support of GIZ the same resource-mapping exercise is in progress for Tuvalu[72]. Multi-temporal aerial photographs and high-resolution satellite images are also used to assess shoreline changes, coastal erosion and flooding, especially in low atolls such as Tuvalu (Ford 2013) and Marshall Islands (Duvat et al. 2013).

In 2008, a process-based dynamic simulation model for coconut was developed and validated for different agro-climatic zones of India (Kumar et al. 2008). This model is being used to anticipate the impact of climate change (Kumar et al. 2013). Simulation analysis has indicated that agronomic adaptations such as soil-moisture conservation, summer irrigation, drip irrigation, and fertilizer application may not only minimise losses in the majority of coconut growing regions, but may also substantially improve productivity. In India, implementing such strategies could increase productivity by 25–32% by 2050 to 2080, depending on the climate scenario (Figure 2.7).

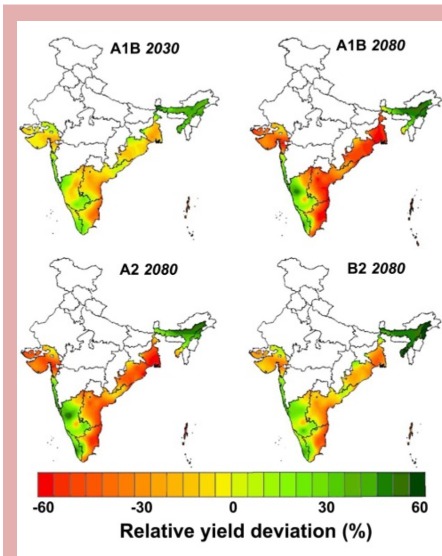

Figure 2.7. Future coconut productivity under different models of climate change. (from Kumar and Aggarwal 2013)

2.5 Utilization of coconut genetic resources

As mentioned earlier, the future of the world coconut economy depends significantly on the conservation and sustainable use of genetic resources. Compared to other crops, there has been limited investment in scientific research aimed at improving coconut productivity and quality, and only a limited number of professional breeders are involved in coconut breeding.

Although evaluation of collections and farmers' selections has shown wide variation for yield, disease resistance and quality, most of the planting material used by farmers

[72] Available from the URL: http://www.sopac.org/index.php/media-releases/1-latest-news/464-keynote-address-dr-russell-howorth-2012-pacific-gisrs-conference

remains low yielding and highly susceptible to prevailing diseases and pests. Furthermore, only a very few varieties have been selected for sensory quality aimed at the specialty coconut market. This underscores the importance of germplasm collections and their utilization by farmers, breeders and all stakeholders in the coconut industry.

2.5.1 Planting material for farmers

Genebanks are repositories where biological material is collected, stored, catalogued and made available for redistribution. The main role of a genebank is to provide safe and well known biological material to breeders and researchers. However, *ex situ* coconut collections are often mandated by their national hosting institutions to also release conserved coconut germplasm on demand to farmers and other private users. This system works well for some Dwarf-type varieties which reproduce naturally by selfing. Affordable Dwarf seednuts from natural pollination are effectively disseminated to farmers. Simple genetic markers, such as emerging sprout colours, allow discarding the few outcrossing palms at the nursery stage.

Beach seller of tender coconuts in Côte d'Ivoire. (R. Bourdeix, CIRAD)

This system does not work so well for allogamous Tall-type varieties. In *ex situ* collections, accessions are planted close together. The only way to reproduce true-to-type Tall populations from the genebank is to conduct controlled pollinations with bagging. Producing a batch of the 200 seednuts needed to plant one hectare will demand a one and half year preparation, costing about US$2,000 in an *ex situ* coconut collection. The cost is far less in a dedicated seed garden. The planting design of the coconut *ex situ* genebanks today is not convenient to produce affordable seednuts for the farmers. Only scientists with healthy research budgets can afford to order Tall-type varieties from classical coconut genebanks. The majority of farmers and other users cannot afford it.

Some institutions managing *ex situ* coconut collections are involved in mass seednuts production for commercial distribution at the request of their Government. From the *ex situ* collections, seed gardens are set up for mass-producing a few coconut varieties which are released to farmers. For a single variety (Dwarf, Tall, Semi-Tall and composite), the seednuts are produced by open pollination in isolated fields to avoid crossbreeding with other varieties.

For hybrid production:

- A first technique consists in inter-planting two varieties in the same isolated field and removing the male flowers on one variety, which will produce hybrid seednuts;

- A second technique consists in planting two separate isolated fields. The largest field is planted with only a variety used as female parent, while the other field is planted with another variety used as male parent[73.] In the first field, all inflorescences are emasculated. In the second field, male flowers are harvested and processed in order to obtain big quantities of pollen. Then a mixture of talc and pollen is dusted on the emasculated inflorescences in the first field.

Such seed gardens now exist in several coconut-growing countries. They are managed directly by a local genebank curator or by another service within the same institution[74]. They can also be run by a private company. Generally, one to four coconut varieties are released on a large scale to farmers by genebank-operated seed-gardens. Producing and transporting seednuts and seedlings is expensive. At least a year and half is needed between pollination and field-planting a seedling. There is a time limit once the seednut has germinated (usually within a few months of harvest) and the seedlings are best planted out during the rainy season. A one-hectare Dwarf seed garden (producing Dwarf x Tall hybrids) requires on average the equivalent of 1.1 full time field workers (R. Bourdeix, personal communication[75]) and generally produces 16, 000 seednuts per year (Dominguez et al. 2003) when managed without irrigation.

In many small countries, the coconut seednuts made available by breeders to farmers remain extremely scarce. Because of the cost of operations, Government agricultural services often promote a single variety, such as a Dwarf x Tall hybrid, which is presented as a 'panacea' to farmers. Unfortunately, it was observed that after a short trial period, farmers often refuse to continue planting this material. Farmers prefer to think and choose for themselves, and wish to choose from a range of varieties (when this choice is offered to them, they generally choose to plant more than one coconut variety in their fields (Bourdeix et al. 2016). India offers a case study regarding farmers' attitudes to coconut hybrids, as summarised in the box on next page

In almost all cases, farmers have to pay for getting seednuts from national institutions or private companies. According to the survey conducted in 2013, 80% of COGENT representatives believe that the genebank and its associated seed gardens provide good material to farmers, at affordable prices (87%) and farmers are not really reluctant to pay for new coconut planting material (67%).

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[73] The field used for harvesting pollen is often an accession conserved in the genebank. This second technique needs more equipment and manpower (workers and a laboratory to process the pollen). It is more flexible because it allows successively producing hybrids with the same female parent but with different male parents.

[74] According to the survey conducted in 2013, genebanks and seed gardens are under the same institution at 80%; for 47%, they are located in the same place.

[75] Based on figures from Côte d'Ivoire genebank: emasculation 0.76 man/ha; pollination 0.14 man/ha; other tasks: 0.2 man/ha. So the yield of a Dwarf coconut seed garden is about 8.5 seednuts per hour of work. If irrigation and high level of fertilization are applied, the yields could reach 250 seednuts per palm per year, 50,000 seednuts per hectare per year, and 27 seednuts per hour of work. Seednuts are often sold at least half a dollar each (and often much more), it give a gross income of at least US$13 per hour of work which represents an opportunity for many farmers and private companies.

Plate 2.2

Diversity of coconut palm trunks

Coconut is much more than coconut!

1. Coconut leaf-bases create the scars on the trunk.

2. Tall-type coconut palm trunk with leaf scars spaced around 8 cm apart.

3. Malayan Dwarf-type coconut palm trunk with much closer leaf scars.

4. Malayan Dwarf-type coconut palm trunk.

5. Compact Dwarf-type coconut palm trunk

6. Tall-type coconut palm trunk, variety "West African Tall" from Côte d'Ivoire.

7. Tall-type coconut palm trunk, variety "Tagnanan Tall" from the Philippines

8. 102 year-old coconut palm trunk, Cook Island.

9. A young coconut palm trunk growing in the shade with white leaf scars and green internodes.

10. Trunk with small plants growing on it in Samoa.

11. Trunk with white lichen in the Sultanate of Oman.

12. Trunk with red-orange lichen in Fiji.

R. Bourdeix, V. Johnson and A. de la Presa

Coconut hybrids in India: views from a private company

Coconut in Indian market.
(R. Bourdeix, CIRAD)

For decades in India, unscrupulous middlemen and petty breeders sold so-called 'improved' and 'hybrid' coconut seedlings to farmers, which have not performed well. Thus, these farmers never saw true hybrids in production. Consequently they lost confidence in private suppliers and came to prefer Government nurseries. They currently have no special preference for hybrids. Yet it is unwise to presume that the standards in Government nurseries are much better. However the Government has no personal stake in the sale, so until now the farmers have put more faith in such Government nurseries.

Now there is a change happening. The real situation reveals the potential of hybrid coconut seedlings for increasing returns for the farmer. Genuine, field-tested hybrids can significantly increase profits. A private Indian company had absorbed costs of investment for development over 20 years before its hybrid seedlings became accepted as highly productive hybrids for copra.

Giving free hybrid seedlings to village leaders, organizing frequent meetings with farmers, and establishing model farms in coconut growing areas, has taken many years to change farmers opinions. After 21 years, this private company has recently made its first profit and now their hybrid seedlings sales are growing. In practice they have proved the superior performance of their hybrid. The farmers with direct or indirect knowledge know it and spread the information. Today in India, the only reasons farmers do not buy hybrids are either lack of awareness or lack of supply. In virtually all other types of agriculture and livestock farming, hybrids have been the main solution for increased productivity. Food production around the world would never have increased as it has, without the advent of hybridization.

In this context, collecting appropriate germplasm becomes even more urgent and necessary. Only when germplasm is easily available to all governments and breeders around the world will better hybrids be researched and produced. The cost of producing and maintaining cultivars that are pure is very high, because selfing or inter-se hand pollination is a necessity. But it is not really so high when compared with the potential value of that stock.

Table 2.6 gives the typology of varieties that are presently used by and released to farmers. In the case of the coconut palm, the term "hybrid" is defined in its widest sense as a cross between two structures belonging to different varieties. The term "structure" here means a population, a family, or an individual (and is not related to the kind of varieties that are being produced through crosses of inbred varieties as in the case of maize).

Table 2.6. Typology of coconut varieties classified by importance of use.

Type of varieties	Countries using these varieties at large scale	Main characteristics	Main reproductive traits
Tall (allogamous)	Everywhere	Multiple uses, late bearing, and resilient, strong vertical growth generally low or medium bearing but some varieties perform very well.	Reproduced by farmers but naturally mix when distinct varieties are planted close together.
Dwarfs (autogamous-Malayan type)	Philippines Brazil, Thailand Everywhere in gardens	Precocious, slow vertical growth, less resilient than Tall, sensitive to cyclones. Used mainly for coconut water and domestic consumption. Very high yields obtained with irrigation and high fertilization level in Brazil.	Easily reproduced true to type by farmers because of autogamy and availability of simple genetic markers.
Dwarf x Tall and Tall x Dwarf hybrids	Almost everywhere	Multiple uses, more precocious than Talls, intermediate vertical growth, heavy bearing but needs care to reach its full potential.	Seednuts harvested of these hybrids do not give the same variety. Cannot be reproduced by farmers at the farm level.
Synthetic varieties (CCVs)	Philippines	Multiple uses, more precocious than Talls but less than Dwarf x Tall hybrids, strong vertical growth, heavy bearing but less than the best Tall x Tall hybrids.	Can be reproduced by farmers.
Dwarf x Tall Improved hybrids	Côte d'Ivoire Vanuatu	Multiple uses, more precocious than Talls, intermediate vertical growth, producing 10 to 25% more than the first generation of hybrid, but need care to reach its full potential.	Seednuts harvested of these hybrids do not give the same hybrids. Cannot be reproduced by farmers at the farm level.
Tall x Tall hybrids	Vanuatu Thailand	Multiple uses, more precocious than Talls but less than Dwarf x Tall hybrids, strong vertical growth, heavy bearing.	Seednuts harvested of these hybrids do not give the same hybrids. Difficult to produce because seed gardens grow fast. Cannot be reproduced by farmers at the farm level.
Intermediate types between Tall and Dwarf	Sri Lanka Oman India	"King coconut" variety in Sri Lanka and Oman: late producing, not heavy bearing, but traditional variety of great cultural importance strongly appreciated for coconut water. Komadan variety in India.	Autogamous Semi-tall, reproduced true to type by farmers and gardeners.
Dwarf (Allogamous compact)	In gardens of Polynesia and Melanesia	Some are less precocious than other Dwarfs. Many promising varieties are not yet described and not transferred to *ex situ* collections.	Reproduced almost true to type by farmers using simple genetic markers.
Dwarf x Dwarf hybrids	None	Precocious, heavy bearing, less resilient than Talls but more than Dwarfs. Tested by breeders, not released to farmers but will be important in the future	Seednuts harvested of these hybrids do not give the same variety, but it remains Dwarf types. Cannot be reproduced by the farmers at the farm level.

The term "improved hybrid" also refers to a cross between two structures belonging to different varieties but at least one of these structures being improved by progeny tests for combining ability. One more generation of experiments is needed to evolve from hybrids to improved hybrids.

2.5.2 Involvement of farmers in breeding and seednut production

Farmers seem to produce more than 85% of the planting material from the varieties they select and (perhaps sometimes unconsciously) conserve germplasm (Bourdeix et al. 2016). Scientists are quite well aware that the present capacity of their institutions for seednut production does not adequately meet farmers' needs, and/or that farmers are sometimes reluctant to plant the advanced genetic material produced by "scientific" coconut breeders. It has been demonstrated that the preferences of many farmers are not only linked with the agronomic value of the planting material, but also that farmers' choices take account of the qualities of planting material as a cultural entity within a human community (Bourdeix et al. 2008).

Many farmers hold some kind of "private collection", containing three to ten cultivars or populations, most of them conserved with a low number of palms, and planted together in the same fields. Indeed, for farmers, creating coconut varieties is not an easy task. It requires monitoring over several years. Tall coconut palms often flower after six years, which is long enough to risk forgetting where the seednut came from. In most situations, farmers cannot prevent coconut varieties from mixing. A coconut palm undergoes uncontrolled crossing with any of its neighbours, so mostly the sought-for characteristics are not found in the progeny. The more the coconut palm is productive, the more it will reproduce by selfing (pollination between successive inflorescences), so the best palms may not give systematically the best progenies because of strong inbreeding depression.

Woman farmer next to a Dwarf palm (R. Bourdeix, CIRAD)

Farmers' knowledge regarding the coconut reproductive system and the use of genetic markers such as germinating sprout colour are key factors for breeding purposes. Both traditional and technical knowledge of farmers and other stakeholders regarding coconut breeding and its reproductive system are insufficiently assessed. For instance, in French Polynesia, at least 80% of farmers do not know that each coconut palm has both female and male flowers. Many farmers' communities are also losing the traditional knowledge to cultivate and select coconut varieties and devote less time than in the past to the management of their palms. A quite frequent trend is to promote "local Tall varieties". In some cases, what is now called a "local variety" is an uncontrolled mixture of various traditional varieties and sometimes modern hybrids. The “best palms” harvested for seednuts are often natural crosses between traditional varieties, or crossed between traditional varieties and modern hybrids. Seednuts are sometimes harvested on Tall-type palms planted very close to Dwarf x Tall hybrids, or even directly on such hybrids.

Governments in many countries are promoting farmers’ organizations. Some countries have tried to engage with such organizations and to strengthen their role and efficiency in seednut production. The idea is for researchers to interact with farmers’ organizations using participatory approaches, and then to use both breeders’ and farmers’ knowledge to educate trainers to help women and men farmers to improve their breeding and seednut production, also in gender-responsive ways. Finally, such interactions increase the knowledge of breeders about the real needs (including gendered trait-preferences) of the farmers or private sector stakeholders and thus lead to better breeding scheme’s programing, and more relevant outputs.

2.5.3 Past and contemporary coconut breeding

Coconut breeding programmes aim to improve yield, to develop varieties tolerant to biotic and abiotic stress and well adapted to the main uses of the coconut palm (Arunachalam and Rajesh 2008). As with most perennial crops, coconut breeding is complex and takes a long time, yet despite this, important achievements have been recorded.

Scientific research on coconut started in India in 1916 but many studies were interrupted by world wars and by the 1929 economic crisis. (Ratnambal and Nair 1998). The first coconut hybrids created by a scientist were produced in Fiji in 1926, by crossing the Malayan Red Dwarf (a classical Dwarf) with the Niu Leka Dwarf (a Compact Dwarf) (Marechal 1928).

Traditional coconut varieties are classified in four types: **Tall**; two kinds of **Dwarfs** (**autogamous Malayan** type and **allogamous Compact** type); and a few rare varieties intermediate between Tall and Dwarf and called **Semi-Tall**. Coconut breeders have tested crosses within and between most of these types.

The first “scientific” hybridizations between Dwarf and Tall coconut varieties were initiated by Indian researchers (Patel 1938). However, recent study shows that Indian farmers from Kerala have long been able to select natural hybrids within the progeny of the Chowgat Orange Dwarf. They choose and value the rare seedlings with brown sprouts in the progeny of the Orange Dwarf that otherwise has an orange sprouts due to selfing (Bourdeix et al. 2008). Indian scientists very probably observed what farmers did and then amplified their efforts with scientific research.

"Modern" coconut breeding only resumed after the Second World War, with the first scientific surveys studying coconut diversity. From 1945 to 1960, numerous hybridizations were produced thanks to the involvement of institutions like CPCRI and IRHO with generally a low number of palms per progeny. Even when hybrids displayed a high yield potential, the lack of reliable seednut production prevented their distribution to farmers.

The development of mass production techniques for hybrid seednuts dates back to the 1970s. These techniques opened the way for distributing coconut hybrids at scale, enabling many farmers to adopt them.

The first international meeting of coconut breeders was organized by Burotrop, GTZ and IPGRI (now Bioversity) and hosted at Marc Delorme Research Station in Côte d'Ivoire in 1994. The meeting aimed to create a connection between the existing coconut breeding programmes around the world and to standardize the techniques employed in coconut breeding (Batugal and Rao 1998, Santos et al. 1996). At the end of the meeting, it was observed that most of the national breeding programmes preferred to rely on their local cultivars rather than to introduce advanced varieties from the largest breeding centres, such as the Marc Delorme research station in Côte d'Ivoire.

In 2001, COGENT supported the APCC in conducting a survey on farmers' varietal preferences in 10 coconut-producing countries. The results showed that: 1) social facts are critical for explaining varietal preferences (Bourdeix et al. 2008); 2) although, there is no universal hybrid, hybrids generally performed better than the Tall traditional varieties under adequate rainfall and good soil conditions; and 3) farmers had not focused exclusively on high yields but were also interested in other traits such as robustness requiring low inputs and special characteristics for producing high-value products.

Between 1999 and 2004, COGENT conducted a multi-location trial (CMT) involving seven countries from Africa, Latin America and the Caribbean. This experiment, funded by the Common Fund for Commodities (CFC) compared the same six promising hybrids for copra production, shipped from Côte d'Ivoire with hybrids and traditional varieties produced locally. Sixteen coconut hybrids tested in this project started to flower two and a half to three years after planting, compared with the five to six years normally required for traditional Tall-type varieties to reach flowering stage. Potential annual copra yield projections for the best hybrids was up to 5 t/ha at the peak of production (10-12 years) compared to the 1t/ha generally produced by the traditional cultivars (Batugal et al. 2005a). Exploitation of mutations has also been considered, such as the breeding work on varieties known as Makapuno/Kopyor or Aromatic (See box next page).

2.5.4 Breeding for yield increase

Coconut yield is expressed in different ways according to uses and markets. Until the 1990s, breeders mainly expressed yield in terms of tons of copra or oil per hectare. Those focused on coconut water consider the number of fruits per hectare, or the water volume per hectare. Sometimes yield is also expressed as the weight of whole fruits per hectare, or quantity of toddy per palm.

Makapuno and Aromatic Green Dwarf: unique cultivars

Some examples illustrating the importance of coconut genetic diversity: a fruit from a Makapuno palm pollinated by another variety will not have the soft and thick kernel specific of Makapuno. A tender coconut from an Aromatic Green Dwarf but pollinated by another variety will lose its special delightful fragrance. Observations conducted notably in Papua New Guinea reveal a wide genetic diversity in fruit quality, which is extremely difficult to capture. For instance, 10 to 20% of the fruits produced by some rare palms have tasty kernels as crispy and tender as apples. In fact, as for Makapuno and Aromatic Green Dwarf, the quality of the kernel and coconut water relies on the genotype of the pollen: the kernel will be tender and crispy only when the mother-palm self-pollinates. This phenomenon occurs less frequently for Tall varieties which are mainly pollinated by surrounding palms. Most Dwarf varieties are homozygous and self-pollinating, so the three sets of chromosomes in kernel and coconut water are almost identical.

Yield was the main breeding target in all locations unaffected by lethal diseases. Yield improvement breeding strategies are either intra-varietal selection (also called mass selection methods) or inter-varietal hybridization.

Mass selection methods, i.e. selecting the best palms within the best plots began to be scientifically applied in the 1940s. All the research stations involved with coconut breeding have used this mass selection method.

There are three variants of mass selection, differing according to the reproduction system used: mass selection using open pollination; selfing[76]; or intercrossing (Bourdeix 1988). Positive mass selection using open pollination has been the most practised, but with variable results[77]. In the most favourable cases, the drastic selection necessary to obtain a substantial improvement would considerably reduce the potential of seednut production. One more generation of multiplication is needed to multiply the best palms. Thus, it is better to use this generation to evaluate parent palms not only from their own performance but also from their progeny's performance. In any event, breeding methods based on progeny tests within a variety (intra population) have rarely been used, generally because the pedigree of the progenies was not kept after planting. Pioneering work was conducted in Indonesia where evaluation of open pollinated progenies of the Mapanget Tall (Tammes 1958) started in 1926.

A list of hybrids tested by most coconut breeding centres was published in 1999 (Bourdeix 1999). From 1960 to 1999, about 400 hybrids between traditional cultivars were evaluated. After 2000, the creation of new hybrids strongly decreased in favour of

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[76] Selfing, also called self-pollination, induces a yield decline without appreciably increasing production homogeneity. In the most favourable cases, the drastic selection necessary to obtain an improvement considerably reduces seednut production potential.

[77] The main drawback of mass selection using open pollination is the unknown rate of selfing, which fluctuates according to seasons and numerous other parameters. From a genetic point of view, this rate is important because selfing often induces inbreeding depression in Tall-type cultivars. Efficiency of mass selection in the case of the coconut palm is hotly debated.

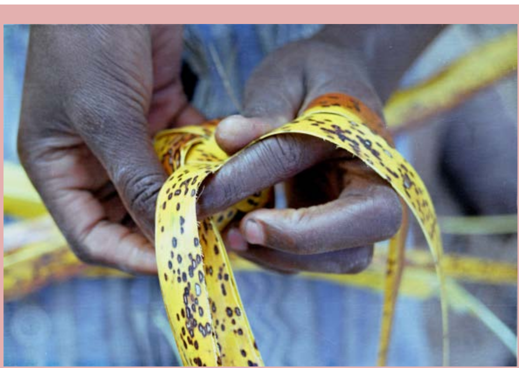
the evaluation of existing hybrids in a wider range of environments. A composite variety was also created in the Philippines and disseminated among farmers.

The genetic progress achievable by crossing two by two traditional varieties appears to be limited. Improvement of the best hybrids started in 1970, leading to a new generation of hybrids producing 10 to 25% more that the initial hybrids between traditional cultivars. The method is based on a half-sib family progeny test and requires multiplication by selfing of parent palms. This demanding process was applied only in Côte d'Ivoire and Vanuatu by planting experiments between 1970 and 1998.

Efforts were also initiated to conceptualize coconut breeding as a continuous process, leading to regular and sustainable genetic progress. The method of recurrent reciprocal breeding started to be applied in Côte d'Ivoire (Bourdeix 1991) but was stopped by the political crisis in 2000.

2.5.5 Breeding for pest and disease resistance

Selection for pest and disease resistance in coconut populations has been one of the primary activities of coconut breeders and pathologists. Fighting crop diseases has proved challenging, for coconut, where pathogens often persist for 50 years. Efficient control methods generally include reducing vector populations, eradicating the first diseased palms, and adopting suitable tolerant varieties. Each of these components appears to be insufficient to control the diseases individually, but together would sometimes be capable of reducing its incidence to an economically manageable level.



Diseased coconut leaflets in Mozambique. (M. Dollet, CIRAD)

The average effective lifespan of a gene for disease resistance has been described as only 10 to 15 years, and then the pathogen generally overcomes the resistance. This happened in Jamaica in the 1980s the Malayan Yellow Dwarf (MYD) and its hybrid with the Panama Tall (PNT) or Maypan were widely used to replant LYD affected regions. This strategy seemed successful for the next 20 years, and then LYD devastated the previously resistant materials[78]. Similar resistance breakdown could also occur where phytoplasma-tolerant varieties are used, such as in Ghana, India, Mexico, Sri Lanka and Tanzania.

In the 1980s, Ghana imported many cultivars from the international genebank in Côte d'Ivoire to test their resistance to local LYD phytoplasma strains. So far, the only tolerant cultivars identified are the Sri Lanka Green Dwarf and the Vanuatu Tall, both coming from countries were the Ghanaian phytoplasma does not exist. This clearly illustrates the crucial value of conserving and using coconut genetic resources.

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[78] Treatment through injection of a tetracycline-type antibiotic is efficient but its high cost and environmental effects prevent its wide application.

Until the 1960s no coconut disease was apparent in Vanuatu. During a breeding programme initiated in 1967, many foreign coconut varieties were planted in Espiritu Santo Island. Within a few years, these imported varieties started to die. Coconut foliar decay virus (CFDV) is a lethal disease which is endemic in Vanuatu. The local populations known as 'Vanuatu Tall' (VTT) constitute the only cultivar that is fully tolerant to CFDV. All introduced cultivars and hybrids were affected to different degrees. Between 1967 and 2008 a conventional breeding programme was conducted with the aim of creating hybrid planting-material combining CFDV tolerance with improved copra yield and high copra weight per nut. This objective was finally achieved by crossing the progeny of selfed palms of the 'Rennell Island Tall' (RIT) cultivar, selected for large fruits and CFDV tolerance in field screening tests, with VTT, improved by mass selection and inter-crossing (Labouisse et al. 2011).

In Colombia, the International Centre for Tropical Agriculture (CIAT) has been involved in research on Red Ring Disease (RRD) caused by a nematode, *Bursaphelenchus cocophilus*, transmitted by the coconut weevil *Rhynchophorus palmarum*. This disease complex usually kills over 80% of palms in affected areas along the Colombian Pacific coast. A methodology for screening for resistance by inoculation of seedlings under greenhouse conditions has been developed.

In Mexico, a second genetic improvement phase began in 2009, to develop LYD resistance with three components:

1. Developing coconut varieties by self-pollination of three CMT hybrids: MATAG, Malayan Red Dwarf (MRD) x Tagnanan Tall; MRD x Vanuatu Tall (VTT); VTT x Tagnanan Tall (TAGT); and PB121+ Malayan Yellow Dwarf x improved West African. These progenies were evaluated from 2002 to 2011 in Tabasco for yield and resistance to LYD;
2. Cloning open-pollinated progenies of the best MATAG hybrid and multiplication by somatic embryogenesis. This step was also achieved;
3. Eleven coconut cultivars, (including Vanuatu Tall and Tagnanan Tall), were also introduced from the International genebank in Côte d'Ivoire to Mexico in 2012 by using *in vitro* cultivated embryos. These international transfers are not yet registered in CGRD. VTT and TAGT will be used as the male parents for producing seednuts from those LYD resistant hybrids identified in the multi-location trial.

Besides traditional breeding efforts, a number of metabolites have been used as chemotaxonomic markers to identify pest and disease resistance. These markers help to elucidate host-pathogen relations and identify potential disease control methods. For instance a recent 5-cultivar LYD-tolerance study in Mexico, suggested that while the individual components of cuticular wax do not play a significant role in palm-insect interactions, their combined presence as wax is critical. In 2005, field experiments began preparing for MAS by planting Dwarf-by-Dwarf hybrid progenies, in Côte d'Ivoire[79].

[79] For instance, the Sri Lanka Green Dwarf (PGD) is tolerant to LYD in Ghana but it produces small useless fruits on the sandy African soils. The Malayan Red Dwarf (MRD) has better agronomic value. It was tolerant to the first strains of LYD in Jamaica

2.5.6 Breeding for quality traits

The main commercial products of coconut are obtained from the fruits, and are used fresh as well as agro-industrially processed for food, human health, cosmetics, and fine chemicals.

Botanically speaking, the coconut fruit is a drupe, consisting of pericarp and mesocarp (husk), endocarp (shell) and testa enveloping the mature endosperm (kernel) which has a central cavity (vacuole) containing liquid endosperm (enriched water). From a genetic perspective, both kernel and coconut water are triploid, comprising two sets of chromosomes from the female parent, and one set of chromosomes from the male parent. So the genetic nature of the pollen strongly influences the quality of both kernel and coconut water.

The top breeding priority is developing cultivars bearing high quality fruit adapted to the various uses. Breeding for copra (dried oily kernel) quantity has been the main target of the last 40 years of selection and often the only one. However, the international copra market is continuously declining (Prades et al. 2016). In coconut kernel for instance, high oil content, rich in lauric acid and minerals is much valued (Dayrit 2015). Thus, instead of breeding for copra content, a more interesting approach is to seek a specific fatty-acid profile.

Coconut water is naturally tasty, and rich in minerals, along with traces of proteins and vitamins but very little oil. Its international market has grown exponentially during the last ten years. In this case, immature coconut fruits are the most suited for the production of this natural beverage. However, a few countries (mainly Brazil and Thailand) have launched breeding programme dedicated to the relevant traits: volume of water, sugar content (measured as Brix), aromatic profile and mineral composition.

Coconut fruits can seem user-unfriendly. The fibrous coconut husk is hard when mature and generally it is impossible to manually remove it. The shell is also hard and can be quite dangerous to break if a suitable tool is not used. The kernel is strongly attached to the shell. It remains too thin, firm and fibrous and sometimes its consumption can harm gums. Regarding tender coconut harvested for water consumption, the husk is too thick and the water makes up only 15 to 26% of the total fruit weight. Thus there remains considerable work for breeders to upgrade the coconut palm to the status of a fully domesticated species. And new selection schemes are urgently needed.

Fortunately, breeding programmes are increasingly interested in selection for quality traits. The most observed quality traits include: husk, shell and kernel percentages in mature fruits (Aragao et al. 2009); kernel oil content (Abreu et al. 2013); oil fatty-acid composition (Kumar 2011); coconut water percentage in tendernuts (Passos et al. 2009); and the sugar content, pH, mineral and vitamin content and flavour quality of coconut water (Prades et al. 2012). Sensory evaluation of coconut water has recently been

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but is sensitive to the Ghanaian pathogen. The hybrid PGD x MRD was created in 1993; in 2005 the F2 generation was planted by selfing this hybrid, so (PGD x MRD) x (PGD x MRD). From this progeny it is expected to find new Dwarf combinations with both tolerance to LYD and good agronomic value. See the Plate 3.1 in Chapter 3.

conducted on four cultivars (Assa et al. 2013). The sweeter water of immature nuts from Dwarf-type cultivars was the most appreciated.

Along with the development of new descriptors, new quality measurement tools and methods are now available for high throughput phenotyping. Near infrared spectroscopy, high performance chromatography, digital image analysis combined with proteomics and metabolomics analyses are available. Some of these tools have already been optimized for the study of coconut fruits' quality (Prades et al. 2006).

2.5.7 Breeding for drought and other abiotic stresses

A wide range of anatomical, physiological, and biochemical features contribute to various stress adaptations in plantation crops. Recent developments in biotechnology and molecular genetics are essential to fasten the breeding processes. Using diverse criteria, early mass screening methods have included:

- For drought tolerance: leaf water potential, leaf stomatal frequency, epicuticular wax content, level of lipid peroxidation, osmotic pressure applied to plantlets cultivated *in vitro* (Gomes and Prado 2007);
- For cold tolerance: measurement of coldness on leaves by electrical conductivity (Caom et al. 2009);
- For resistance to cyclones: presence of a bole, stem base width, stem height 10 and crown characteristics (weight and volume of fronds and fruits) (Labouisse et al. 2007);
- For salinity adaptation: leaf stomatal frequency, leaf gas exchange, the quantum yield of chlorophyll fluorescence, and the relative chlorophyll index (Da Silva et al. 2017).

Water is an increasingly scarce natural resource required for crop production. Growing cultivars that use water efficiently is a key step in achieving sustainable coconut production in the many areas affected by a long dry season.

Coconut killed by drought in Nuku Hiva, Marquesas Islands. (R. Bourdeix, CIRAD)

The coconut palm generally grows well where annual rainfall is between 1300 and 2500 mm or more. An average monthly precipitation of 150 mm is generally considered ideal in zones where irrigation is not practiced. A prolonged dry season lasting for up to four months may adversely affect the palms. This constraint occurs periodically in various coconut growing zones, such as in southern India (Kerala), Sri Lanka or the West African coast. In low rainfall areas and in places where the soils have poor moisture-retention ability, improvement of soil moisture retention capability will reduce damage to palms and even reduce mortality of palms when the drought is prolonged. In professionally managed large coconut plantations, and smaller farms, coconut husks are buried in various patterns to improve soil moisture retention.

The coconut needs about 44 months to develop from inflorescence primordia initiation through to fruit maturity. As a result, serious drought affects coconut yield not only during the drought period but also in the three following years by constraining the development of female flowers.

Research on drought tolerance has shown variability for revival capacity, water use efficiency, dry matter production and yield of coconut cultivars. Heterosis was observed for some of the desirable characters for drought tolerance. Results obtained in India indicated that hybrids using Talls as mother palms (Rajagopal et al. 2005).are generally more tolerant to drought when compared with Dwarfs (Malayan types) and with hybrids using Dwarfs as the mother palm (Rajagopal et al. 2005).

Maoris coming from tropical Polynesian islands tried so many times to grow coconut palms in New Zealand but never succeeded due to the cold weather[80.] Polynesians living in the Austral Islands (southern French Polynesia) also suffer greatly from scant coconut production. Because it gives any landscape a more 'tropical' look, many people attempt growing coconuts in non-tropical climates. Studies conducted in Florida shows that palms subjected to long periods of low temperature have soft, sunken, reddish areas on the trunk. These cold-damaged trunk areas are often invaded by secondary fungi and/or bacteria that cause trunk-rot and, several months later, the collapse of the entire crown. Fertilization may improve cold tolerance (Broschat 2010).

There is a significant potential market for cold-tolerant coconut varieties able to survive in countries with a temperate climate. The first cold-hardiness studies in Hainan Island (China) indicated the existence of genetic variability. The semi-lethal temperatures ranged from 7.3 to 12.4 °C according to the cultivar. Local Hainan Tall coconut varieties had the strongest growth vigour but lower yield when compared with some introduced cultivars (He-shuai et al. 2009).

Study results have contributed to refining the criteria used for collecting abiotic stress tolerant germplasm (Kumar et al. 2006). The methodologies developed were mainly used to compare varieties but not yet to commonly select individual coconut palms within a given variety.

2.5.8. Genomics and DNA markers

Germplasm curators and coconut breeders who are increasingly using the new molecular and genomics tools optimize coconut germplasm conservation and harness its potential. A wide variety of molecular markers have been used to study the evolving structure of coconut genetic diversity (Lebrun et al. 2005). Genomics contributes increased specific knowledge at various levels:

- At genus level, it helps to more precisely locate coconut's position within the cocoseae subtribe;

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[80] Latitude greater than 36 degrees.

- At species level, it provides crucial information on the evolving structure and history of the relevant genepools;
- At cultivar and accession levels, it helps in differentiating between collected germplasm, checking the reliability of the regeneration process and optimizing collecting strategies;
- It complements and enhances traditional breeding approaches with regard to use of genetic markers and candidate genes for commercially important traits, and to better understand the interactions between genome and environment.

Cross-specific studies utilizing gene sequences have allowed clarifying the position of coconut within the cocoseae subtribe, identifying the genus *Syagrus* as its closest relative[81]. Furthermore, the cross transferability of DNA markers to closely related palms was demonstrated as early as 2001 and confirmed in 2012 (Zaki et al. 2012).In 2000, a CFC grant funded developing a 14 microsatellite markers set by CIRAD. A population-assignment software was developed as part of this kit and has since been used by hundreds of teams (Piry et al. 2004). More than 100 genebank accessions and *in situ* populations collected through COGENT were studied using this kit. The technique has been transferred to nine member-countries. Using such a common marker system provides the facility to compare the results of successive studies.

Global level intra-species have allowed identifying two large genetic groups, known as "Pacific" and "Indo-Atlantic" which can be seen as sub-species (Gunn et al. 2011). Based on a different set of DNA markers (Illumina transcriptome sequence), Chinese coconut germplasm has been found similar to a subset of coconut germplasm from South-east Asia (Xiao et al. 2013).

Molecular markers have been also used recently to monitor the accuracy of the seed production process, where contamination by allogenic pollen can be as high as 20%. Molecular markers can be used to monitor the benefit of improved techniques but they cannot replace such methods. Some molecular studies have focused on marker-trait association, including one where three linkage maps allowed locating quality-trait loci (QTL) associated with seedling traits, epicuticular wax, and yield and fruit components on their respective chromosomes. This study identified alleles statistically associated with resistance to Eriophyes mite and LYD. In general, populations showing some degree of resistance to LYD are connected (directly or indirectly) to South-east Asia and the Pacific region.

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[81] See more pictures at:
http://www.kew.org/science/tropamerica/imagedatabase/large1/cat_single1-4040.htm
http://www.kew.org/science/tropamerica/imagedatabase/large1/cat_single1-4042.htm

Studies have been conducted on the gene sequence, regulation pattern and expression of various genes involved in fatty acid metabolism during *in vitro* culture, as well as in the Makapuno trait and in disease resistance. Single nucleotide-amplified polymorphism SNAP markers linked to enzymes involved in endosperm development were shown to be polymorphic when comparing Makapuno/Kopyor and normal coconut (Sukendahm et al. 2009). Markers associated with the Tall-type palm trait in coconut were identified using either sequence-characterized amplification region (SCAR) (Rajesh et al. 2013) or SSR (Bandupriya et al. 2013) markers The genomes of key coconut pathogens (Phytoplasma, Eriophyes) has also been studied.

Apart from SSR markers, expressed sequence tag (EST)-derived single nucleotide polymorphism (SNP) and insertion-deletion polymorphism (indel) markers also been applied in coconut genomics research. Coconut WRKY transcription factor genes were used to assess variation at the single nucleotide level, and SNPs were detected. Recently, an extensive transcriptome sequencing campaign has allowed identifying 57,304 unique genes (Fan et al. 2013) and the complete chloroplast genome has been obtained (Huang et al. 2013). Thus, the genomics and information revolution has generated a wealth of information which is now beginning to be used for breeding purposes.

2.5.9 Coconut, climate change and coastal areas

Many studies have shown that global warming is a key likely threat to future biodiversity. The impact of climate change on crop cultivation is assessed via controlled environment experiments and/or simulation models. For perennial crops, field experiments are expensive and time consuming. However, they provide crucial information for model inputs which are then used for wider applications. Such predictive simulations are important for alerting scientists, decision-makers and other stakeholders. They support the development of proactive strategies to reduce climate change impacts on biodiversity, food security and livelihoods (Bellard et al. 2012). For instance, location-specific management of coconut plantations can double yields in many regions of India.

Although rise in sea level is one of the most certain consequences of global warming, it remains one of the least studied. Several simulations state that rises in sea level will accelerate in future with a potential rise from 0.5 to 0.98m by the end of the century (IPCC 2013[82]). Globally, around 180,000 islands (Bellard et al. 2012) enclose a fifth of

In 2016, Bioversity embarked on a UK Darwin Initiative[1]-This genebank is being transferred to a safe site in PNG, to avoid phytoplasma infection. The project is identifying, mapping and collecting unconserved coconut diversity that is threatened by predicted climate change, in Fiji, PNG and Samoa. This diversity will be conserved in a new ICG-SP embracing the three countries.

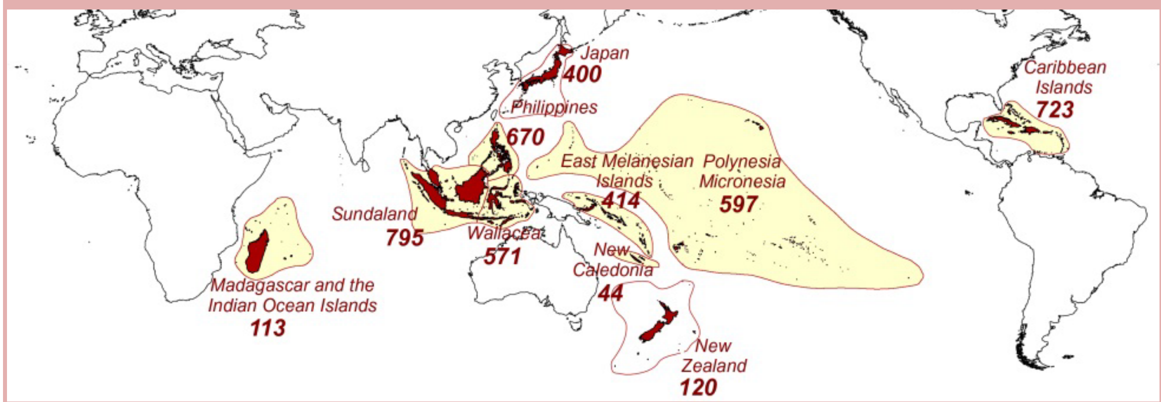
[82] See the URL: http://www.ipcc.ch/report/ar5/wg1/ More details about sea level change in Chapter 13 of the report at URL: https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter13_FINAL.pdf

the world's biodiversity) (Kier et al. 2009) and certainly more than 50% of coconut diversity. At least two thirds of coconut plantations are located in coastal zones and the majority of coconut growing countries are islands.

Effects of climate change are already obvious. For example, on some Polynesian islands in the Tuamotu Archipelago, coconut farmers point out increasingly frequent phenomena of high tidal swell and saltwater incursions from the ocean on atolls. This phenomenon is not new but this swell sweeps fallen coconuts off the strands and salt water stays longer on the land and contributes to a high salinization of soils and the fresh-water lens on atolls, inducing a decrease in coconut production (Prades and Ollivier 2013).

Recently, a study was conducted on 10 insular biodiversity hotspots (Bellard et al. 2014), eight of which are spread over 3927 islands, which include important coconut cultivation areas (Figure 2.8). Depending on the sea level rise scenario, the number of "coconut" islands with submersion risk ranges from 231 to 700 (Table 2.7). Therefore, priorities for collecting the most endangered germplasm are to be set by integrating these projections from climate scenarios, the knowledge on *in situ* coconut diversity and the analysis of the diversity presently conserved in *ex situ* collections.

Figure. 2.8. Localization of the eight insular biodiversity hotspots (in red) which includes important coconut cultivation areas (in pale yellow). Adapted from Bellard et al. 2012.



In addition to sea level rise, climate change is projected to increase mean temperatures, accentuate skewed precipitation, and increase the frequency and intensity of extreme rainfall events and tropical cyclones, leading to more frequent flooding. Apart from low altitude islands, the cultivation zones most endangered by climate changes will be the river deltas and the zones prone to longer dry or hot periods. Some models project a substantial decline in winter rainfall in South-east Asia.

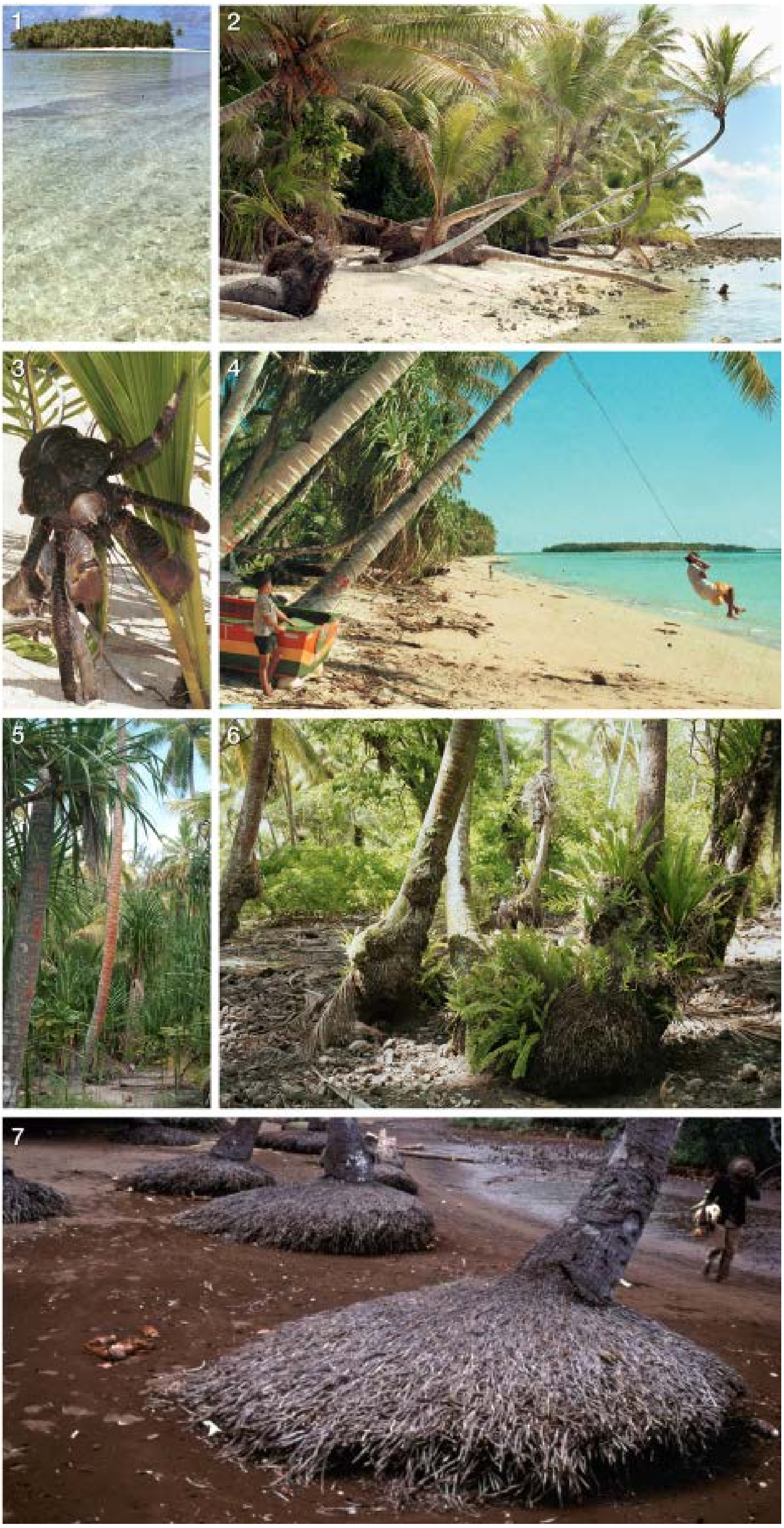
Growing more resilient varieties is essential for regions that are projected to be negatively impacted by climate change. 'Climate resilient' coconut varieties possessing characteristics such as: stronger root systems, thicker and shorter stems for tolerance to cyclones; drought tolerance for regions affected by longer dry seasons; and tolerance to greater heat (Ranasinghe et al. 2012) and more saline environments, when appropriate.

Plate 2.3

Coconut, climate change and coastal area

Coconut is much more than coconut!

At least two thirds of coconut plantations are located in coastal zones. Coconut palms could be more extensively used to mitigate coastal erosion and protect villagers against weather hazards.



1 & 2. A coral island in Funafuti Archipelago, Tuvalu, Micronesia, and the area of its beach most exposed to storms and cyclones.

3. A coconut crab from the same island.

4. A village beach in Funafuti Archipelago, one of the areas most threatened by sea level rise in Tuvalu.

5. View of typical vegetation of small coral islands in Micronesia. Increasingly frequent high tidal swells and saltwater incursions from the ocean contribute to a high salinization of soils and the fresh-water lens on atolls.

6. Extreme erosion along Quelimane river in Mozambique.

7. Soil erosion near a river delta in Moheli Island, Comoro archipelago. Planting the coconut palms more densely would probably have better protected the soil.

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Table 2.7. Projected numbers of islands to be submerged by the sea - under two scenarios: A - Rise in sea level by 1 m and B - by 6 m (From Bellard et al. 2012).

Hotspots	Total	Scenario A	Scenario B
Madagascar & Indian Ocean	113	4	13
Sundaland	795	61	122
Walacea	571	39	7
New Caledonia	44	1	5
East Melanesia-Polynesia	597	15	84
Philippines	670	48	113
Caribbean Islands	723	63	356
Total	3 513	231	700

By 2030, 50% of the world population will live within 100 km of the coast (Bindo et al. 2007) and hence inside coconut cultivation areas in tropical countries. Coconut tolerates moderate salinity and is the most adapted crop to sandy coastal areas. In India, the CPCRI has developed a coconut-based technology for littoral sandy soil management by adopting soil-moisture conservation measures and resorting to intercropping. The technique converts hot sandy stretches of land into highly productive and remunerative cropping systems. It involves moisture conservation with coconut husk and coir pith, and intercropping during the wet season with a variety of vegetables, pineapple and fodder grass. This system enables farmers to double their income and has potential for wider application.

Interactions between coconut and climate occur in two main ways. While climate change influences coconut plantations, the climate itself is also moderated by the plantations. Coconut plantations are very good candidates for mitigating greenhouse gas emissions. Depending on their extent of spread, coconut plantations contribute to microclimates which regulate the weather and allow intercropping. Coconut plantations capture carbon dioxide and release oxygen, as for any photosynthesising plant. The carbon sequestration potential of coconut plantations is estimated to be about 8-32 Mg CO_2/ha/year depending on the age, soil type and management as well as the components considered (Kumar 2009, Roupsard et al. 2002). Apart from these, coconut oil is also used as fuel oil in remote islands where the cost of imported fuel transportation is high, as well as in

Palms for Tsunami survival

People of the Pacific Region traditionally used coconut palm to survive a tsunami or cyclones: for instance in the Tuamotu Archipelago, the Polynesian practice to survive tsunamis was the following: when isolated on a low coral island, quickly climb a tall coconut palm, cut off all its leaves, and attach yourself with a rope to the top of the trunk, and wait...

some bigger islands such as those of the Philippines. Utilization of coconut biomass residues such as shells and husks for heat and power generation is common in the coconut and allied industries.

Although coconut palms are widely planted in coastal zones to reduce erosion, no scientific study has yet been conducted to assess, quantify and eventually promote this use. When used for beach landscaping, these palms tolerate flooding better than *Casuarina* trees (filao). For instance, coconut palms played a crucial role during the 2004 tsunami and saved hundreds of lives by reducing the intensity of wave. In many coastal villages, coconut palms remained standing even when many houses and other buildings were flattened.

2.5.10 Coconut conservation, landscapes and ecotourism

In 2015, more than 1.2 billion international tourist arrivals were counted worldwide[83]. For a long time, tourism has been associated with sea, sand and sun, often referred to as the 3Ss. Local and international tourism is significantly associated with coastal environments. Coconut palms have long been associated with the natural aesthetics of tropical tourist destinations.

Ecotourism can potentially provide important economic benefits to local people and help protect biodiversity. Community-based ecotourism has become a popular tool for biodiversity conservation and sustainably boosting livelihoods; based on the principle that biodiversity must pay for itself by generating economic benefits, particularly for local people. Local stakeholders and international companies involved in tourism can be convinced to develop ecotourism programmes favouring coconut genetic resources conservation. For the tourism industry evolving in a competitive environment, it becomes more and more important to stand out from the standard fare that tourism offers. Coconut palms should not symbolize anonymous exoticism. They can tell true stories, specifically related to local cultures, and they could be used in the framework of an ecotourism and anthropotourism approach.

In addition to the beauty of standing coconut palms, there is a wide range of possibilities to use coconut for tourism and ecotourism activities. The concept of a coconut park (Coconut World) was elaborated in Australia to harness the potential of coconut for ecotourism, linked with education, research and genetic conservation (Samosir et al. 2006).

[83] See URL: http://data.worldbank.org/indicator/ST.INT.ARVL

BenTre Festival

A fine example is the 3rd Coconut Festival held in Ben Tre, Vietnam, with hundreds of thousands of domestic and foreign visitors and local people taking part. The festival is not only a show-case of coconut products made by local processors but it also features the unique beauty of the Ben Tre province. These include highly appreciated activities such as: A coconut product exhibition and commercial fair; Community cultural activities; a coconut road art installation ; a coconut food festival; a Miss Beauty of coconut land; Visiting coconut plantation; a fine arts & handicrafts contest; a seminar on how to best promote the value chain of coconut; a ceremony to honour coconut farmers;

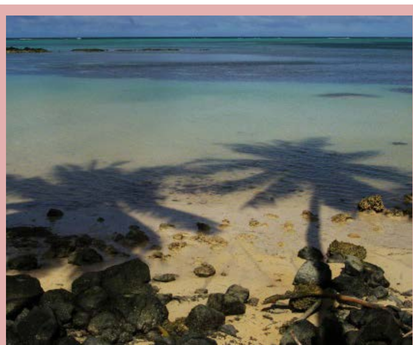
Dragon made from tender coconuts in Ben Tre festival, Vietnam

It is an opportunity for farmers, researchers, managers, processors and traders to exchange their techniques on growing coconuts and processing high value products to improve the local Ben Tre coconut industry in particular and Vietnam coconut industry in general.

The majority of world's inhabitants are urban. Coconut palms are widely used for landscaping in cities and towns in tropical regions. The number of coconut palms planted annually in public places greatly outstrips the total number palms existing in all the *ex situ* coconut genebanks. Many coconut palms are planted in public places without considering genetic resource aspects, and even sometimes without even a landscaping rationale.

Adult palms for landscaping?

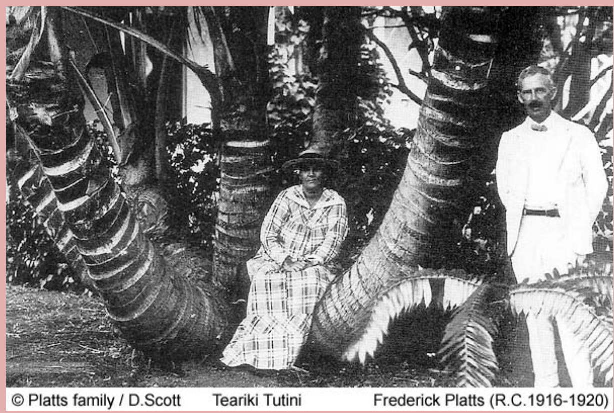
It is feasible to transfer and replant Tall adult coconut palms, even reaching 10 m high or more. There is a substantial and very lucrative market for such adult palms for public places and resorts; the palm prices are often calculated by the length of the stem, at US$100 per meter or more.



Some exceptional coconut palms have become local tourist attractions such as the 'Seven in one' palm in Rarotonga, Cook Island[84], the "Seven Branch coconut freak" in Karakit, Malaysia, the Eight-headed coconut palm in Ko Samui Island in Thailand, or

[84] See the full story, including DNA molecular analysis, at URL: http://cookislands.bishopmuseum.org/showarticle.asp?id=9

the 14-branch coconut palm at Baa in Maalhos Island, Maldives[85]. These rare "branched" palms were never studied and sampled for conservation in *ex situ* collections. They may help understand the functioning of the growing point; this may contribute to the improvement *in vitro* cultivation techniques.



A 14 branched coconut palm located on the island of Baa. Maalhos (left) and The "Seven in one" coconut palm in Rarotonga, Cook Islands (right).

2.6 Coconut germplasm exchange

Coconuts have been moving all over the tropical world. Recognition of the importance of coconut germplasm collecting, movement, exchange and conservation has prompted the establishment of national and international genebanks with a considerable collective range of genetic diversity.

The Convention on Biological Diversity (CBD) entered into force on 29 December 1993. It has three main objectives:

- The effective conservation of biological diversity;
- The sustainable use of the components of biological diversity;
- The fair and equitable sharing of the benefits arising out of the utilization of genetic resources.

The International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) is an international agreement with the overall goal of supporting global food security, allowing governments, farmers, research institutes and agro-industries to work together by pooling their genetic resources and sharing the benefits from their use – thus protecting and enhancing food crops while giving fair recognition and benefits to local farmers who have nurtured these crops through the millennia. It was adopted in 2001 by the United Nations Food and Agriculture Organization and came

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85 See URL: http://www.flickr.com/photos/48697218@N04/4525383340/

into force in 2004. The Treaty's truly innovative solution to access and benefit sharing, the Multilateral System, puts 64 of our most important crops – crops that together account for 80 percent of the food we derive from plants – into an easily accessible global pool of genetic resources that is freely available to potential users in the Treaty's ratifying nations for some uses. Coconut is one of these 64 crops, listed in the Annex 1 of the Treaty.

However, access to these resources is often restricted by pests and diseases affecting the germplasm and its safe movement, by the complexity of institutional legal and policy frameworks for the exchange of materials, and by the lack of commitment of some countries to provide conserved germplasm at the international level.

As presented below, the safe movement and exchange of coconut germplasm has been a major focus of COGENT and international organizations like CGIAR and FAO.

Traditional coconut germplasm exchange

Historically, international germplasm movements were sometimes conducted by monarchs or chiefs. This even influenced the name of some countries. For instance, Niue is an island nation in the South Pacific Ocean, 2,400 kilometres northeast of New Zealand which was originally known as Nukututaha. It was renamed after a chief's sons and their followers travelled to their ancestors' original homeland in Samoa. When they decided to return to Nukututaha, the chief of Manu'a, Moa, gave them two special coconut varieties and explained why each one was special. On returning to Nukututaha, the chief's sons held up these special coconuts and said "Ko e Niu è!" (Behold the coconut!). One coconut variety is Niu pulu, the coconut grown especially for making sennit rope used in constructing traditional buildings and making canoes. The other coconut is the Niu tea, the medicinal coconut. Its juice, husk, leaves, and just about every other part are used as medicine for a variety of ailments as well as for drinking and as food. According to this tradition, the name of the island was changed to Niue to honour the arrival of these two special varieties of coconut and to remember the chief of Manu'a, who gifted them.

Plate 2.4

Coconut for landscaping

Coconut is much more than coconut

1. A young coconut palm in a park in Samoa.

2 & 3. Coconuts and dwarf coconut palm used in landscaping restaurant and swimming pool areas in Samoa.

4. An attractive hybrid coconut palm (Malayan Red Dwarf x Rennel Island Tall) planted in a park, Samoa.

5. Landscaping for a small beach resort, Samoa.

6 & 7. Traditional landscaping of coconut palms using coconut husk circles in Sri Lankan households.

8. Coconut trunks providing support for creepers in a Samoan garden.

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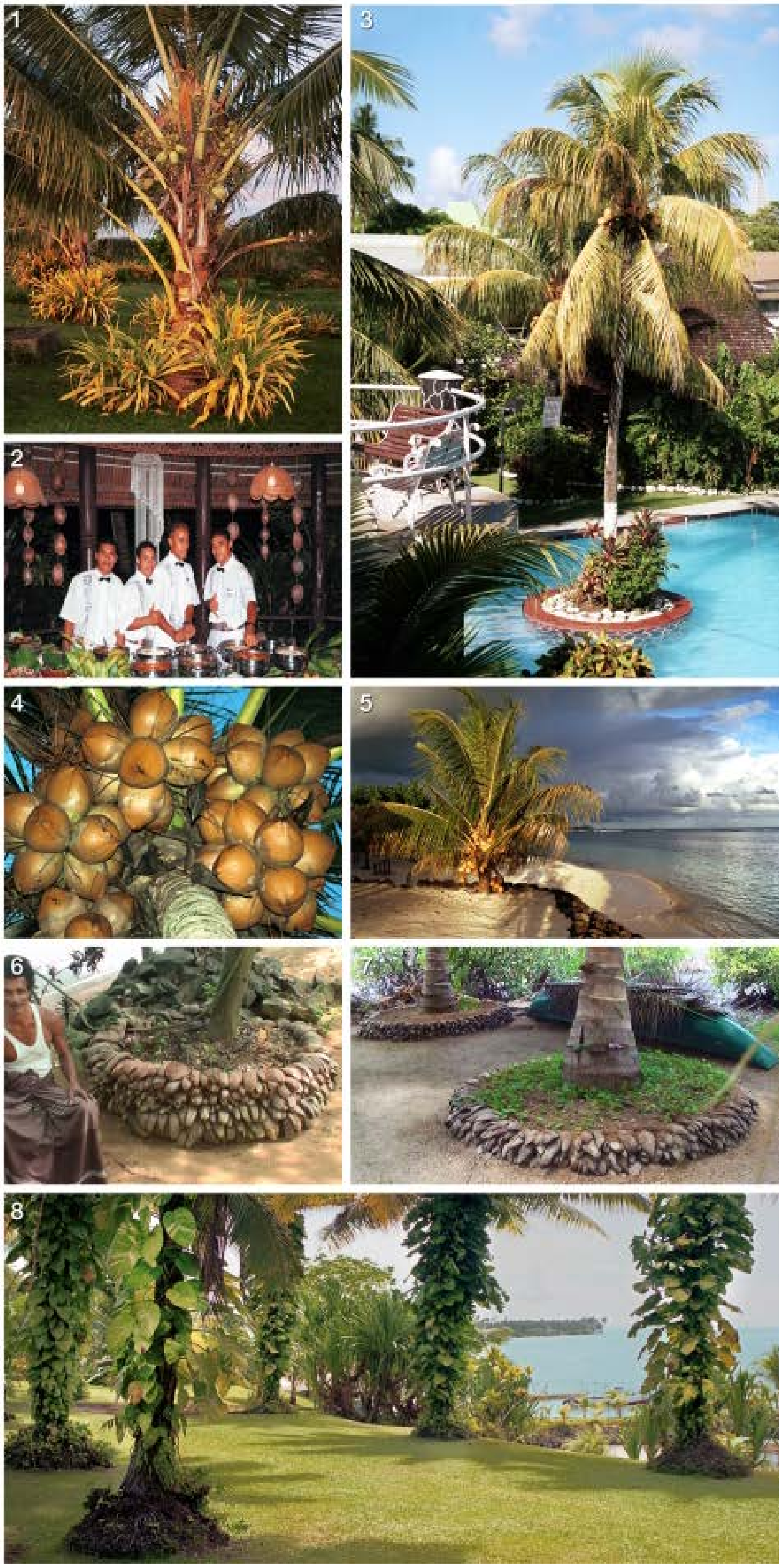

2.6.1 Benefits of sharing coconut genetic resources

The rapid growth of biotechnology over recent decades has prompted many countries to recognize the significant economic potential of their genetic resources and indigenous knowledge. The development of a global system on plant genetic resources was launched in 1983 under the auspices of FAO. The Commission on Genetic Resources for Food and Agriculture (CGRFA) aims to provide a flexible, fair and equitable framework for sharing the benefits and burdens of conservation and use of genetic resources.

Through the multilateral system promoted by the Treaty, stakeholders benefit from an easier and simpler access to a broader range of coconut diversity. Such access is often critical for increasing coconut production. Global collaboration in sharing these genetic resources should offer numerous benefits:

- Enhanced access to a broader range of germplasm including:
    - ✓ Populations and cultivars collected in farmers' fields, conserved and characterized in several *ex situ* collections in different geographical areas,
    - ✓ Breeding populations with enhanced agronomic and quality traits (especially pest and disease resistance),
    - ✓ Facilitated and more secure international germplasm movements.
- Enhanced free access to information and knowledge regarding coconut germplasm:
    - ✓ Global Information Systems providing reliable, standardized and comparable data, and dedicated to the wide range of stakeholders using coconut germplasm, such as consumers, farmers, processors and researchers,
    - ✓ Easier access to technologies, procedures and methods for coconut cultivation, conservation, breeding, research, processing and use.
- New or enhanced strategic alliances and partnerships within and beyond COGENT generate synergies in several ways including:
    - ✓ Effectively harnessing technologies such as standardized characterization and evaluation of coconut germplasm; quarantine measures for pest and diseases; genetic diversity analysis; cryopreservation of pollen, embryos or plumules; somatic embryogenesis; and a wide range of molecular tools,
    - ✓ Enhancing the legal status of the genebanks for securing conservation at the national level and extending the roles and responsibilities of NARS up to international level,
    - ✓ The opportunity to interact in a much broader and more efficient manner and to participate in defining common objectives in this Strategy,
    - ✓ Developing and harnessing new funding opportunities and commitments to support the implementation of this Strategy.

2.6.2. Safe movement of germplasm

Although essential to the utilization of coconut genetic resources, movement of coconut germplasm may also transfer pests and diseases. The *FAO/IBPGR Technical Guidelines for the Safe Movement of Coconut Germplasm*[86] provides country-based information about the risks associated with each particular pest or disease and recommendations on appropriate quarantine measures. It recommends that coconut germplasm be preferably distributed as *in-vitro*-cultivated embryos to reduce chances of introducing diseased material into disease-free areas.

COGENT is following these guidelines. At present, recommendations are to transfer germplasm only from reportedly healthy zones, and using preferably the technique of cultivating coconut embryos. *In vitro* techniques should be used for exchanging coconut germplasm in the form of excised embryos or plantlets grown from these embryos. However, even if these techniques are working well in the labs, they need further refinement to be adapted to a wide range of situations and germplasm. Funded by the Trust and CRP-FTA, a project was conducted from 2009 onwards to optimize, validate and apply a standard embryo culture protocol. This project applied existing techniques to a wide variety of genotypes and conditions, and led to the 2012 publication of improved guidelines (Cueto et al. 2012) available on the COGENT website. However, all the COGENT member countries need to upgrade their capacity and resources in order to successfully implement the embryo transfer protocol and thus to benefit from them.

Diseases caused by viruses, viroids and phytoplasmas are particularly serious threats to the safe movement of germplasm, since some of them cannot easily be eliminated and, moreover, virus and viroids can remain latent (symptomless) in some genotypes. In 2004, COGENT and Bioversity International published its *Manual on Germplasm Health Management for the International Coconut Genebank* (Ikin and Batugal 2004) which also serves as a guide for international and national genebank managers and any quarantine services.

Only a few of the genebanks carry out virus, viroids and phytoplasma indexing or have this indexing done by a partner institute. Indeed, effective differentiation, detection and diagnosis are still unavailable. Phytoplasma were detected on excised embryos taken from diseased palms, but transmission of the disease to plantlets has yet to be observed. No phytoplasma was detected in seedlings harvested from both symptomatic and non-symptomatic palms. Seedlings tested after two years did not develop LYD symptoms (Oropeza et al. 2011). On the other hand, phytoplasma transmission by seedlings was recently demonstrated in other species such as winter oilseed rape, tomato and corn (Calari et al. 2011). The Cadang-Cadang viroid was also detected on embryos, seedlings germinated *in vitro* and pollen taken from diseased palms. Transmission of the viroid through pollen, seeds and harvesting tools has been demonstrated (Pacumbaba et al. 1994).

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[86] See URL: http://www.cogentnetwork.org/images/publications/TG_safe_movement%20_germplasm.pdf

Pesticide and disinfection treatments are systematically applied to seednuts and seedlings internationally moved, following the rules and methodologies described in international guidelines. For endosperm plugs and embryos, disinfection treatments prior to *in vitro* culture should always be applied before they are moved from one laboratory to another. Plant health authorities of both the importing and exporting countries are involved in the process, by providing and checking the requested phytosanitary certificates which should accompany any coconut material being transferred internationally. Post-entry quarantine stations are present in a few coconut-producing countries, such as Brazil, and some material has been lost due to the delay for managing the imported seednuts, and because phytopathologists in charge of country-level quarantine were not trained to manage coconut seednuts or coconut embryos cultivated *in vitro*.

The risk linked to pests and diseases preventing distribution of germplasm has strongly restricted the development of all the coconut collections. Within this period, the International genebank for Africa and the Indian Ocean, located in Côte d'Ivoire and free from major diseases, has provided about 45% of the germplasm distributed internationally. The recent detection of lethal diseases caused by phytoplasmas in Côte d'Ivoire and also in Papua New Guinea will probably restrict germplasm exchange, especially if research does not provide solutions. At time of press, the PNG ICG is being transferred to a safer location, to avoid the threat of the Bogia phytoplasma. It is also being upgraded, with UK Darwin Initiative support, to protect Pacific coconut diversity threatened by climate change, embracing also Fiji and Samoa. These islands will host satellite genebanks for the PNG ICG.

Currently there is no Coconut Quarantine Centre offering quarantine for regional and international transfers. Laboratories able to index coconut material for Cadang Cadang viroid and/or for phytoplasmas are available in India, Sri Lanka, the Philippines, Australia, UK and France.

2.6.3 International germplasm transfers

CGRD records show that during the past 30 years, among the 145 accessions transferred from 1 genebank to another, 17 have been moved within the same country and 128 have been transferred internationally[87]. These international transfers have been conducted using either seednuts or embryos cultivated *in vitro*. The use of the embryo technique generated a decrease of at least 42% in accessions sizes, when compared to transfers conducted by using seednuts.

Figure 2.9 illustrates the international germplasm transfers facilitated between *ex situ* collections from 1983 to 2017. International genebanks have been involved in 57% of these transfers, but in a very unequal manner. The international genebank of Côte d'Ivoire has contributed 45% of the internationally transferred germplasm (57 accessions). During the same period, the international genebank of Papua New

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[87] The International Coconut Genetic Resources Database (CGRD) does not take in account germplasm transfers conducted during the recent embryo project funded by the Trust (it is necessary for the accessions to be planted in the field), nor the material recently taken by Mexico and Brazil from Côte d'Ivoire (no data transmitted by countries).

Guinea has provided a total of 12 varieties to Côte d'Ivoire, Malaysia, Vanuatu and Sri Lanka. In India, the international genebank provided only four varieties to Sri Lanka in 2002 and has acquired 22 varieties from other genebanks. International collections located in Indonesia and Brazil did not distribute germplasm to other countries[88]; However, Brazil has received 10 varieties from Côte d'Ivoire; Indonesia did not receive any variety from any other genebank. In the 2013 COGENT survey, only 40% respondents agreed that international collections are effectively playing their role in distributing germplasm at international level; 73% believed that the number of international genebanks should be doubled in order to increase efficiency and number of germplasm movements.

Among national genebanks, the Philippines was the most active germplasm provider, even exceeding all international genebanks except Côte d'Ivoire. Sri Lanka has provided varieties to Vietnam, Tanzania, Papua New Guinea and India; and Bangladesh, Mauritius and Madagascar have provided varieties to India. The national genebank of Solomon Islands provided the Rennell Island Tall to India, Vanuatu and Fiji.

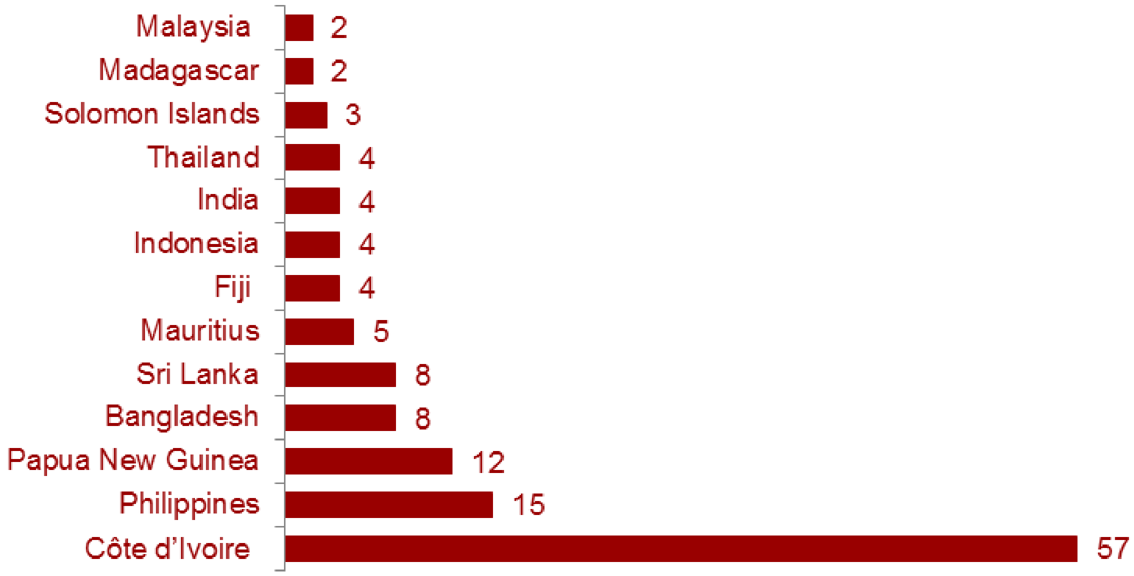

Figure 2.9. International transfers of coconut germplasm.

During the past 30 years, according to CGRD records, only a third of the 39 COGENT country-members benefited from receiving coconut germplasm from 13 countries. However, this data does not reflect the complete picture of germplasm exchange over the period. For instance, varieties were also sent from Côte d'Ivoire to Mozambique and Mexico, from Sri Lanka to Oman. Due to lack of budget and manpower for managing the CGRD and to lack of response and transmission of data from national researchers, these varieties have not yet been recorded as transferred accessions in the database.

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88 The four varieties sent from Indonesia to Côte d'Ivoire came from a private company.

According to the CGRD during the past four decades, germplasm exchanges have generally decreased. Transfer between genebanks reached 99 accessions in 1980; it doubled (104 more accessions) from 1981 to 1990, and then it increased much more slowly: only 34 germplasm transfers from 1991 to 2000, and 34 more from 2001 to 2017. This decrease is mainly due to emerging diseases, to the growing complexity of regulations on germplasm exchanges, and to the technological constraints of *in vitro* embryo cultivation. From a global perspective, in recent years, access to crop genetic resources has been constrained by exclusive technological and legal restrictions (Halewood 2013).

To our knowledge, since 2004, the year when the Treaty was signed, no Standard Material Transfer Agreement (SMTA) was used when moving coconut germplasm, despite the recommendations of the Treaty and the fact that many COGENT members are contracting parties of the Treaty. The SMTA[89] is a mandatory model for parties wishing to provide and receive material under the Multilateral System.

The first SMTA was recently signed in 2015 between CNRA and CIRAD while exchanging very specific material called "mapping population" which was used to prepare the sequence of the coconut genome.

COGENT countries agreed that the germplasm conserved in *ex situ* collections is a common good which is not for sale. Countries requesting germplasm from *ex situ* collections do not have to pay for the value of the germplasm itself. Nevertheless, managing this germplasm is costly, so requesting countries or dedicated projects should contribute. In 2011, the COGENT Secretariat launched a first initiative to standardize the cost of preparing germplasm for international exchange. Côte d'Ivoire and the Philippines, which are the main providers of coconut germplasm worldwide, agreed on the same germplasm preparation costs which are summarized in Annex 7.

2.7 Partnerships and networking

A wide range of partners are collaborating through COGENT, most of whom have contributed to developing this Global Strategy. These include national and international institutions directly involved in coconut research, international institutions dealing with all aspects of biodiversity management, local and international NGOs, private companies, international independent experts and some highly committed individuals.

These partners are too numerous to be cited in the main text of this document. Lists are given in annexes, as follows:

- Annex 1: the national institutions from the 39 member-countries officially involved in COGENT;
- Annex 2: the contributors to the Strategy and their parent institution(s);
- Annex 3: the individual contributors to the Strategy by chapters and sections.

[89] http://www.fao.org/plant-treaty/areas-of-work/the-multilateral-system/the-smta/en/?q=content%2Fwhat-smta

COGENT's nascent international thematic action groups (ITAGs- see Annex 4) also embrace a number of other individuals and institutions who have provided supporting expertise during the Strategy development. Full lists of proposed members are available on the COGENT website.

The "Coconut knowledge network for information exchange about *Cocos* ", known as the coconut Google group[90] and coordinated by Dr Hugh Harries is the main international forum in which important subjects have been usefully debated, contributing to the relevance and focusing of this Strategy.

All these partners, particularly those holding germplasm in the public domain, as well as any other organizations, institutions or networks involved in coconut genetic resources in recent years, are likely to participate in the implementation of this Strategy. The coconut genetic resources scientific community is currently collaborating through a number of networks, projects and international legal and technical frameworks. COGENT is linking all of the key partners in the coconut sector, worldwide.

COGENT aims to harness the benefits of its networked approach, particularly in the context of the Treaty and its global Plan of action. Since 1992, COGENT has developed an increasing number of connections with genebank curators, decision makers from the public and private sectors, scientists, private companies, farmers from the field until the highest levels. The COGENT Steering Committee, where official representatives from 39 coconut producing countries stand is a unique place to produce recommendations going directly to the Governments. These recommendations, being based on the inputs of hundreds of the most eminent scientists and hundreds of stakeholders working in the coconut sector for many years, are strong and highly reliable.

COGENT network is the only global entity able to generate a world vision of the status of the biodiversity and genetic resources of the coconut crop. Its existence should be recognized by FAO and UN as crucial to protect and ensure the food security of the future generations of coconut farmers and stakeholders. Without genetic resources preservation, the capacity of adaptation of this specific crop to challenges such as climate change, pest, disease or urbanization will be jeopardised. Thus, the monetary equilibrium of millions of people on the planet will be threatened.

2.8 Facing emergency situations: an overview

Despite the crucial role of COGENT in the coconut sector at the global level, this network is today threatened by the lack of interest of major international institutions. Thus, the key emergency situations to be addressed by the Strategy that can be concluded from the above are summarised below:

- There is a lack of commitment to conserving and using coconut genetic resources at local, national and international levels. This situation is mainly due to: 1) insufficient communication between researchers and other stakeholders;

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[90] See URL: https://groups.google.com/forum/#!forum/coconut

2) the ambivalent and multifaceted coconut symbolisms which often make decision-makers forget that coconut cultivation greatly influences the livelihoods of millions of poor farmers; and 3) the huge constraints linked to the biology of the plant that sometimes discourage both researchers and donors.

- The present global system, based on 5 international genebanks and 19 national genebanks, has not been fully effective and efficient in terms of both quality of conservation and germplasm sharing. This system needs to be revised, taking in account the specificities and the real activities of all COGENT genebanks.
- Emerging phytoplasma lethal diseases have recently threatened two international genebanks.
- One of the main risks threatening ex situ coconut collections is land pressure, often due to urbanization. Some accessions have already been destroyed and many remain endangered.
- Alternative methodologies such as cryopreservation of zygotic embryos and callus embryogenesis are not yet fully operational.
- Funding and business models for the conservation and sustainable use of coconut genetic resources are inadequate. As a consequence, many *ex situ* collections are conserved to sub-optimal standards, due to lack of sufficient expertise, trained staff, reliable methodologies and dedicated laboratories. At least 16 of the 24 COGENT *ex situ* collections have many aged accessions and are presently not able to regenerate them true to type using controlled hand-pollination.
- In the existing *ex situ* collections, there is a lack of sufficient variation for economically important selection traits such as: dwarfism, fruit quality, and tolerance to biotic and abiotic stresses. This, among others, limits the uptake of accessions in breeding programmes.
- On-farm and *in situ* coconut genetic resources are threatened by prevailing socio-economic dynamics, emerging diseases and the environmental and social consequences of climate change and hazards. Farmers are losing their traditional knowledge; their technical knowledge needs to be improved; they lack information about diversity and availability of planting material; and they often face shortage of good seednuts. Communication between genebanks staff, farmers and private sector is not efficient, sometimes even does not exist. Thus the link between genetic resources and their use is not possible.
- The existing international databases are at risk of becoming obsolete. The COGENT recording system is not yet linked to any of the various Big Data initiatives launched around the world. They need continued support to improve sharing, accessibility and interpretation of the available information. They provide the only tool allowing a global assessment of ex situ coconut conservation.
- At time of press COGENT is reviewing options for hosting its secretariat, as the current hosting model is no longer viable (see end of Annex 4).

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3. Where we need to be to secure diversity and promote use

Coconut cultivation has entered a modern phase. Most growers are no longer interested in cultivating mixed populations of early and late maturing palms that produce unpredictable and varying yields, with variably sized nuts, containing varying kernel and water contents.

COGENT believes that most farmers would like to plant discrete, recognised cultivars, i.e. as defined in the glossary "often intentionally bred and selected subset of a species that will behave ***uniformly and predictably*** when grown in an environment to which it is adapted". Farmers want precocious, high yielding varieties, adapted to market needs, growing ***predictably*** and ***uniformly***. Farmers prefer a diversity of planting material, but they want to ***control*** this diversity. Where they have a choice, most of farmers will choose to plant more than one cultivar in their fields.

The main objective of this Strategy is to propose a global system, which will allow ***efficiently conserving 600 coconut cultivars*** by the end of the next decade (2018-2028). This would still represent only ***50 cultivars per million hectares of cultivated area***. This approach will include rationalizing the present conservation system (detecting and merging duplicates, and increasing the size of small accessions), and collecting additional germplasm.

For sustainable germplasm conservation, facilitated access and efficient use in breeding programmes, ***each coconut cultivar should preferably be conserved in three countries*** located in three different regions of the world. This triplication system could include three *ex situ* field genebanks or, in the future, only two *ex situ* field genebanks plus cryopreserved material (which is often conserved in duplicate batches). This is not such a demanding target as, in any event, breeders from the 24 COGENT member-countries with genebanks need living material to work with. To reach this optimal level of conservation, secured germplasm exchanges will need to be conducted between COGENT member-countries. Coconut breeders will use the germplasm conserved in the fields to produce planting material, such as the best cultivars from farmers' fields, and promising new hybrids or composite varieties.

At the global level, around 419 cultivars are presently conserved in the 24 COGENT *ex situ* genebanks, representing a cultivation area of about 12 million hectares. So, the present "global conservation rate" is estimated to be no more than 35 cultivars per million hectares. The COGENT Secretariat estimates that a fifth to a third of these conserved cultivars are duplicates, greatly mixed populations or represented by an insufficient number of palms. Thus the number of "unique and true-to-type" cultivars presently conserved at the global level is estimated to be 300-335, so only ***at most 25 to 28 coconut cultivars per million hectare*** of cultivated area.

Within the next decade, it is proposed to ***collect 500 to 600 coconut populations*** or phenotypes having targeted favourable traits from farmers' fields and home gardens. Curators and breeders will carefully study these populations in order to select the 300 cultivars to be added to and conserved in the *ex situ* COGENT coconut collections.

Based on the constraints affecting the current conservation systems, the many discussions conducted within COGENT and with broader coconut community, and the effective participation of 90 key contributors in developing this document, the future direction of the Global Strategy has the following ten strategic components (in order of priority):

1. Reinforce COGENT as a sustainable, powerful and effective platform for the collaborative conception, coordination and implementation of priority projects in the field of coconut genetic resources
2. Strengthen local, national and international commitment to identify, collect, conserve, document and better use coconut genetic resources.
3. Revisit and optimize the present organization of the COGENT coconut collections in close collaboration with other partners.
4. Develop the mechanisms and procedure, skills, knowledge, capacity, laboratories and other resources required for safe and facilitated international germplasm movements.
5. Identify critical genetic and geographical gaps in existing *ex situ* collections, prioritize and build up missions aiming both to collect germplasm, boost *in situ* and *ex situ* local conservation and strengthen their interface.
6. Develop and improve national and global coconut germplasm databases and sharing of technical information regarding germplasm and planting material.
7. Secure the conservation of existing *ex situ* coconut genetic resources and their distribution
8. Prepare the field of coconut genomics that will become a crucial tool for conservation and use of coconut genetic resources. This will be conducted by seeking and establishing 'strategic alliances' with already existing genomic research teams and set-ups.
9. Strengthen the use of the coconut genetic resources by enhancing characterization and evaluation of germplasm, dissemination of breeding results as well as marketing of improved varieties.
10. Promote and strengthen *in situ* conservation of landraces and dissemination by local stakeholders of good planting material in a sustainable and equitable manner. This will integrate a gender approach to better understand and valorize the effective role of women in these activities.

The following sections gather COGENT recommendations to address the major constraints to the long-term conservation and use of coconut genetic diversity at the global level. They provide a clear framework for public and private sector investment in securing the availability of coconut diversity in perpetuity in the most cost-effective manner. It should be an important guiding document for donors, identifying funding priorities.

3.1 Strengthening communication and commitment to conservation and use of coconut genetic resources

As pointed out in sections 1.1.7 and 1.2.2, the main objective of COGENT communication strategy is to increase the commitment to conservation and use of coconut genetic resources.

From the institutional perspective, global communication regarding the coconut value chain has been mainly conducted by the Asian and Pacific Coconut Community (APCC), COGENT and the national institutions from its member-countries, and to a lesser extent, by ACIAR, Bioversity International and the Crop Trust.

The communication strategy of the APCC has been mainly oriented towards consumers and processors. It focused first on promoting coconut food products as natural, healthy and nutritious. ACIAR also effectively applied a similar strategy (Foale 2003). Both were fruitful. Nowadays, marketing by private companies and the abundant supply of coconut water products are mainly based on the health-giving, natural qualities of coconut water. Recently APCC developed a broader vision, enabling policy support and implementation of programmes that will create market demand and promote greater access to a wider range of coconut products both in the domestic and export markets, as well as in traditional and non-traditional market destinations[91]. APCC strengthened its role in coordinating market matching activities, buyers and sellers meetings, including the participation of the private sector especially the coconut processors and exporters in high impact Trade Fairs and Exhibitions.

3.1.1. Targeted audience

The markets for high-value coconut products are currently expanding, strongly driven by coconut water and VCO (Prades et al. 2016). It is highly likely that in the future these markets will become more and more competitive. Producers, processors and exporters will have to make the difference by ensuring and maintaining a high quality of their products. The way coconut palms are cultivated in respect to environment and health of consumers, the special characteristics of the varieties which are cultivated, and the notions of “terroir” or “branding by origin” will become increasingly important in marketing coconut products.

The APCC strategy is efficiently orientated towards consumers and processors. To be really coherent, the COGENT strategy should preferably be complementary to that of the APCC. Thus, it will focus mainly on national and international research institutions, international organizations, farmers, decision-makers and to a lesser extent to landscapers and the tourism industry.

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[91] See: Creating Market Demand and Promoting Market Access for Coconut Products "The Cocommunity" - Monthly APCC Newsletter Volume 43, Series No. 10, 1 October 2013.

3.1.2. Concepts for communication

The communication strategy will be based on the three following concepts:

- 'Coconut is not coconut'. **All the coconut palms are not the same.** They do not grow the same way; they do not attain the same yields. They are not linked to the same cultural and environmental contexts. Food products made from different varieties and in different places do not have the same taste and the same nutritional qualities. Coconut diversity exists. Coconut diversity matters. Conservation and use of coconut genetic resources are therefore highly marketable.

- **Give back diversity to seedling producers and to farmers.** Coconut is crucial for the livelihood of millions of stakeholders. The agricultural and market contexts have strongly evolved during the last decade. Thanks notably to Brazil and India, the profitability of well-managed coconut plantations producing high-value products is now clearly demonstrated. Indeed coconut breeding takes time. Indeed coconut conservation is challenging, as not everything can be achieved in a 3-year period, which is the duration of most international projects; nevertheless a longer-term vision, and a sense of general interest and working for future generations need to be vigorously promoted.

- **Coconut is an emblematic, aesthetic and attractive plant.** Landscapers in tropical countries could greatly benefit for integrating conservation of coconut genetic resources into their plans. No other plant is as closely linked to tourism activities under the tropics than the coconut palm. For the tourism industry evolving in a competitive environment, it becomes more and more important to stand out from the standard fare that tourism offers (Bourdeix et al. 2011a). Many tourists are no longer satisfied by golden exotic beaches bordered by anonymous palms; and those who are will more likely choose the cheapest destinations. Coconut palms should no longer serve as symbols of anonymous exoticism. They tell true stories, specifically related to islanders' cultures, in the framework of an ecotourism approach. The wealth of amazing cultural and agricultural coconut stories should greatly interest the media and especially TV channels and radios.

3.1.3. Implementing the communication strategy

The COGENT website (www.cogentnetwork.org) is a crucial tool for implementing the communication strategy. This website has been significantly improved in 2012 and 2013, by adding numerous components such as numerous FAQs[92], a new section "Research ideas", databases of geo-referenced photographs (on Flickr) and videos (new YouTube and Vimeo channels). However, this website is not yet fully developed due to lack of financial and human resources in support of COGENT secretariat. For the same reason, COGENT is not yet represented within online social networks. More resources should be devoted to COGENT communications in the coming years. COGENT needs a full-time position for a communications assistant who will manage

[92] Frequently Asked Questions, see the URL: http://www.cogentnetwork.org/faq

the website, coordinate exchanges with media and help produce short videos such as those recently released on coconut climbing techniques.

All the photographs presented in this Strategy were produced as very high definition images. They have been made available for downloading from the COGENT website or in the new website "Planting Material for the Pacific Region" [93]. These plates can also be printed in poster size format. They will be used to promote the various aspects of coconut genetic resources and use.

Communication with farmers

Recommendation 3 of the 2012 COGENT Steering Committee meeting includes:

- Encouraging local stakeholders (men and women farmers, private enterprise, NGOs and CBOs) to become more involved in supplying quality germplasm, and to teach farmers and other stakeholders how to autonomously produce quality seedlings of hybrids and other varieties, using the *Polymotu* concept or any other adopted method.

- Assessing farmers' knowledge regarding the reproductive biology of the coconut palm and the use of genetic markers such as sprout colour for breeding purposes. This study should be conducted by 1) drafting a standard gender-sensitive questionnaire by ethno-biologists and geneticists, 2) training local researchers to implement the survey, and 3) interviewing at least 100 farmers in each of at least 20 countries of the 39 COGENT member-countries.

- Developing a communication strategy to increase farmers' knowledge regarding coconut reproductive biology and breeding methods, including training tools, video guidelines, media communication, and an approach for marketing of genetic resources.

- Conducting a similar survey with the same questionnaire five years after launching this process, in order to assess progress regarding the farmers' knowledge.

As it will be discussed in section 3.7.2 and 3.9.3, the access to a database "seednuts for farmers" will be added to the main page of the COGENT website. As not all farmers can access internet, the database will include downloadable and multilingual technical documentation which will be easily printed and distributed if needed.

Communication with media

Researchers cannot replace journalists, but they can greatly assist them in providing unique raw material. Journalists generally work on a reportage for only a few days; many researchers are in the field, interacting with stakeholders almost every day. So researchers can capture images that journalists could never portray. Each research centre should have at least a small High Definition camera able to record professional quality images, videos and audio recordings. Researchers should receive a 2-4 hours training to be able to produce good quality footage and stills. Journalists will obtain the best footage by mixing their own recordings with those made by researchers.

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[93] See the URL: https://replantcoconut.blogspot.com

In 2013, twenty–five short videos have been released by the Secretariat on the COGENT website, of which eight were prepared by COGENT itself. During the next five years, COGENT plan to make and release about 50 more short videos. They will last from one to about 13 minutes each and deal with various subjects, such as: guidelines for controlled hand-pollination and fields observations; presentation of the *ex situ* collections and their curators; How do coconuts reproduce? How to distinguish a Dwarf from a Tall coconut? The amazing diversity of the coconut palm, etc.

A provisional list of these videos is to be prepared, published on the COGENT website, and submitted for approval during the next COGENT SC meeting. The COGENT secretariat, together with the NGO Diversiflora International[94] has already made HD shootings related to the all coconut value chain in more than 15 COGENT member-countries. At least 60% of the shootings needed for making these 50 videos are already available.

Communication with decision-makers

The communication with decision makers of COGENT Secretariat and collaborating institutions in COGENT member-countries should follows the official channels existing in the various national, regional and international institutions collaborating with the network. These channels and the identities of decision makers at the successive levels must perfectly be identified in order for COGENT communication to be as targeted and efficient as possible.

As part of the "early warning system" for identifying threats to germplasm, an interesting exercise could be to simulate, in each country, the worrying situation that happened in Indonesia a few years ago. As mentioned in section 2.3.1, fifteen hectares of coconut accessions were destroyed with bulldozers to build a horserace track. When a genebank gets under threats, the curator should precisely know who to contact at national level in order to solve the problem. She/he also should contact immediately the COGENT Secretariat. Thus, the COGENT secretariat should be able to react and alert the accurate people in national and international organizations in order for warning calls to be instantly given to the Ministry level(s) in the country concerned.

International recommendations emitted by the COGENT SC[95] provide also an efficient way to communicate with decision-makers on crucial aspect of conservation and use of coconut genetic resources. This was for instance applied with the recommendation 3 of the COGENT SC held in 2012, which includes:

- Decision-makers at the local, national and international levels to adopt effective portfolios of strategies and gender-sensitive guidelines for conservation and sustainable use of coconut genetic resources to meet the needs of men and women stakeholders, and especially to ensure both effective conservation and availability of good planting material for coconut replanting programmes.

[94] See: https://diversiflora-international.blogspot.com

[95] It could be interesting for COGENT to associate with APCC for emitting joint international recommendations.

- National Agricultural Services and breeders to allow farmers to make their own decisions, and consider not advising farmers to grow a single coconut variety, be it Tall, Hybrid, Dwarf or whatever.
- Seednut producers and agricultural services to provide farmers, at the national level, a range of at least six different coconut varieties, including Talls, hybrids, Dwarfs and eventually composite varieties, and to explain to farmers the specificity of each variety regarding environmental adaptation and cultural practices. Most farmers are very likely to choose to plant more than one variety.

Communication between research institutions and stakeholders in charge of agricultural development (National institutions and NGOs) need also to be strengthened notably through an approach "train the trainers". This approach should aim at more participation and evolves in a situation of "learning and training the trainers". Practical and traditional knowledge of agricultural officers and farmers should and will also benefit the researchers!

Communication with consumers and processors

To be really coherent, the COGENT communication strategy should preferably be complementary to that of the APCC. Anyway, COGENT communication will also target consumers and processors but with a unique and precise objective: promoting the branding of cultivar-specific high-value products. The way coconut palms are cultivated in respect to environment and health of consumers, the special characteristics of the varieties which are cultivated, and the notions of "terroir" or "branding by origin" will become increasingly important in marketing coconut products.

The markets for high-value coconut products are currently expanding, strongly driven by coconut water[96]. It is highly likely that in the future these markets will become more and more competitive. Producers, processors and exporters will have to make the difference by ensuring the highest quality of their products.

As far as we know, there is presently only one case of branding a coconut cultivar. The Thai coconut variety named "Ham Hom" is the most famous for aromatic water. It is now gaining international acceptance and Thai coconut water is being increasingly exported to the USA and Canada and several other countries. The Tahiti Monoï is made only from coconut growing on atolls soils of French Polynesia; it is branded by geographical origin but not by variety, as farmers in the Tuamotu Archipelago cultivate different varieties, such as various Tall-types and the hybrid between the Brazilian Green Dwarf and the Rangiroa Tall.

Communication with landscapers and the tourism industry

Communication with landscapers will include sending them catalogues of coconut varieties, publishing papers about coconut diversity in their specialized journals, and

[96] From Dr Vinay Chand, international coconut expert, in Coconut google group, 24th October 2013: "One billion coconuts processed when fresh generate US$2 billion in export earnings. Three million tons of coconut oil extracted from 20 billion coconuts exported earns less than US$3 billion. Of course, there are not enough established markets to absorb another 20 billion coconuts of wet process products. But should we not be taking active steps to promoting markets for wet products?

through direct interaction. In five to ten COGENT member-countries, interns should work on how to integrate coconut conservation in landscaping of both public places and tourism locations. In many tropical cities, the municipality could be engaged in a municipal coconut planting programme from accessions conserved *ex situ* or well-identified varieties from farmers' fields. The city will communicate about its role in conserving genetic resources and will develop a positive and popular image about this role. The same kind of "marketing of genetic resources" could be used for interaction with hundreds of sites and stakeholders including: tourist centres, university campuses, research institute sites, municipal parks, botanical gardens, golf courses, and farms and farmers.

3.1.4. Impact assessment of the communication strategy

The objective of COGENT communication is to increase commitment to conservation and use of coconut genetic resources. For evaluating such a wide objective, impact assessment should be conducted by taking into account the targeted audiences of the communication actions.

Indicators common to all targeted audiences will be those linked to the frequentation of the COGENT website, and of the pictures and videos channels. These indicators will be: numbers of unique visitors; numbers of links from and to other websites; and the number of download of technical documents.

Other indicators to measure the impact of the communication: to the farmers, could be the diversity of planted material in the fields; to the research community would be the number of scientific journal articles citing COGENT; to the media, the number of articles in the press (paper, radio, TV…); to the decision makers, the amount of money dedicated to coconut genetic resources conservation compared to other crops, taking into account the level of importance of the coconut tree cultivation for the country; and to the landscapers, the urban planners and the tourism area, the number of new plantations citing or including coconut trees.

3.2. Revisiting the concept of the Global COGENT coconut collection

The present global system, based on five international genebanks and 19 national genebanks, has been shown to be only partially effective in terms of both germplasm sharing and quality of conservation (as stated in sections 2.6.3 and 2.8). In the 2013 COGENT survey, only 40% respondents agreed that international genebanks are effectively playing their role in distributing germplasm at international level, and 73% believed that the number of international genebanks should be doubled in order to increase the efficiency and number of germplasm movements.

Plate 3.1.

Cultivation of Malayan Dwarf-Types coconut varieties

Wider future variety

1. & 2. Brazilian Green Dwarf cultivated by a Brazilian smallholder with high irrigation and fertilization levels.

3. & 4. Brazilian Green Dwarf planted in an International Genebank and cultivated with low fertilization and no irrigation, during the dry season.

5. Cameroon Red Dwarf cultivated by a Brazilian smallholder with high irrigation and fertilization levels.

6. Cameroon Red Dwarf planted in an International Genebank and cultivated with average fertilization and irrigation levels.

7. Cameroon Red Dwarf planted in an International Genebank and cultivated with low fertilization and no irrigation, during the dry season

. 8. Pemba Orange Dwarf cultivated in a Tanzanian garden. Pemba Orange Dwarf and Cameroon Red Dwarf are closely related varieties.

9. Huge nursery of Brazilian Green Dwarf in Brazil. Using polybags is strongly recommended when planting Malayan Dwarf-types coconut cultivars.

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Thus, an improved global system will be established to:

- vigorously encourage better quality of conservation and readily sharing of both information and germplasm,
- offer a better protection against threats such as the expansion of lethal diseases, lack of financial resources, land pressure and climate change,
- create new *ex situ* genebanks, either field conservation or cryopreservation of pollen, embryos and embryogenic calluses.

3.2.1 Crucial importance of field genebanks

People commonly reiterate that conserving coconut palms in field genebanks is very costly. However, it should be considered that on the one hand, institutions spend a lot of money on growing coconut palms for conservation purposes; but on the other, farmers are becoming wealthy by planting more or less these same conserved varieties (e.g. in Brazil and Tamil Nadu). *Therefore, with an optimal management, the maintenance of a field genebank could become a financially beneficial affair.*

Fields genebanks are important for many reasons. The conserved germplasm is conserved in a natural environment and thus, continues to evolve in the presence of pests and diseases and other environmental and management factors. Such genebanks remain actually the only way for stakeholders to see the germplasm, and for breeders to characterize and use the material while planted in the field. Tall-type accessions are not clones but heterogeneous populations. There is a need for breeders to see and select the best palms within these accessions. Breeders cannot select the best palms from batches of embryos frozen in liquid nitrogen.

Coconut plantations of 100 to 800 hectares, including those maintained by many COGENT coconut research centres, also offer high earning potential. They are often coveted by neighbouring stakeholders, as many genebanks are facing land tenure problems. As pointed out in section 1.1.2, by planting common Dwarf varieties, Brazilian farmers have achieved a yield of 250 nuts per palm per year, generating a gross annual income of US$10,000-14,000 per hectare. *So a first objective for field genebanks could be to generate a gross annual income of at least US$3000 per hectare.*

3.2.2. Diversification of coconut genebanks

As discussed in Section 2.3.5, some of the coconut genebank already practices intercropping. *In the absence of constraints, coconut genebanks should strengthen their involvement in conserving other tree crops.* This option has several advantages, including to:

- Increase the global commitment to promote the importance of these genebanks. If more than one crop is conserved, genebanks will become increasingly mandatory and committed places for conservation of genetic resources.
- Increase the visiting frequency to the genebank. Researchers working in genetic resources of different crops will meet more frequently, exchange more information, and cooperate more closely.

- Make at least part of the genebank closer to the planting systems used locally by farmers, as many of them practice intercropping.
- Ensure a better agronomic management, especially for intercropped fields that often require irrigation facilities and higher fertilization and will serve as demonstration fields.
- Benefit from the multifunctional use of the landscape. Some coconut plantations, especially seed gardens, are generally surrounded by other tree crops for pollen isolation purposes. Instead of planting any tree crops, these buffers areas can also conserve genetic resources of appropriate species.

Conversely, coconut conservation could also be integrated into many other agricultural research centres' programmes within the tropics. Thousands of coconut palms are planted in these research centres without considering genetic resources and diversity aspects. As observed for instance in 2018 in Fiji at the Koronivia research station, which is mainly devoted to cattle breeding, researchers and breeders working on other crops did not know the names of coconut varieties they are planting in their research centres. Thus, developing multifunctional land use is one of the highest priorities, and hence has thus recently been included as a new theme of the CGIAR research program on Forests, Trees and Agroforestry (FTA). As discussed in section 2.2.3, the CNRA is starting to implement this last approach by duplicating accessions of the international coconut collection in Côte d'Ivoire. Coconut germplasm will be planted in isolated small units of about one hectare, each conserving only one Tall-type accession and each planted in reproductive isolation in the middle of other tree-crop plantations, in 5 of the 13 CNRA research centres scattered around the country.

3.2.3 Geostrategy: doubling the number of international genebanks

COGENT will continue to strengthen links between the 24 genebanks of its member-countries, FAO, the Crop Trust, the Governing Body of the International Treaty, CGIAR and other international stakeholders in order to promote the placing of coconut germplasm collections in the public domain under the Treaty's designation. This has already officially been achieved with genebanks in Brazil, Côte d'Ivoire, India, Indonesia and Papua New Guinea. Once coconut accessions have been given public domain status, they can become freely available to *bona fide* users and exchanged legally, transparently and fairly, via a standard material transfer agreement (SMTA). Non-contracting parties to the international Treaty are also encouraged to use SMTAs to facilitate germplasm exchange.

Despite set-up costs, *designating or creating new international coconut genebanks should not been seen as a costly and demanding strategy*. This will often involve using pre-existing facilities and providing them with extra status. Two additional international coconut genebanks (large coconut plantations of minimum 200 ha) could also be *de novo* established. These new genebanks could become profitable and self-funding within a few years. Success regarding self-funding will depend very much on quality and stable management to achieve potential yields, and added value generated from the production of coconut products.

In **Southeast Asia**, the Indonesian international genebank now faces many difficulties. As discussed above, part of the genebank was recently destroyed. The genebank lacks the necessary manpower and budget to conduct controlled hand-pollinations. Until 2012, all the Tall-type allogamous accessions had been regenerated by open pollination, resulting in unwanted varietal mixes. Excepting a few common varieties, the conserved germplasm originated from within Indonesia only. According to the CGRD, no germplasm was released from the ICG to other COGENT countries. Within the region, the Philippines are the most active in exchanging germplasm, and their genebank is more diversified than the Indonesian one. *Considering the constraints encountered in Indonesia, part of those facilities already existing in the Philippines or in another COGENT country from the region could be formally developed as a new ICG, thus doubling the number of international genebanks in the region.*

In **South Asia**, the international genebank located in India is very active for collecting germplasm abroad, as well for breeding and research activities. However, as discussed in section 2.6.3, during the past 15 years, only a few coconut accessions were released by India to other COGENT countries. At the regional level, Sri Lanka is the most active country in term of exchanging germplasm. It has a smaller genebank than the Indian one, but well-managed and efficiently maintained. *Considering constraints faced in India, part of those facilities already existing in Sri Lanka or in another COGENT country from the region could be formally developed as a new ICG, thus doubling the number of international genebanks in the region.*

For **Africa and the Indian Ocean**, the Marc Delorme research centre, based in Côte d'Ivoire, has been the main provider of coconut germplasm worldwide. It is now threatened by urban development[97] and by the spreading of a phytoplasma lethal disease, which is at about 150km from the genebank. Other countries, such as Ghana, Kenya, Mozambique, and Tanzania are also strongly affected by these kinds of diseases. As recently highlighted by a COGENT recommendation[98], Madagascar has unique coconut genetic diversity. Indonesian travellers visited Madagascar more than ten centuries ago, bringing their own coconuts that created exceptional mixes between the Indo-Atlantic and Pacific coconut groups. *Considering the threats faced by the genebank in Côte d'Ivoire, Madagascar could provide a good location for the creation of a second ICG, and could significantly strengthen its role in providing germplasm and planting material at the sub-regional level* - on the condition that the phytosanitary situation of this country is adequate and well documented.

For **Latin America and the Caribbean**, Brazil is the actual international genebank but faces several challenges to reproducing its existing accessions, including: high labour costs, senile palms becoming too tall, lack of manpower, unsafe palm-climbing techniques and land availability issues. It is presently envisioned to regenerate some old Tall-type from material planted by a private company in the north of the country. Up until 2013, no germplasm has been released by Brazil to any other COGENT

[97] CIRAD has conducted a reconnaissance mission in early 2018.

[98] Recommendation 5 in 2012, see URL:
http://www.cogentnetwork.org/images/2012_sc_meeting/cogent_recommendation_5.pdf

member-countries. Also, the Brazilian genebank has yet to succeed in regenerating its own accessions, so producing seednuts by controlled hand-pollination for other countries is currently not practically feasible. In Jamaica, lethal yellowing is spreading and is a concern in regards to the country size. In Mexico, LYD is also very active, especially in Yucatan, where CICY is located. Any other country from the region could host a new ICG - on condition again that the phytosanitary situation is adequate and well documented. *Colombia is an interesting option: national institutions are already conducting coconut research in collaboration with the CGIAR CIAT research centre located in Cali, in the south of this country; this cooperation could be strengthened in the framework of the creation of a new international coconut genebank.*

For the **Pacific region**, the SPC-ACIAR regional coconut meeting held in Samoa in October 2012 endorsed SPC to be the focal point leading a negotiation role with technical assistance from the COGENT secretariat and linked with APCC. The current international genebank is located in Madang, Papua New Guinea. Although it needs to be duplicated to escape Bogia disease[99], it may not be able continue to serve as the international genebank because of the disease. It will continue to play a crucial role for screening coconut varieties for tolerance to the Bogia disease. Considering these constraints, the scenarios envisioned are for *Fiji and/or Samoa, or another country of the region, to host (a) new international coconut genebank(s)*. The UK Darwin Initiative has funded work to expand the ICG-SP to include sites in Fiji and Samoa. Transferring coconut genetic resources from Madang will need to be carefully assessed and subject to biosecurity protocols of the selected countries. As pointed out in section 3.6.3, the creation of quarantine centres appears as a real necessity.

COGENT will continue to strengthen links between the 24 genebanks of its member-countries, FAO, the Global Crop Diversity Trust, the Governing Body of the International Treaty and other stakeholders, in order to promote the placing of coconut germplasm collections in the public domain through designation under the Treaty. This has already been achieved with genebanks in Côte d'Ivoire and Papua New Guinea. Once coconut accessions have been given public domain status, they can become freely available to *bona fide* users and exchanged legally, transparently and fairly, via a standard material transfer agreement (SMTA).

Today, the existing ICGs face challenges which constrain their capacity to share their germplasm and these constraints need to be addressed as COGENT envisions upgrading selected genebanks' status (from national to international) or increasing the number of international genebanks, or both.

COGENT proposes a certification system to be managed in a similar manner to a Quality Management System for the ICGs. This label should be renewed at

[99] This genebank was very recently threatened by the rapid expansion of the Bogia disease (caused by phytoplasma) which has now spread to an area less than 15 km from the collection. The genebank is isolated from both geographic and scientific points of view. It never had the facility for making controlled pollination, so coconut breeding remains limited. Except for a few common Dwarf and Tall varieties, all the conserved germplasm originates within Papua New Guinea. During the past ten years, many commercial coconut hybrids were planted in the centre, but the accessions of the genebank were not rejuvenated. These accessions have become very tall. Technicians rarely climb tall palms, and the only way they do it is using ladders, which are now too short to reach the inflorescences.

appropriately frequent and regular intervals. To maintain funding from the Trust or other international donors, genebanks should comply with any specific rules defined by within the certification system. These rules should be defined by and within COGENT member countries.

The COGENT Secretariat will promote the establishment of a concerted set of criteria for the quality management system of the international genebanks. **These "COGENT Standards for ICG management" will be adapted for use by coconut field collections** from those standards already published by FAO, the Treaty and the Trust or other institutions conserving germplasm.

Criteria for funding the conservation of accessions by international agencies could include the following:

- Accessions placed in the public domain and available for international germplasm transfer or which can be simply exchanged using a multilateral system.
- Size of accession reaching the standard (45 living palms for Dwarf and 92 for Tall).
- Quality of conservation: accession reproduced with a reliable technique; field observations done; passport and characterization data available in the CGRD and secured in two different sites; off-types well detected and removed from the fields.
- Quality of management = training session and planning for staff, safety measures in place for coconut climbers.
- Quality of equipment = good maintenance of the equipment (field, laboratory, computer, and vehicles), along with adequate regular investments.
- Accessions available in a zone free of those lethal diseases that are transmissible by embryos.
- Accessions preferably conserved first in their country of origin,
- Then preferably conserved by the genebank that shared most of this germplasm at the international level,
- Then in a cryobank if feasible.

Other criteria will be proposed by a group of experts in charge of presenting the "COGENT standard for ICG management" at the SC meeting, followed by discussion and endorsement.

Based on this quality baseline, **the international genebanks will be regularly audited in order to maintain their international status.** National genebanks will also be able to apply for such audits. These regular audits will help the genebank curator and the Director of station to plan and evaluate the cost of the investments, the capacity building of the staff, anticipate the regeneration period, etc.

Within this system, some existing national genebanks could graduate to international status, as using pre-existing facilities and providing them with extra status will provide cost-savings.

Maintaining efficient genebanks, including developing cryobanking facilities, doubling the number of international genebanks will probably require more than the decade covered by this Strategy. *On the other hand, for some of the already existing coconut genebanks, evolving from national to international status could be achieved at much lower cost.*

3.2.4 Sharing international resources between genebanks

Activities for conserving and using coconut genetic resources are currently funded by the many national research institutes, with no help from industry and almost no help from international organizations. Even the funding for the five international collections is assumed by national governments. Presently, network structures for genetic resources conservation seem to be under-valued within the CGIAR system. Thus, crops having their genetic resources under the mandate and management of one of the CGIAR centres seem to have huge advantages when compared to species like the coconut palm for which no CGIAR centre has taken such responsibility. Therefore, it is proposed to bring this imbalance to the attention of the Funding Council.

As a first priority, *the Strategy calls for the development of an endowment fund (or similar sustainable funding mechanism) dedicated to the conservation and use of coconut genetic resources.* The Crop Trust[100] has been established to do so for the crops included in Annex I of the Treaty. Such an endowment would ensure that coconut conservation is placed on a firm financial foundation for the foreseeable future. This section discusses the questions about how such an endowment could help to improve conservation and the sharing of responsibilities between genebanks, and about how the revenues of this endowment could be shared between genebanks.

COGENT proposes creating a label to be managed along the lines of a Quality Management System for the ICG. This labelling should be reviewed or audited on a regular basis. To maintain funding from the Trust or other international donors, genebanks should comply with specific rules defined under this label. These rules should be defined by and within COGENT member countries. This approach has already been launched thanks to the 2012 Crop Trust project "Upgrading Genebanks"[101] and was approved by recommendation No. 5 of the COGENT Steering Committee in November 2017[102] on Genebanks Audit.

The specific interests of countries may sometimes differ from the global conservation approach, for justified reasons. For instance, if the objective, in its strictest sense, is to optimize conservation at the global level, there is no need to conserve the Brazilian Green Dwarf (BGD)[103] by using 20 accessions located in 9 genebanks and totalling 2690

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[100] The Crop Trust was founded by the United Nations Food and Agriculture Organization (FAO) and Bioversity International, acting on behalf of the foremost international research organizations in this field (CGIAR).

[101] See the URL: http://www.cogentnetwork.org/network-projects/past-projects/upgrading-genebanks

[102] See the URL: http://www.cogentnetwork.org/meetings/steering-committee-meetings/18th-cogent-sc-meeting-and-workshop-fiji

[103] Brazilian Green Dwarf (BGD) remains presently also referenced in some genebanks under another cultivar name (Equatorial Guinea Green Dwarf). In Côte d'Ivoire which is the collecting country, the cultivar "Equatorial Guinea Green Dwarf" was renamed as a population of BGD: Brazilian Green Dwarf *Equatorial Guinea*. In other genebanks, this renaming is yet to be fully achieved.

palms. Three replications of 45 palms are sufficient to ensure an efficient global conservation of this cultivar.

Conversely, many researchers from other countries may also be interested to introduce the BGD in their breeding programmes. If COGENT ensures that BGD remains fully available to these countries, the cost of transferring BGD to another country (and subsequent conservation costs) will no longer be covered by the international system, because BGD is already adequately conserved at global level.

The future endowment fund should be devoted to optimizing the conservation of the species at the global level. Its sharing may result in articulating donor requirements and collective wishes of COGENT country-members as described below; *the future endowment fund could be used for the following priority activities*:

- Helping genebanks to comply with the COGENT standards for ICG management and authorize regular audits by independent experts.
- Strengthening conservation quality. For instance, it seems inappropriate to fund Tall-type accessions which have been rejuvenated by open pollination within an *ex situ* genebank (even if at an international genebank). These accessions are mixing when reproduced by open pollination.
- Favouring the observation and the sharing of passport and characterization data. Those compliant genebanks who effectively release their data to the CGRD should be prioritized.
- Developing and applying genebanks' capabilities regarding controlled hand-pollination, *in vitro* cultivation of coconut embryos, and all techniques for extending the lifespan of field-based accessions.
- Helping genebanks to improve their self-funding capability.
- Conducting phytosanitary measures that would avoid the spread of pests and diseases along with the germplasm.
- Safely duplicating internationally agreed accessions in another genebank in a country of a different continent.

- To re-iterate the example of the Brazilian Green Dwarf (BGD), there is a need to identify the three accessions of BGD located in three genebanks which would best serve global conservation and which could be supported by a putative endowment fund. Criteria for choosing these accessions could be the following:
- Accession placed in the public domain and effectively available for international germplasm transfer or which can be exchanged using a bilateral or multilateral system.
- Size of accession reaching the minimum standard (i.e. at least 45 living palms).
- Quality of conservation: accession reproduced with a reliable technique; field observations being carried out; passport and characterization data available in the CGRD; off-types within the variety well detected and removed from the fields.

- Accession available in a zone free of lethal diseases transmittable by embryos.
- Preferably conserved in its country of origin: in this particular case, Brazil.
- Then preferably conserved by another genebank that shares readily its germplasm at the international level: in this case, Côte d'Ivoire.
- Then in yet another genebank. BGD is also conserved in Ghana, Sri Lanka, Tanzania, Vanuatu, Vietnam, Ghana and the Philippines. Three countries, namely Ghana, Tanzania and Vanuatu suffer under high pressure of lethal-diseases and cannot be considered for global conservation activities. So the third accession could be conserved in one of these other countries chosen according the criteria list given above and preferably based in yet another continent.

The responsibility of funding such a global system could be shared by participating countries (who could provide part of the infrastructural costs) and by donors (through an endowment fund focusing on improvement of ex situ *conservation of priority accessions).* In order to improve the quality of conservation, funding could be partially allocated on an accession basis, according to expert evaluation conducted collectively by the COGENT network (Bourdeix et al 2009a). The cost of managing such an organization should not exceed 10% of the total amount of available funding.

Building such an endowment fund and securing funding for all the components of the Strategy will certainly take time. The highest priority will be to secure the conservation of the genetic diversity currently held in the public domain in *ex situ* collections and facilitate its distribution.

3.2.5 Towards a concept of a "networked" or "virtual" coconut collection

A networked collection, also called a virtual collection, is located at more than one geographical/institutional site; it spans the genetic diversity of a given species (genepool) and gathers stakeholders having a mutual interest for rationally conserving and exchanging germplasm (Bourdeix et al. 2009b). In the extreme application of this concept, each accession could be conserved at a distinct site, as illustrated by the CNRA project in Côte d'Ivoire described in section 2.2.3 and the recent planting of two small islands in Samoa. All intermediate strategies are thus conceivable.

The establishment of a networked collection would involve more countries, sites and stakeholders in the global coconut conservation system. Because most coconut varieties are allogamous, the main limiting factor to effective conservation is the regeneration of true-to-type accessions via controlled hand-pollination. In the case of coconut, this regeneration technique is very costly, requiring a well-equipped laboratory, well-trained technicians able to climb the palms, and considerable manpower. Not all genebanks can yet afford this. In order to overcome this limiting factor, the *Polymotu* concept involving reproductive isolation (see section 2.2.3) is being proposed as a new approach and will have to be fully evaluated. Several coconut accessions could be planted, each in a distinct, isolated site. These sites could be islets near bigger inhabited islands, insulated valleys, large plantations of a unique variety, large urban facilities such as university campus or golf course, or any other designs using a pollen barrier. Reproductive isolation will ensure true-to-type breeding of the crop varieties through free and natural pollination.

The criteria for an accession to be included in a possible networked collection have been discussed: germplasm uniqueness, genetic representativeness, ability to reproduce its trueness-to-type and policy considerations.

There is no plan to push the global system of coconut conservation into a networked/virtual collection over the next decade. Gathering accessions held in international genebanks (in the same legal framework, network and database) poses the biggest challenge, including those accessions conserved on islets owned by municipalities, islanders' clans or tourism enterprises. This possible future approach could lead to the modification of the classical delineation between *in situ* and *ex situ* conservation.

3.3. Securing existing *ex situ* coconut genetic resources

The immediate priority of the Strategy is to rationalize and secure the conservation and accessibility of existing and valuable genetic diversity currently maintained in *ex situ* collections worldwide. The following sections present possible solutions to reduce threats to *ex situ* genebanks and to the accessions maintained within them.

3.3.1. Business plans for genebanks

Coconut genebanks could greatly increase their capability for self-funding

An international project should help COGENT genebanks to increase their profitability, in order to secure conservation of coconut genetic resources. *Socio-economist internships should be conducted in at least ten COGENT member-countries for costing conservation activities*, for increasing self-funding of genebanks and for integrating coconut conservation in landscaping of both public places and tourism locations, using a multifunctional land management approach.

Many genebanks and research centres have been established close to cities which are now rapidly expanding. Land pressure on these genebanks is mounting. For instance in India, the CPCRI genebank is now surrounded by Kasaragod residential areas. In Côte d'Ivoire, the ICG-AIO genebank will soon be completely engulfed by popular residential areas of Abidjan, the capital city. Some genebanks will soon remain the main or only green space available in their respective areas. *The status of the coconut genebank should evolve towards and be recognized as a higher benefit for neighbouring citizens*. Genebanks might no longer be seen as exclusive spaces reserved only for researchers. They could evolve towards a kind of botanical garden, public park or green space, open to citizens and where researchers work as well. As citizens will benefit from sharing these spaces, land pressure should decrease.

The first opportunity for self-funding is by selling coconuts produced by the genebanks. A factor limiting genebank fruit yield is often linked to the organization of host institutions. Curators do not have clear interests to increase the level of production of their genebanks[104]. For varieties such as Brazilian Green Dwarf, some genebanks currently record an average annual fruit production of less than 60 fruits per palm[105], when Brazilian farmers succeed in achieving annual yields of 250 fruits per palm under comparable conditions. For both demonstration purposes and income generation, most of genebanks should have at least one field of Dwarf cultivars managed in a sustainable way

Another way to increase self-funding would be to process high-value coconut products (HVCPs) within the genebank. During the SPC-ACIAR meeting held in 2012 in Samoa, the COGENT secretariat recommended that pilot units for developing new HVCPs and integrated coconut processing centres should preferably be located in coconut genebanks. This kind of approach has recently been initiated at the Taveuni coconut centre (Fiji). It allows coconut stakeholders to see both the available planting material and the new processes for producing HVPs. It will also provide a wide range of germplasm to researchers in processing for testing their techniques and equipment.

Other by-products that could be valorized by genebanks include coconut timber and palm hearts[106] obtained when felling old accession trees. For landscaping public places and tourist areas, adult palms are often sold for about US$100 per meter of trunk. Genebanks could be particularly well placed on this market because they can sell adult palms from certified varieties. Genebanks could also produce and process toddy which is often more profitable than selling fruit.

Another method of increasing self-funding is linked to diversification of coconut genebanks, as discussed in section 3.2.2. *A very lucrative option could be to include in coconut genebanks plots devoted to the conservation of other palm species*. There is a huge and very profitable market for adult palms used for landscaping of public places and tourist areas. So the genebank could also sell adult trees from other palm species and replace them in the genebank as long as this operation remains profitable.

Thus, another way for genebanks to increase their resources could be *to develop joint-ventures with the tourism industry at both international and local levels*. As stated in section 1.1.4, many coconut research centres can be regarded as small paradises from aesthetic, environmental and human perspectives. There is great potential for developing ecotourism activities. Ecotourism could be emphasized by the concept of coconut genebanks being autonomous for energy. Every site could have a small unit to produce coconut oil and biodiesel. This oil can easily run electric motors that provide

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104 In many cases, the management and the sale of agricultural production fall under separate administrative services. This situation has already been encountered in two international genebanks, but may concern many more. A curator told us that she spent half her annual budget buying fertilizers for the genebank, yet the genebank did not benefit from the resulting yield increases, as all the income was pooled and kept by another service.

105 Calculated on the period 9-12 years for an accession of BGD conserved in one of the international genebanks.

106 The palm heart, also called palm cabbage, has a flavour resembling fresh hazelnut. It is eaten under the name of "millionaire's salad". Coconut hearts are sold in La Réunion, for €80 per unit (about US$108). When the COGENT secretariat tried to convince farmers to reduce the price and increase production, farmers replied that customers agree to pay high prices for food such as caviar, so there is no reason for customers to pay less for coconut hearts.

energy to the laboratory, offices, engines and, of course, guest-house for the visitors, reducing carbon footprint.

3.3.2. Extending the duration of accessions in the fields

Extending the duration of accessions in the field should contribute to reduce costs of maintaining *ex situ* coconut genebanks. Most of the expenses are conducted during the first 12 years and when regeneration is conducted. After 12 years, the cost of maintaining coconut palms should be covered by the value of fruit production. Thus extending the duration of coconut accessions from 30 years to 60 years could thus halve the conservation costs per accession. Three approaches could help extend the lifespan of field-based accessions:

- ensure palm longevity by appropriate management.
- improve palm-climbing techniques.
- Reducing palm height.

Longevity could be increased by addressing the causes of palm degeneration or death. Diseases and pests need to be controlled where possible. In some genebanks, soils are depleting due to compaction, excessive grazing by livestock and lack of fertilization. In disease-free areas, the main cause of palm death is lightning, which strikes more frequently in specific places. If accessions are kept for 60 years in the field, earthling against lightning will have to be considered.

COGENT therefore, needs to implement a project for selecting one or two secure climbing techniques that are well adapted to controlled hand-pollination, and to diffuse this technique among all genebanks (see sections 1.1.4 and 2.2.1 for more details).

Reluctance to innovation in coconut climbing

An experiment was conducted in Côte d'Ivoire more than 15 years ago. Workers use triple ladders reaching 15m, without any security system. They were advised to establish a secure system, but collectively declined, arguing that such a system would make them think that they could fall, would psychologically perturb them and would increase workers' falling rate. . These psychological aspects will have to be taken in account when climbers will be requested again to change their climbing methods. Palm-climbing is dangerous. In Côte d'Ivoire, during the last genebank regeneration, two workers fell and were severely injured. Field workers have ingrained climbing habits on which their life depends. It is not be easy to encourage them to change their habits, even when their technique has proven to be unsafe. In some genebanks, palm-climbers are very poorly paid, almost as little as daily labourers, despite the complexity and danger of the task they perform. One solution could be to increase palm-climbers' wages for those using the safer techniques.

Research must also be conducted to reduce the palm-height of Tall-type varieties:

- Vertical growth of coconut palm has not been sufficiently studied and quantified. The rapid growth of Tall-type coconut palms occurs mainly during the first 25 years. Later, their growth becomes very similar to that of Dwarf-types.

- Farmers of the Mekong Delta use a technique to stunt Tall-type coconut varieties. A study should assess if this technique, as shown in a recent movie[107], is manageable for genebanks.
- The genetic determinism of Dwarfism is still unknown, but the vertical growth of the coconut palm is very probably under phytohormonal control. When these mechanisms will be elucidated, it could become possible to apply phytohormones during a 2-4 years period for strongly reducing the vertical growth.

In the future, it is envisioned that regenerating an accession will be undertaken only when the palms are 60-years old, when more than a fifth of the palms are dead, or when their annual yield drops below 20 fruits per palm during two successive years.

3.3.3. Triplication of germplasm in distinct geographical sites

Coconut germplasm is highly vulnerable to disease and other threats, making safety duplication and rationalization of its conservation at the global level an immediate priority. As pointed out in section 1.1.5, much of the germplasm in *ex situ* collections is poorly safety-duplicated outside of the host collection. This puts the material at risk from loss.

Physically speaking, a coconut accession in an *ex situ* field genebank is something very consistent. This is not only a small handful of seeds; it is often more than half a hectare of large palms planted in the field for 30 to 60 years. COGENT believes that, in the case of the coconut palm, the most efficient way to globally manage coconut genetic resources is to do it at the accession level. The specificities and history of each accession conserved in *ex situ* genebanks must be meticulously recorded for optimizing conservation and use.

Triplication as a practical and pragmatic approach

The numerous discussions conducted with genebank curators and COGENT representatives led to the proposal that coconut cultivars should preferably be conserved in three different countries. They could be planted in field genebanks in three different countries on three distinct continents. Alternatively, in the future, they could be planted in the field genebanks of only two different countries, and cryopreserved in another country. As discussed in section 2.3.7, this "triplication" system would be applied at the cultivar level, and not for all the accessions presently conserved in *ex situ* genebanks.

This triplication proposal is based on a simple, practical and pragmatic approach. For curators, safety duplication is effectively reached only when the coconut germplasm is available for international transfer. The present system of five international genebanks does not meet this requirement: in reality (as discussed in section 3.2.3), three of the five existing international genebanks released little or no germplasm during the last 20 years. Moreover, in 2012 and 2013, the international genebanks of PNG and Côte d'Ivoire (the most active in releasing germplasm) became threatened by lethal yellowing diseases caused by Phytoplasma. So the situation is critical. It

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[107] See the URL: http://coconutvietnam.blogspot.com/2016/01/coconut-bonzai-reducing-vertical-growth.html

becomes more and more difficult to move germplasm. The great majority of curators and member-countries agree that each cultivar should be kept in three countries. In this way, it will be easier to access the germplasm they need.

Meticulous management of conservation at the accession level: a practical example

In order to better understand the constraints and specificities of this triplication proposal, and to show how germplasm should be carefully managed, accession by accession, it is better to illustrate the triplication process by using practical examples. The example of the cultivar "Sri Lanka Tall" is developed in this section while some other examples are also presented in annex 9 of this document.

The cultivar Sri Lanka Tall (SLT) is presently conserved worldwide by 103 accessions totalling 7082 palms. The proposed triplication system is to internationally conserve the SLT population *Ambakelle* in just 3 accessions of no more than 96 palms, and located in 3 distinct countries on 3 continents. Table 3.1 gives details about some of the accessions of Sri Lanka Tall presently conserved worldwide.

Table 3.1. Some of the 103 SLT accessions registered in CGRD and the 3 of them (in grey) to be presently considered for conservation at global level.

Country	Accession Number	Population Number	Population name	Conservation site	Acqui-sition date	Number of living palms
Sri Lanka	CRI SLT02	SLT02	Ambakelle	Ambakelle	1954	1609
Sri Lanka	CRI SLT02 R2	SLT02	Ambakelle	Pothukulama	1988	81
Sri Lanka	CRI SLT03	SLT03	Debarayaya	Pothukulama	1991	79
Sri Lanka	CRI SLT04	SLT04	Goluwapokuna	Pothukulama	1991	74
Sri Lanka	CRI SLT83	SLT83	Thatin	Pallama	2008	14
Sri Lanka	CRI SLT84	SLT84	Unawatuna	Pallama	2008	18
Côte d'Ivoire	SMD GSL	SLT02	Ambakelle	M. Delorme	1972	266
Côte d'Ivoire	SMD GSL R1	SLT02	Ambakelle	M. Delorme	2002	144
India	IND015	SLT		Kasaragod	1939	11
India	IND015 R1	SLT		Kasaragod	1990	13
India	IND015 R2	SLT		Kidu	2001	90
Jamaica	CIB SLT	SLT		CIB	1966	NULL.
Solomon Islands	YSI SLT	SLT		RIPEL	1965	43
Thailand	CHRC010	SLT02	Ambakelle	Chumphon	1965	133

Sri Lankan researchers have collected many SLT populations across their country. They have been working on this germplasm with the help of a PhD internship partly funded by CGIAR research program FTA. As explained in the box below, Sri Lankan researchers will have to make decision about the future of these populations.

International cultivar names may evolve with time. For instance, researchers from Vanuatu, a Melanesian Archipelago, gave population names to the many Tall-type accessions they collected, under the cultivar “Vanuatu Tall”: Pélé, Nipeka, Waluembue, Walanaro, etc... Researchers will observe in the genebank the characteristics of these populations, using morphological, productivity and molecular traits (DNA analysis). For instance, if the population "Vanuatu Tall Nipeka" proves to have distinct traits, its name will have to evolve: it will be renamed as a new cultivar, probably “Nikepa Tall”. On the other hand, if the populations "Vanuatu Tall Waluembue" and "Vanuatu Tall Walarano" prove to be identical, these accessions or cross between selected palms of these accessions could be merged under one name only, to be chosen by curators; when the accessions will have to be regenerated, the two accessions will be merged, as there is no need to conserve the same germplasm as two separate accessions.

If for instance, the population *Thatin* (SLT83) is proven to be an interesting distinct cultivar, they will have to change the status to rename this population: The SLT population “Sri Lanka Tall *Thatin* (SLT083)” will probably become the new cultivar Thatin Tall (THIT). If such an evolution occurs, and if Sri Lankan researchers agree to release this new cultivar in the public domain or to exchange it, THIT will also have to be conserved as three accessions located in three countries on three continents.

On the other hand, if some of the other SLT populations prove to be similar (for instance: SLT15, SLT16, SLT17 namely *Palugaswewa*, *Pitiyakanda* and *Razeena*), Sri Lankan researchers will have to make the decision to merge these populations or discard some of them from the accessions conserved by their national genebank.

Which cultivars need triplication?

Some cultivars are found only in one genebank while some other cultivars are conserved in more than 15 countries. According to the CGRD, among the 338 living cultivars conserved in COGENT *ex situ* genebanks:

- 269 are conserved in only one country, thus they would ***theoretically*** need to be transferred in 2 more countries,
- 25 more cultivars are conserved in 2 countries so these would ***theoretically*** need to be transferred to only 1 genebank,
- 44 cultivars are already conserved in at least 3 countries.

So ***theoretically*** 563 accessions need to be moved internationally.

A comprehensive and documented list of the coconut cultivars presently conserved in *ex situ* genebanks has been released on the COGENT website[108]. Among the cultivars

[108] See the URL: http://www.cogentnetwork.org/images/FAQ/2012_04_419_cultivars_ranked_by_names.pdf

conserved in only 1 country, 11 are conserved with only 1 to 5 living palms, and 58 Tall-types are conserved with 6 to 40 living palms, values which remain far below the recommended standard size for effective conservation. For some of these cultivars, the first priority will be to increase their genetic bases by re-collecting seednuts, embryos or pollen from farmers' fields. Some of these cultivars with low palm numbers are at risk of being also discarded from the list of cultivars to be internationally conserved if they are deemed to have no special advantageous characteristics.
A few cultivars will also be kept by the countries which do not want to share this particular germplasm at the international level. Despite the problems encountered with international genebanks, COGENT past experience indicates that this case will not be very frequent *if the countries receive germplasm from abroad* in exchange to their own cultivars.

As discussed in section 2.3.6, there is another level of analysis which is not yet fully implemented: choosing among accessions conserved under different names but which are appear genetically similar, although molecular analysis must be supported by phenotyping and other means to avoid the risk of excluding epigenetically-based diversity. So in order to avoid additional and unnecessary duplication, there is a need to prioritize deploying a three-step approach:

1. Improve the data available in the CGRD. For instance, Mexico recently obtained many varieties from Côte d'Ivoire, but this transfer was not registered in CGRD. In order to rationalize conservation at global level, it is highly recommended that all the germplasm movements be appropriately registered in CGRD and done through SMTA or at least MTA in order to be registered at the Treaty level. If not, this will conduct COGENT to undertake useless international transfers of cultivars which are already adequately triplicated.
2. Increase the characterization and evaluation level of selected accessions. This will include field observations, assessment of quality traits and genomic analysis. Encourage capacity building and/or technology transfer on coconut genomic analysis for regions that have established laboratories and or regions that could afford to establish genomic facilities.
3. Coordinate at COGENT level the germplasm movements for conservation purposes with the best common interest of both member-countries and the global conservation approach.

As discussed in section 2.6.3, from a global perspective, access to crop genetic resources has been recently subject to various forms of exclusive technological and legal restrictions. COGENT's opinion is that *promoting the Treaty at the international level should not become a constraint that limits germplasm exchanges*. During the past 15 years, COGENT's practical experience shows that some countries that placed coconut germplasm in the public domain have released little or no germplasm to other countries, whereas some countries working under a bilateral or multilateral exchange system have exchanged and shared a considerable amount. *The procedure for a set of accessions, or even a single accession, to be released into the public domain should also be optimized, streamlined, and published as an international guideline* and facilitated through the COGENT website. Beyond the Multilateral System (MLS), other systems for exchanging germplasm already exist at local and national levels (traditional and cultural exchanges in the Pacific and in Africa for example). Other movements like the Open Source Seed Initiative[109] are emerging today and moving material in some countries. In the future, COGENT will try to keep its members informed of these initiatives.

International management of the cultivar Sri Lanka Tall

In the specific case of the cultivar "Sri Lanka Tall", global triplication is already achieved. The most renowned SLT population is *Ambakelle* (SLT02). In fact Ambakelle is a large isolated seed garden, interplanted with Dwarf varieties and SLT, which have produced tens of millions of hybrids and Tall-type seednuts from the 1940s.

This seedgarden is still active, with more 1,600 living palms of Sri Lanka Tall *Ambakelle*. For conservation purposes, Sri Lankan researchers have also regenerated 81 palms of SLT02 in a distinct conservation site (Pothukulama). So ***Sri Lanka is obviously the first component of the triplication system.*** Although in Sri Lanka, SLT02 is not under international mandate, this population was already released from Sri Lanka to many countries.

In Côte d'Ivoire, SLT02 was planted in 1972, regenerated in 2002, and is under international mandate. Côte d'Ivoire was very active in releasing coconut germplasm. Although the lethal yellowing disease is now at about 150 km from the genebank, ***Côte d'Ivoire can be considered as the second component of the triplication system***.

In India, the SLT accession held at the Kidu International genebank is under international mandate. In 1939, only 11 palms were planted at Kasaragod, Kerala. This initial introduction was regenerated in 1990 by planting only 13 palms, again at Kasaragod. In 2001, the palms available in Kasaragod were used to plant 90 palms at Kidu. The three successive regenerations are still alive in the field. This population was named SLT and not SLT02. India never released this population to another country. The accession has a narrow genetic basis and its genetic integrity is questionable[1]. So, at this stage, and although this accession is under international mandate, ***this 'SLT' population cannot be considered as part of the triplication system*** If needed, India could renew its accession by importing pollen from Sri Lanka.

The SLT02 accession held in Thailand was obtained from open pollinated seednuts harvested in the isolated Ambakelle seed garden. The palms are 48 years old, Thailand does not have the skills for conducting mass controlled hand-pollination on such tall palms, and the accession is not under international mandate. However, ***Thailand could be considered as part of the triplication system***. The accession held in Solomon Islands is very old; as no recent information was transmitted by curator, and we do not know if the palms are still alive in the field.

In the present situation, a country requesting SLT02 would probably obtain a ***lot of embryos from open pollinated seednuts harvested in the Ambakelle Seed garden*** in Sri Lanka[2], or a more costly lot from controlled pollination produced in Côte d'Ivoire.

[1] It would be necessary conduct a molecular study (by using the 15 SRR markers kit) in order to understand the composition and pedigrees of SLT accessions in India, and to compare them to the SLT accessions presently held in Sri Lanka and Côte d'Ivoire. From this study, and from the comparison of the field characterization data, a decision could be made to include the accession conserved in India in the triplication system.

[2] So the isolated Ambakelle seed garden, initially designed for seednut production, will be used *de facto* for conservation and multiplication purposes, avoiding the need to reproduce this accession by using expensive controlled hand-pollinations.

[109] http://osseeds.org/

Such a global triplication process needs again to be precisely quantified, but *would aim to move about 250 accessions within a period of ten years*. A possible strategy could be for international donors to pay for preparing and sending the germplasm (embryos or plantlets cultivated *in vitro*), and for the interested recipient countries to assume other costs (from reception of embryos or plantlets cultivated *in vitro* to palms growing in the field).

Coordinating and implementing the triplication process

Coordinating and implementing these germplasm transfers will have to integrate the following aspects:

- The countries' willingness to release their germplasm, be it in the public domain or under a bilateral or multilateral exchange system.
- The curators' and breeders' knowledge of the germplasm they conserve and use, part of it being made accessible in the CGRD.
- The curators' and breeders' preferences for germplasm they would like to receive.
- The status of accessions: is there a sufficient number of living palms? Is this accession conserved in a place free from lethal disease(s), or transferred with a technique ensuring that the disease(s) will not be transmitted? This last point is first under the responsibility of the germplasm provider, but is also addressed via the quarantine sites.
- The characterization and evaluation data of these accessions, including field data and genomic, transcriptomic, proteomic and metabolomic analyses when available.
- The requirements in terms of global efficiency of the conservation. The international system would not pay for the same germplasm to be conserved in more than three countries. The requests from curators can be different from was it needed for global conservation: for instance, many curators could ask for receiving the Rennell Island Tall, when this cultivar is already well conserved at global level.
- The willingness of countries to place the received germplasm in the public domain. Countries that place the received germplasm in the public domain will be favoured for the exchanges devoted to conservation purposes at global level.

The higher costs of cryopreservation is due to the higher number of embryos needed. It is not expected that the improvement of the technique will allow a great reduction of embryo numbers to be preserved: *one* cryogenebank is generally constituted by *two* sets of similar accessions; lots of embryos should also be made available for regeneration and for the genebanks which will request the germplasm. Cryogenebanking is discussed in the next section.

3.3.4. Cryogenebanking

A cryogenebank of pollen is feasible now

Pollen cryopreservation is simple and affordable (Karun et al. 2006, 2014). Pollen can be easily collected in *ex situ* genebanks when accessions start to flower. Frozen pollen will serve for exchange, breeding and regeneration[110]. A novel application of pollen cryopreservation could use systematically cryoconserved pollen from farmers' fields or from the original accession for successive regenerations. In this way, we will be sure that at least 50% of the genes are fully conserved- those coming for the male parents from which the pollen was cryoconserved. The drift resulting from successive regenerations will therefore be reduced.

As pointed out in section 1.1.4, climbing the palms for implementing controlled hand-pollination is one of the main constraints to coconut conservation and breeding. Pollen could be harvested easily when the accessions are six to eight years old and immediately cryoconserved. Thirty to sixty years later, when regeneration time comes, this pollen will serve for making the controlled hand-pollination[111].

Cryopreservation of embryos

Creating a cryogenebank of embryos is indeed important. The main limiting factor is the cost of the controlled pollination needed for producing true-to-type accessions of Tall-type varieties already conserved in *ex situ* genebanks.

A drawback of the controlled pollination (CP) process could surprisingly benefit the constitution of a cryogenebank of frozen embryos. The yield of CP is erratic, due to many factors including climate variability and the varying physiological status of palms and pollen. To produce enough progeny, curators and breeders are forced to plan high numbers of controlled pollinations: one CP is normally planned to establish one palm planted in the field. Controlled pollinations may be much more successful. Larger numbers of seednuts are obtained, sometimes more than twice the expected yield. In this case, surplus seednuts can be cryopreserved as embryos with very limited additional cost. So the cryogenebank of embryos could be preferably be constituted with embryos from surplus seednuts obtained during programmes of field regeneration and germplasm exchange across the world.

For conserving an accession in a coconut cryogenebank, the number of embryos is still to be identified. As the technique is not yet mature, it is difficult here to provide a reliable figure. Some researchers propose that about 600 embryos will be needed per accession: 200 embryos on a recurrent basis, 200 embryos as safety duplication, and 200 embryos to afford a facility for responding to requests for germplasm supply from field genebanks and other users but this proposal has to be refined.

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[110] For regenerating an accession or creating a new hybrid, about 25 g of pollen from about 24 male parents is generally used. When coconut palms start to flower, 100g of pollen should be collected palm by palm and frozen. Thus, cryopreservation of an accession will consist in 100 units of 1g, and 25 palms each producing 4g of pollen.

[111] This will not fully address the constraints to palm climbing (those used as female parents) but it will reduce the number of old palms to climb. This could also probably allow reducing the minimum size of accessions conserved in the field.

Cryopreservation of embryogenic calluses

If the method for obtaining coconut clones becomes widely applicable, it will have significant repercussions on both conserving and breeding coconut palms. It could allow conserving a piece of tissue with the potential to regenerate thousands of plants from it. Recommendation 9 from the 2012 COGENT SC meeting states that:

- A project to be implemented to address the need for an alternative conservation system based on the cryopreservation of embryogenic calluses, involving a group of researchers from different COGENT member-countries.

- The research on *in vitro* cultivation of zygotic embryos and cryopreservation of zygotic embryos to be continued and the results compared with the new alternative conservation system based on embryogenic callus generation.

Mexico and Australia seem to have recently made progress, the only method fully available is presently to produce clones from embryo plumules. This rather unusual situation has important consequences. It remains impossible to clone a palm, to reproduce identically its genotype: only "sexual clones" are obtainable from the progeny of this palm.

So, if any Tall-type accession is to be conserved via cryopreservation of the embryogenic callus and if it is economically viable, the following steps will need to be carried out:

- make the 75 to 96 requested controlled hand-pollinations using preferably 48 female parents and 24 male parents,
- extract the embryos from 100-120 seednuts,
- grow independently these embryos into embryogenic calluses,
- cryoconserve at least 75 sets of embryogenic calluses, each coming from a different embryo and representing a different genotype.

Thus, conserving a coconut accession *as it is presently conceived* will be challenging. On the other hand, when coconut clones will become available, their conservation would have to be envisioned.

If the method for obtaining coconut clones becomes widely usable, cryopreservation of embryogenic calluses will also be applied when collecting germplasm in farmers' fields, for instance when prospecting for disease resistance, or other important traits, as discussed in section 3.5.3.

Collecting coconut embryos and pollen by boat

The accessions presently conserved in field genebanks are in relative security when compared to the many farmers' varieties endangered by socio-economic and climate changes. Thus, cryoconservation should be used as a priority to safeguard the endangered varieties still existing only in farmers' fields.

Collecting embryos and pollen from these endangered varieties is envisioned and, at the first stage, to keep them only as cryoconserved material[112]. Later, when COGENT genebanks and breeders will have both the interest and the available funding to plant the accessions, or to use the pollen, part of the frozen material could be released. In exchange, these genebanks will have to provide double the quantity of embryos and/or pollen from the next generation.

For the specific purpose of collecting in the small islands most isolated and/or endangered by climate change, a boat, possibly equipped with cryopreservation facilities, could be used to visit selected islands and collect coconut germplasm. The scientific expedition could also collect whole nuts and bring them to the cryoconservation facility. Criteria for selecting these islands are discussed in section 3.5.4.

For an economy of scale, this boat should collect not only coconut palms but also other crops or natural resources. A multi-crop research team could be assembled to develop this emblematic project.

Cryopreservation of embryos from farmers' fields will require a refinement of the techniques. The example of cassava well illustrates that the efficiency of the cryopreservation process can drop considerably (70%) when applied during surveys in farmers' fields in comparison to plants sampled from *ex situ* genebanks (Dumet et al. 2013). Cryopreservation will still be needed for pollen collected from farmers' fields. As pointed out in section 2.2.4, the challenge is now to evolve from validated laboratory protocols to standardized methods giving regular and consistent large-scale results in a wide range of situations.

Where to locate cryogenebank(s)?

The question of where the cryogenebank could be located has been debated. COGENT representatives agree that each genebank should have a small cryopreservation unit, linked to a tissue culture facility to facilitate local conservation of pollen and to allow exporting cryopreserved samples (both embryos and pollen). In some COGENT countries, large cryo-facilities and tissue culture laboratories are already available for other crops that could be used for coconut conservation.

For safety duplication, a centralized cryogenebank should be established which would conserve the coconut germplasm of all COGENT countries. For economy of scale, this genebank will probably be best developed from a structure already serving as a cryogenebank for other crops. As pointed out in section 3.6.3, the future centre(s) could serve both as cryogenebanks, as disease-indexing centres, and as export facilities for embryos and plantlets cultivated *in vitro*. This genebank could be located anywhere. It could be even easier to locate it outside of the coconut cultivation zone as this could simplify quarantine processes (as for Bioversity's International Transit Centre (ITC)

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112 A probabilistic decision support tool will be used to refine the exact number of embryos to be conserved in the cryogenebanks, but globally it can be assumed that about 40% of conserved embryos will result in palms in the fields; the sample size must allow for planting the accession twice in the field, so 150 palms for Tall-type varieties. This allows conserving one "accession" as frozen and using the "other" for field regeneration or testing new hybrids. When available, about 400 embryos and 50 to 100g of pollen per accession should be collected and frozen.

managing the Global *Musa* Genebank in, Leuven, Belgium). Thus, the centralized cryogenebank will be located in the first politically stable country which, in accordance with COGENT, will:

- agree to devote appropriate funding to this crucial facility with expected support from international agencies,
- develop consistent capability for coconut cryopreservation, including regular verification of genetic integrity of plant material maintained,
- ensure that the germplasm will be kept in trust and safely transferred to recipient countries and stakeholders,
- make the germplasm available in perpetuity for COGENT country-members and other committed stakeholders.
- and preferably also serve as a disease-indexing centre.

3.4 Strengthening conservation beyond *ex situ* genebanks

The following sections are mainly focused on *in situ* conservation, but as described in sections 2.2.3 and 3.2.4, some of the concepts developed in this strategy overstep the classical delineation between *ex situ* and *in situ* conservation.

3.4.1 Conservation by use

Tree species have been the focus of increasing interest regarding a conservation-through-use approach, which aims to achieve conservation by increasing the value of resources to local communities, and thus to ensure that the crops/species stay in use. In the case of the coconut palm, this approach mainly relies on production of high value products from specific varieties thus creating niche markets, on production of seednuts of both traditional and hybrid varieties, and on ecotourism activities.

COGENT will assist APCC for increasing and diversifying the production of high value coconut products at local level. Traditional coconut varieties sometimes have lower yield; some of them could acquire a reputation for quality and be increasingly appreciated by gourmet specialty markets. Higher farm-gate revenues from the premium market may provide incentives for demand-driven on-farm conservation. *The branding of coconut products by origin or variety should be promoted* as it creates lucrative niche markets from which farmers benefit. .

Farmers producing coconut-planting material should be identified and registered in a way which will help them to market the seednuts and seedlings they produce. They need to be trained for better understanding of the reproduction mode of the coconut palm and to use appropriate techniques for improving the quality of their planting material. For instance, production of seednuts of traditional varieties should not be conducted on Tall-type palms planted close to coconut hybrids or other varieties, because the resulting seednuts will not be true-to-type.

The initiative launched in Samoa by replanting two small islands using Polymotu concept needs to be pursued and evaluated. Tools such as ecological management of small islands, production of coconut hybrids by farmers and linked ecotourism activities must be fully developed and applied to other countries. As part of a conservation-through-use approach, an ecotourism "kit' will help stakeholders to develop new lucrative ecotourism activities. It will include downloadable documentation and video guidelines. For instance, basic ecotourism activities will consist of: creating a small nursery; recognizing Dwarf, Tall and Hybrid by using colours of the germinating sprouts; emasculating inflorescences for producing hybrids; and the floral biology of Dwarf and Tall coconut palm. Preliminary tests conducted in Amanu'a island in Samoa indicates that both American and local tourists really enjoyed to learn such details, which gives to them a completely different view of what are coconuts and their diversity[113]. From this common base, stakeholders will develop other ecotourism activities specific from their own culture and location.

Regarding on-farm conservation, farmers make the ultimate decisions about conservation and use in their community. I*t is crucial to better understand the socio-economic determinants that influence farmers' decisions* about the conservation and use of particular varieties in their community. From an ethnological perspective, as discussed in section 1.1.4, the symbolisms associated with the coconut palm strongly influence the stakeholder behaviours. *These symbolisms and their consequences should be further studied*, and particularly by integrating a gender approach. Mechanisms for identifying negative trends in crop genetic vulnerability and genetic erosion should be developed at national and international level. These "early warning systems" will draw attention to immediate threats to *in situ* conservation of traditional varieties.

3.4.2 Multifunctional landscape management

The example of Vanuatu

The case of Vanuatu illustrates how the involvement of local stakeholders could be strengthened in producing good, diverse and advanced planting material. The Vanuatu archipelago contains 80 islands, but "official" improved coconut varieties are only produced in one of those, Espiritu Santo[114]. Until recently, VARTC was mainly producing two varieties for farmers: the improved Vanuatu Tall (IVTT) and the hybrid between the Vanuatu Tall and the Rennell Island Tall (RIT).

Although this hybrid is performing well, production of hybrid seednuts was stopped in 2013: managing a seed garden of Vanuatu Tall for producing this hybrid is highly challenging since these palms grow very fast; and climbing for inflorescence emasculation is dangerous. Transportation cost also considerably limits the use of these varieties by farmers.

Instead of using a unique seed garden under the method of assisted pollination, which requires climbing the palm, isolated units could be planted in farmers fields scattered over islands. These units would consist in planting 60 Green-coloured IVTT palms and

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113 Valerie Saena Tuia, personal communication.

114 Only two plots of Improved Vanuatu Tall were recently planted by farmers in an other island (Pentecost) ; in the future these plots could serve for producing planting material. Tiata Sileye, personal communication.

40 Brown-coloured RIT palms[115]. These fields would need to be protected from pollen contamination by any kind of design. These units will produce, simply by open pollinated, seednuts of IVTT, RIT and their hybrid IVTTxRIT, as follows:

- Green sprouted seedlings harvested from IVTT will be IVTT.
- Brown sprouted seedlings harvested from IVTT will be natural hybrid IVTT x RIT.
- Seedlings harvest from RIT, all of brown of brown-green colour, will be either RIT or the hybrid between RIT and IVTT.

In this scenario, palm climbing is not required; production of planting material is de-centralized across many islands; planting material is made more accessible; more than only one variety is released to farmers; and responsibility of producing the planting material is shifted, at least partially, from the national institution to farmers.

The case of the University of South Pacific in Fiji

The University of South Pacific (USP) is a regional facility supported by 12 Pacific Island Countries[116]. Contact has been initiated to locate a "*Polymotu* unit" inside the Suva campus (Fiji), using the amazing red compact Dwarfs recently found in Fiji and a Tall-type sweet husk variety from Rotuma island in Fiji. The coconut palms will not be all planted in one small separate location, but scattered between all the campus buildings as in standard landscaping. This design offers an extraordinary opportunity to strengthen the commitment and interest of the thousands of students and teachers from all Pacific regions regarding more effective coconut genetic resources conservation.

More examples from Indonesia, Fiji again, Côte d'Ivoire and Thailand

In Indonesia creating many "Kopyor" islands is envisioned, similar to the "Makapuno Island" existing in Thailand but with a different design[117].

Fiji plans to create a "sweet husk" island such as the traditional conservatoire already existing in Tonga but with a different design[118].

Côte d'Ivoire plans to create artificial "coconut islands" designed for conservation purposes and seednut production and planted in the middle of plantations of other tree crops (as described in section 2.2.3). Another project has been designed in

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115 These palms will have to be carefully selected using information on their progenies because they need to be genetically homogeneous for colour.

116 Cook Islands, Fiji, Kiribati, Marshall Islands, Nauru, Niue, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu and Vanuatu. This public research university is a regional centre for teaching and research on Pacific culture and environment. USP's academic programmes are recognised worldwide, attracting students and staff from throughout the Pacific Region as well as from other regions and beyond.

117 The "Makapuno Island" in Thailand is planted with a mix of Tall-types and Green Dwarf types of Makapuno varieties. In Indonesia, it is envisioned to plant in each island with a different set of varieties including both Tall-type and Dwarf types (preferably red or yellow) Kopyor varieties, obtained or not from vitroculture.

118 The traditional conservatoire in Onoiki islet, Tonga; has been planted with only one Tall-type sweet husk variety; in Fiji, an island will be planted with a Tall-type sweet husk variety and two red Dwarf compact varieties. This will allow conservation of these three varieties, production of hybrid seednuts by farmers and linked ecotourism activities.

collaboration with the NGO "Ivoire Développement Durable". It plans to landscape a new large customs-free area located near the city of Grand Bassam with 20,000 fruit trees belonging to 200 varieties of 40 species, including 15 coconut varieties.

Thailand is also proactive in developing this multifunctional landscape approach. Coconut varieties have been collected and planted at King Rama IX Botanical Park in Bangkok (50 varieties) and King Rama II Memorial Park in Samut Sakhon (85 varieties). In 2014, 115 varieties (now already in the nursery) will be grown in a privately-owned area in Samut Songkham but where the public can visit freely. French Polynesia plans to build a new museum close to the CRIOBE research centre in Moorea Island; landscaping the gardens of this new museum will integrate a conservation of the local compact Dwarf coconut varieties.

Whether inland or on islands, it is expected that many COGENT countries will be interested in testing and scientifically evaluating these designs to allow conserving traditional varieties, producing advanced planting material and developing ecotourism activities, often with strong involvement of local stakeholders and beyond *ex situ* genebanks.

3.4.3 Botanists, ecologists and the coconut palm

Botanists' and ecologists' approaches towards the coconut palm, in terms of biological diversity, are sometimes problematic. Both observe a great variation within coconut populations but this variation may seem inconsistent. Botanists sometimes do not understand the dynamics of the species in its historical context. In many locations and especially in the Pacific islands, landraces are mixed. Within the same small field or large plantation, one may observe big and small fruits; large roundish coconut with flat bottom used in the past as container; long thick-husked fruit used to make rope; palms selected specifically for copra, with medium fruits and thick kernel; fruit with very thin kernel very probably selected as tender nut to drink; and all intermediate between these forms, including some depressed consanguineous progenies resulting from occasional natural self pollination. Therefore it is difficult to distinguish between these mixed landraces, especially when the palms are old and tall. When focusing their interest on other species, botanists and ecologists often seem to perceive the coconut as industrial, invasive and harmful. When renowned scientists write that the coconut palm is environmentally damaging (Young et al. 2010a, 2010b), this may negatively impact conservation and use of coconut genetic resources.

Indeed, as described in section 1.1.1, excessive and reckless coconut planting on atolls has damaged and could still threaten local biodiversity. In any event, there are solutions to manage conservation of both endemic species and coconut palms, for which genetic diversity is also strongly threatened. Experiences in implementing the *Polymotu* concept in Samoa islands shows that organizing coconut conservation in Nuusafee Island has led to removing around 12,000 seedlings (done), felling about 200 senile palms (not finished), and replanting only 150 coconut palms from 3 varieties. As described in section 2.5.9, the design planned for Tetiaroa Atoll consists of removing between 1500 and 2000 coconut palms in favour of endemic vegetation and bird nesting, and then replanting only 500 coconut palms from 5 traditional varieties.

Coconuts and tourism

In 2012, two small Samoan islands started to be converted to traditional coconut conservatoires Namu'a Island hosts a small resort owned by local people. Nuusafe'e Island is uninhabited, but tourists regularly hire boats from fishermen and resorts for day trips. Funding for the research programme and the subsequent scientific visits to these islands was insufficient to fully develop and follow ecotourism activities. Nevertheless some recommendations have been drafted:

- Planting of the islands needs to be continued. For a while, tourists could be invited to sponsor/plant a seedling (especially in the hard but picturesque slopes of Namu'a). During the initial planting, Niu afa seedlings were planted by American female tourists,
- When the new coconut palms bear fruit, after all unwanted palms have been felled; it will become possible to create nurseries from the seednuts harvested in the islands. Tourists could be taught how to recognize the different varieties produced by the islands by using the colour of the germinating sprout: red for Dwarf, green for Niu afa Tall and brown for their hybrids,
- Tourists could be taught about floral biology and how to emasculate Dwarf inflorescences in order to increase the proportion of hybrid seednuts produced by the islands,
- Extracting and braiding fibres from the Niu afa variety could be demonstrated and the resulting artefacts sold.

Beyond *ex situ* genebanks, rationalizing coconut conservation can often be achieved by reducing the total number of coconut palms and simultaneously by increasing their genetic diversity. It is crucial for COGENT to convince the scientific community, including botanists and ecologists, to share these views. The research programmes initiated in Samoa islands and Tetiaroa Atoll needs to be pursued by integrating a broader ecological approach. Moreover, as highlighted in the next section, collaboration with botanists and ecologists is crucial in other areas related to conserving coconut genetic resources.

3.4.4 Coconut reproduction patterns

As pointed out in section 1.1.4, the complexity of natural breeding modes of the coconut palm remains a challenge that needs to be better managed.

The most important topic relates to pollination distance. Although some experiments have been conducted in the past (Sangare 1981), further study is needed on the pollination distance for optimizing the production of certified varieties in geographical and reproductive isolation. As discussed in section 3.4.1, production of seednuts of traditional varieties should not be conducted on Tall-type palms planted close to coconut hybrids or other varieties; otherwise the resulting seednuts will not be true-to-type. Three elements need to be determined:

1. The ***minimum isolation distance*** needed to produce at least 95% of true-to-type seedlings.
2. As an alternative guarantee of sufficient isolation for seednut production, ***the size and thickness of a buffer zone*** made from the same varieties and surrounding the

seed garden. This kind of design was envisioned for replanting the Samoan *ex situ* collection[119].

3. If ***such buffer zones can feasibly be used*** in *ex situ* genebanks in order to avoid making controlled pollinations, as explained in the above Samoan example. Presently it is estimated that conserving one accession by using buffer zones will require 8 to 10 ha, when compared to 0.7 ha for conserving the same accession in classical *ex situ* genebanks.

Another important topic is related to self-pollination, inducing an inbreeding depression of 20-30% in the yields of 10-30% of the natural progenies of most Tall-type coconut palms. Simple techniques need to be tested for selecting the seednuts, which result only from cross-pollination. This will consist in sowing seednuts selected only from green-coloured parents in populations mixed of green and brown colours; then comparing the yields of the progenies according to the colour of their sprouting. In this case, seednuts from natural self-pollination show a green sprout. Seednuts with brown sprout come from the cross between a Green coloured female parent with a brown coloured male parent, but never from self-pollination. Thus, in these progenies, comparing the yields of green sprouting and brow sprouting palms will allow to estimate the losses in yield due to self-pollination.

As discussed in section 2.5.6 with regard to fruit quality, the characteristics of the triploid kernel are influenced by the set of chromosomes transmitted by the pollen. Thus, it is important to assess how many male parents are represented in a coconut bunch.

Many farmers plant seednuts directly harvested on Dwarf x Tall hybrids, so *the reproduction mode of these hybrids needs further assessment to better understand the consequences of this practice.* We presently do not know the percentage of selfing in such seednuts.

From a more general perspective, it appears crucial to convince ecologists to conduct more fundamental research on the coconut palm. Most of ecological studies are presently devoted to wild palm species. The coconut palm is an extraordinary model for ecological studies because of its dispersal pattern, because of the co-existence of different reproduction modes and because of the specificities of its coastal habitats and associated fauna.

Thus, a better understanding of the natural reproduction pattern of the coconut palm could greatly benefit the quality of conservation and of production of planting material.

3.5 Collecting and filling gaps in *ex situ* collections

The global objective of COGENT for filling gaps within the next decade in *ex situ* collection is to collect up to 500 well-chosen populations or varieties and successfully transfer them in *ex situ* genebanks. COGENT country members will probably collect more germplasm in the framework of their national programmes; but

[119] See the URL : http://coconutsamoa.blogspot.fr/2010/03/15.html

common priorities and rationalization need to be defined at the global level for a coordinated international action.

The COGENT Secretariat will work to identify adequate funding for carrying out collection trips and subsequent establishment of the collected materials in *ex situ* collections (in national as well as international). Missions should no longer be devoted only to prospecting or collecting germplasm; they must also contribute to strengthen links between *in situ* and *ex situ* conservation at local level and make a detailed characterization/description of the material in its geographical original site. This approach will be systematically included in the terms of references of the surveyors.

The successful establishment of collected germplasm in an international collection will require the willing cooperation of the host country holding this germplasm. Experience suggests that release of such genetic resources by host countries is not always easily achieved. COGENT will facilitate this process. Although priority setting may need some refinement, COGENT already have a clear appraisal of which germplasm should be collected during the next ten years, and where to collect it (see recommendations from 2012 and 2014 Steering Committee.

3.5.1 Compact Dwarfs and other special varieties

One of the ten international recommendations emitted in 2012 by the COGENT SC meeting deals with collecting activities[120]. Recommendation 4 focus on "Strengthening coconut genetic research, coconut conservation and specific uses of traditional coconut varieties in the Pacific Region."

Cultivation of Dwarf coconut varieties is rapidly expanding. This expansion is based on a narrow genetic basis, mainly the "Malayan Dwarf" type, characterized by thin stem easily felt down by cyclones, low resilience and sensitivity to drought. As soon as possible, COGENT should introduce in the global system the cultivation of compact Dwarfs and/or crossed between compact and Malayan Dwarfs. These types have thicker stems, slower vertical growth and a better resilience. ***Pollen of compact Dwarfs should be collected and sent to the coconut breeders working in COGENT country members.***

Coconuts able to both produce suckers and fruits have been described. This germplasm urgently need to be safeguarded and further studied, especially by researchers who are trying to propagate the coconut palm *in vitro*. The organization of national or regional coconut varietal contest was recently proposed as a new approach to locate crucial germplasm and increase public awareness about coconut diversity (https://replantcoconut.blogspot.com).

Within the next decade, it is envisioned to collect up to 50 varieties or populations of compact Dwarfs (or intermediate forms between compact and Malayan-type Dwarfs), and up to 50 Tall-type varieties or populations having both special characteristics such as sweet husk, special taste and texture of kernel, special taste of coconut water, medicinal uses or other rare quality traits.

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[120] http://www.cogentnetwork.org/images/2012_sc_meeting/cogent_recommendation_4.pdf

Plate 3.2

Compact Dwarfs are crucial varieties for the future of coconut breeding

Wider future diversity

1, 2 & 3. The Niu Leka Dwarf from Taveuni island in Fiji was the first Compact Dwarf to be described by scientists, but this is not the most productive.

4,5, & 6. During surveys conducted in French Polynesia, the first Compact Dwarfs with orange-red fruits were identified in Moorea island.

7. Some of the best Compact Dwarfs from Moorea island produce big round fruits with a tasty coconut water and a specific nice pink colour in the immature husk.

8. Around Suva in Fiji, more than twenty new varieties of Compact Dwarfs were observed, such as this Yellow form with pointed fruits. Some may derive from crosses between Compact Dwarfs and the Malayan Red Dwarf.

9 & 10. Two more Compact Dwarf Varieties from Tahiti island.

11 & 12. A compact dwarf variety from Tubuai Island, Australes archipelago in French Polynesia, showing very unusual terminal flowers at the end of the spikelets.

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3.5.2 Collecting for pest and disease resistance

Collecting actions may be directed to areas where disease resistance is expected to be found. These areas are not necessarily those under disease pressure.

These surveys will also often consist in collecting the few palms remaining alive in a zone devastated by a pathogen. Observations conducted notably in Mozambique indicate that it could be better to collect before reaching the stage where most of the palms are dead: In the fields threatened by high pressure of Phytoplasma disease, the rotting stems induce a proliferation of insects, such as *Oryctes* or *Rynchophorus* sp., which finally kills all the remaining palms, be they tolerant to Phytoplasma or not.

Within the next decade, the Strategy aims to collect about 100 populations having putative pest and disease tolerances. In such surveys, phytopathological aspects are crucial because of the risks of transmitting the pathogens with the germplasm. Thus, the use of quarantine centres and disease indexing methods appears as a necessity for releasing such collected germplasm to *ex situ* genebanks.

Large companies in Brazil are investing millions of dollars in producing coconut planting material, in optimizing plantation management and in coconut processing. However, they face the constant risk of losing consistent production due to pest and disease damage and the risk of introducing even greater disease problems, such as Lethal Yellowing Disease. Companies from Brazil would like to be able to access sources of interesting genetic material, as well as to participate in implementing strategies to protect the genetic material. Public-private participation will facilitate developing and implementing strategies of common interest for the crop. Establishing exclusion zones or quarantine for introducing new germplasm for breeding purposes would enhance effectiveness and efficiency. Private companies already operate in the acquisition of new genetic material. A large, worldwide programme would give greater security to private companies for new investments as well as the expansion of existing projects, ensuring profitability and reducing business risks, especially with regard to industry of tender coconut water, which is in expansion, with new companies working in the field every year.

3.5.3 Islands most isolated and/or endangered by climate change

Genetic diversity can be split into two dimensions; one concerned with adaptive variation and the other with neutral divergence caused by isolation. Different evolutionary processes suggest alternative strategies for collecting and eventually conservation. Planning should emphasize the survey protection of historically isolated lineages because these cannot be recovered (Moritz 2002).

It is envisioned to collect germplasm in remote small islands. These islands needs to be carefully selected using a multidisciplinary approach based on the following criteria:

- most endangered by climate change,
- most geographically remote and only accessible by boat (no airport) but preferably where people are living,

- islands where copra was never a business because traditional varieties will probably be better conserved,
- island where coconut was or is culturally important,
- and, as it is envisioned to collect more than coconut, islands having special interest for researchers working on the other concerned crops or animals.

Numerous historical data and information from old planters and their families will also be collected, so participation of an ethno-biologist to this survey will have to be considered.

This kind of survey may concern many archipelagos, such as Maldives, Tuvalu, Kiribati, Tuamotu, the many Indonesian atolls, etc. Highest priority is Tonga for reasons linked to cultural context and high isolation index of some islands. The choice of islands will also depend on willing cooperation of the host countries holding the germplasm. As the cost of such missions is high, COGENT Secretariat will strengthen links with international organizations, national museum, botanical gardens, universities and research institutions programming collecting expeditions in order to join existing collecting missions organized by national or international teams. During these missions, scientists involved (on behalf of COGENT countries) will follow the International Code of Conduct for Germplasm Collecting and Transfer[121]. It is envisioned to collect embryos and pollen from coconut populations, the majority of which will be directly (and only) conserved as cryopreserved material This activity is only envisioned when protocols for cryoconservation of coconut germplasm will be available.

The dynamics for the Pacific Region described in section 1.1.1 have important consequences regarding the appropriate methods for collecting Tall-type coconut germplasm. Palms with special characteristics will be sought within populations in farmers' fields. In many cases, the classical approach that consists of selecting palms at random in a given population seems no longer appropriate. Such a method samples and conserves an uncontrolled mix of traditional varieties[122]. Due to the low multiplication rate of the coconut palm, such mixes are of little interest to breeders, except in certain cases when prospecting for disease resistance. Thus, the collecting method will focus on the few palms having desirable traits within populations existing in farmers' fields. The number of fruits collected per population will probably be reduced when compared to previous surveys. A "change detection database" would allow visualizing increase or reduction of plantations, deforestation or reforestation, and coastal erosion[123]. It will help prioritizing the areas where endangered coconut germplasm must be collected.

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[121] SeeThe URL: http://www.fao.org/biodiversity/instruments/en/

[122] Some of the accessions collected in the Pacific region and presently conserved in *ex situ* genebanks are this kind of varietal mix: for instance Rangiroa tall, Rotuma Tall...

[123] SPC SOPAC Division Published Report 45.

The Strategy aims to collect embryos and pollen from 100 to 200 coconut populations, the majority of which will be directly (and only) conserved as cryopreserved material.

3.5.4 Filling geographical gaps

As discussed in section 2.4.3, gap analysis is applied to map the actual distribution, agro-climatic preferences, and potential distribution of coconut. Geographic Information Systems (GIS) are used to analyse spatial distribution of different coconut populations. The degree of variability expected to be found in new collecting areas is another important consideration. Information on allelic diversity in the coconut populations could provide an important criterion to guide future collecting.

A first analysis was conducted by the COGENT secretariat at country level. Accessions conserved in *ex situ* genebanks comes from only 45 countries and territories of which 30 are COGENT member-countries. According to FAO, there are 92 coconut producing countries and territories (CPCT), so 47 (51%) are not yet represented in the germplasm conserved *ex situ*. The ratio between coconut planted area and the number of accessions conserved *ex situ* was calculated by region. On average, this ratio is 90 accessions per million hectares, and ranges from 64 (Africa) to 282 (Pacific Region). This first approach indicates some basic trends, but it needs to be refinemd by adding other criteria. Based on this single geographical criterion, the higher the ratio, the higher the range of geographical diversity represented in the *ex situ* collections.

This analysis was pursued using predicted area calculated from the maps produced by Ecoclimatic Niche Modelling. Prioritization of areas for collecting will not consider only sizes of predicted areas, but their isolation status (for example isolated valleys will be preferred). The ethno-biological literature and, when available, predicted allelic diversity will also be taken in account.

Based on the sole geographic criterion, some areas like Latin America, the Caribbean and Africa should benefit from more accessions' registration and preservation. The Strategy aims to collect 100 to 200 populations following the approach of filling geographical gaps.

3.6 Strengthening the distribution and the safe movement of germplasm

The introduction of new accessions is generally driven by a specific goal, e.g. germplasm tolerant to phytoplasma diseases in countries that suffer significant losses due to these diseases. Another objective can be to introduce germplasm with resistance to diseases that are not yet present in the country, so that resistance can be incorporated into breeding lines as a safeguard in case of the accidental entry of the disease. Furthermore, countries may wish to introduce germplasm from a particular genetic group that is under-represented in their national germplasm collections, such as for instance compact dwarfs, aiming at broadening the genetic base of these collections. Each country generally have its own policy.

3.6.1. Policies for international germplasm transfers

The legal situation regarding access to coconut genetic resources needs to be assessed, clarified and influenced by improving awareness on COGENT activities and by disseminating information regarding benefit-sharing and dedicated legislation. This will facilitate the involvement of decision-makers in formalizing arrangements for germplasm movements. It will also improve their political understanding of the interest of conservation and use of coconut genetic resources towards supporting the development of a sustainable coconut industry in their country.

Linking legal expert groupss to various initiatives like pest and disease monitoring projects in coconut fields in EMBRAPA Brazil for instance, the IPM network from APCC at the regional scale, and international groups such as the International Plant Protection Convention[124] (IPCC) and (FAO), is crucial to get the most accurate and updated information. COGENT will engage with the IPPC and its Regional Plant Protection Organizations to ensure that updated guidelines for safe movement of coconut germplasm will be widely available to those responsible for the phytosanitary systems in coconut producing countries. Another important field of collaboration is risk analysis and policy making for avoiding spreading pests and diseases via stakeholders from other countries or regions (Zu et al. 2010).

For collecting missions, an important step is to secure the administrative authorization necessary before any collecting trip. When the permits for germplasm collection are obtained from the authority concerned in a given country, the aims and objectives of the project will be explained to the local populations using language that they can understand. Missions should no longer be devoted only to collecting germplasm; they must contribute to strengthening conservation at local level. Local farmers associations and NGOs might be important links in facilitating such meaningful communication.

The COGENT ITAGs on Phytopathology and coconut germplasm movements should have opportunity to meet in order to update the guidelines as new information becomes available on coconut pests and diseases and integrate new technologies as they become available. The guidelines should be formally reviewed every two years. If new information become available in the meantime, e.g. on the spread of a particular pest, then the guidelines will be updated accordingly.

This will ensure the most effective means of raising awareness and communicating the importance of safe germplasm movement to the coconut community. Without this understanding, there is the danger that illicit movement of coconut plant material will spread pests and diseases.

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[124] The IPPC works with Convention contracting parties, to develop phytosanitary measures that underpin the parties' ability to manage pest risks and the environmental, economic and social impacts of plant pests. Its Commission on Phytosanitary Measures (CPM) meets annually to review the state of plant protection, identifies action to control the spread of pests into new areas, develops and adopts international standards and establishes procedures for the sharing of phytosanitary information. The IPPC works with Regional Plant Protection Organizations and international organizations to build phytosanitary capacity, to identify and address risks that cross national borders.

3.6.2. Transfer of germplasm via embryo culture and pollen

As pointed out in section 2.2.4, the application of embryo culture to international germplasm transfers needs further review and refinement, together with strong concerted capacity building. A recent Trust-funded project clearly demonstrated that coconut embryo transfer is only feasible where the provider and recipient have sufficient capacity and other resources to strictly apply the recommended protocol. *Further support is needed to build such capacity and resources within many of the coconut genebanks*.

As discussed in section 2.6.3, from a global perspective, access to crop genetic resources has been recently subject to various forms of exclusive technological and legal restrictions. Thus, it seems very important for countries and stakeholders *to be allowed to receive coconut germplasm even if they do not have facilities and expertise* for *in vitro* culture of coconut embryos. A solution could be to cultivate the plantlets *in vitro* up to the stage where they are ready to be removed from the tubes and transferred to the nursery; then to send young plantlets in sealed tubes to the receiving country and stakeholders. This will need further research and the publication of simple guidelines explaining how to cultivate these young plantlets after removal from the tubes.

International transfer of pollen is the cheapest way for exchanging germplasm and the fastest way to include this germplasm in breeding programmes. So, another research area will be to optimize international transfers of pollen. Even if previous studies indicate that the exchange of pollen is a safe method, there is a need to re-assess the risks of transmission of pest and disease via coconut pollen.

3.6.3. Disease indexing and quarantine centres

Pest and diseases seriously constrain or even prevent international germplasm movement. Germplasm collected as embryos and pollen often needs to be transferred from the surveyed country to other countries hosting genebanks. This germplasm should preferably transit by quarantine centre(s). Such centre(s) will grow the embryos into plantlets, conduct disease indexing and securely transfer the germplasm to genebanks around the world.

Where to locate these future quarantine centres? If a coconut lethal disease exists within a country hosting a quarantine centre, the entire quarantine process needs a reinforced and fully isolation protocol, with no contact between embryos, plantlets and the exterior. Thus, quarantine centres could also be located out of the coconut production area. On the other hand, research on disease indexing need also be pursued; it is easier to conduct such research close to the disease-infected areas. For an economy of scale, it seems also interesting to merge these quarantine centres with cryopreservation facilities for embryos and pollen. One centre, at least, should serve both as quarantine and cryogenebank.

Two options are to consider a unique site serving both as quarantine centre and cryogenebank, or to organize disease indexing centres in a more regional basis. In this last case, each or some of the world regions (such as Africa, America, Asia, Europe, Oceania) could host a quarantine centre. Feasibility studies will assess these options. It would be preferable that these activities will not be implemented in newly built centres, but by adding a coconut component to the facilities already existing for other crops.

As discussed in section 3.3.4 on cryogenebanking, disease indexing centre(s) will be located in the first country(ies) which, in accordance with COGENT and other institutions, will:

- agree to devote appropriate funding to this crucial facility with expected support from international agencies,
- develop consistent research and capability for coconut disease indexing,
- ensure that the germplasm will be kept in trust and safely transferred to recipient countries and stakeholders,
- and preferably also agree to host a cryogenebank.

COGENT will support developing such international quarantine centres in areas preferably (but not necessarily) free from lethal coconut disease.

3.7 Promoting the use of coconut genetic resources

In the light of promoting the effective use of coconut genetic resources, this section considers the following important elements: global objectives in terms of planting material; promoting farmer-produced and certified varieties; germplasm characterization and evaluation; international breeding trials, and the development of coconut clones whenever possible.

3.7.1 Global objectives in terms of planting material

The current status of coconut planting material production has been outlined in section 2.5.1. However, there is a need to assess more precisely the amount, type and quality of the coconut-planting material produced by national institutions, private companies and, especially, farmers. Information regarding the planting material will need to be widely disseminated among stakeholders.

As pointed out in section 2.5.2, farmers are collectively much more involved in coconut breeding and seednut production than scientists are. Farmers produce more than 80% of the planting material by themselves from the varieties they breed and conserve.

Nursery at PCA. (A. Prades, CIRAD)

For sure, COGENT does not advocate a situation where farmers become only diversity *users*, and where all conservation and breeding is implemented by national institutions or large private companies, as illustrated by the example of maize in 'Western' countries.

The question of global objectives in terms of planting material has been debated at various levels. Even if COGENT exerts influence on coconut-planting material at global level, its objectives must be realistic and feasible in a global context mainly driven by market forces. Thus, COGENT will focus on the three following targets:

1. Reach a situation where *farmers will have the choice*. The amount and diversity of planting material should become sufficient to fulfil farmers' needs. At the national level, seednut producers and agricultural services should provide a range of at least six different coconut varieties, including Talls, hybrids, Dwarfs and eventually composite varieties[125]. Most farmers will choose to plant more than one variety.
2. Help farmers to preserve and increase their knowledge regarding coconut palm diversity and breeding. The specificities of each variety regarding environmental adaptation and agricultural practices must be clearly explained to farmers. Farmers and other stakeholders can be trained to autonomously produce quality seedlings, including self-production of hybrids[126] using the *Polymotu* concept or any other adapted method.
3. To better understand the reasons for farmers' and consumers' preferences. Coconut is not only 'agricultural'; it is a highly cultural plant. Profitability and economic aspects are not the sole drivers of farmers' preferences. In India for instance, farmer preferences also embrace the planting material qualities as a cultural entity within a human community (Bourdeix et al. 2008).

In this context the market will continue to play its regulatory role, where farmers will enjoy better control of their business. At the global level, a reasonable objective for the next decade could be to reach in each country the target of a maximum of a third of the planting material produced by national institutions and large private companies (NIPC); and to support farmers in enhancing the quality of their farm-produced planting material.

How long it will take to achieve a third of total planting material to be produced by NIPC depends mainly on market forces. Recently, private companies have strongly increased their involvement in coconut seednut production, notably in India and Brazil. Large companies in Brazil are investing millions of dollars for producing planting material, for optimizing the management of plantations and the processing of the fruits. Such an evolution is foreseeable, in the short term, at least in the Philippines and Indonesia, and potentially in many other COGENT member-countries.

At the end of the next decade, the Strategy plans that, in each COGENT member-country, at least five varieties will be made available as planting material to farmers by national institutions and/or private stakeholders. At least 80% of these varieties will have to be documented in the future online database described in section 3.8.3. The role of COGENT will be to make a balance of the existing and to help countries in developing action plans for reaching this objective.

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[125] As stated in Recommendation 3 of the COGENT SC 2012.

[126] See the URL: https://replantcoconut.blogspot.com.

3.7.2 Promoting farmer-produced planting material

Farmers are disseminating coconut planting-material. This is often restricted to social networks such as family, clan or village. Researchers and their institutions could help local stakeholders (men and women farmers, private enterprise, NGOs and CBOs) to document, promote and supply larger amounts of good quality germplasm. Information on farmers and the seednuts they produce must be collected and compiled in a dedicated database, as described in section 3.8.3. This database and other communication tools will help the interested local stakeholders to market the varieties they produce.

Local traditional knowledge, especially from the elders, must be preserved and shared by elders with other community members and the younger generation. Scientific and technical knowledge produced by researchers must be made more easily accessible, understandable and user-friendly to these farmers. In some cases, the scientific and traditional knowledge can be contradictory. Such situations must be carefully managed because scientific knowledge can obliterate traditional knowledge.

As pointed out in section 2.5.1 and 3.1.3, farmers' knowledge regarding the coconut reproductive system and the use of genetic markers such as germinating sprout colour is a key factor for breeding purposes. Farmers' traditional and technical knowledge needs to be further assessed. This study that should include the following steps:

1. Drafting a standard gender-sensitive questionnaire by ethnobiologists and geneticists.
2. Training local researchers on survey implementation.
3. Interviewing at least 800 farmers in at least 20 countries of the 39 COGENT member-countries.
4. Developing communication tools to increase farmers' knowledge regarding coconut reproductive biology and breeding methods.
5. Conducting a similar survey with the same questionnaire five years after launching this process, in order to assess the evolution of farmers' knowledge.

Here again, there is an evident interest in such conducting research not only on the coconut palm but also on other tree crops.

As discussed in section 3.3.2, farmers and other stakeholders can be taught how to autonomously produce seedlings of hybrids and other varieties. On-farm conservation can be strengthened through activities such as participatory variety selection, coconut breeding and farmer field schools. There is also a great interest for developing a simpler controlled hand-pollination method[127] which could be used by farmers and by small research centres lacking pollen-processing labs. Such an approach was initiated in India by transcending gender barriers and teaching Indian women to climb the

[127] It will be a technique where spikelets with fresh male flowers will be introduced inside the bags isolating the emasculated inflorescence.

palms for pollination purposes[128]. As discussed in section 3.1.3, videos should describe these techniques and help make them workable for farmers. Researchers in charge of collecting germplasm could bring some pollination bags and teach these techniques to local stakeholders.

3.7.3 Germplasm characterization and evaluation

The benefits of conserving and utilizing the coconut genetic diversity will only be realized if this diversity is of interest and is made available to researchers engaged in breeding programmes. Funding to support characterization and evaluation of accessions as well as to support the systematic documentation and dissemination of the information is imperative to ensure efficient genebank management and use of genetic resources by breeders. This should include the digitization and dissemination of important historical data.

The use of accessions depends on their evaluation for economically and culturally important traits. The main traits to be assessed are yield determinants, adaptation to biotic and abiotic stress,yield components, precocity and tree size (quality and vigour). Although increased yield potential is the main aim, yield potential can only be reliably estimated in collections with uniform planting conditions or by the use of appropriate statistical tools.

The list of international coconut descriptors dates back to 1995 and needs to be revised and completed. For instance, although a few traits regarding fruit quality are included in the international list of standard descriptors, there is a need to increase and standardize these quality descriptors, and to promote their systematic evaluation. For instance, no specific data regarding tender coconut is yet included in the Stantech Manual whereas the international market for coconut water represents today more than two billion US$.

In order to increase differentiation of cultivars, putative new descriptors should be studied, especially for roots, the morphology and size of female and male flowers, the morphology of pollen, the upper part of the fruit, the three eyes of the nut, and the top of the canopy. Organoleptic and physicochemical components linked to nutritional qualities of the kernel and the water are other important criteria and should be better taken into account. For some products, such as Makapuno fruits, tendernut and even mature coconut sold as fresh fruits, the short shelf-life is limiting markets for fresh consumption; genetic diversity for these characteristics should be assessed in conjunction with the available preservation techniques.

Heavy winds damage coconut palms in cyclone prone locations of many countries such as Philippines, Fiji, Jamaica, Vanuatu and India. Drought tolerance and establishment ability in coconut have also become important traits due to the growing concerns about climate change, notably with the dry seasons getting longer, harsher

[128] See : http://www.icar.org.in/en/node/5913

and less predictable in some regions. Especially, draught tolerance could be linked to changes in the coconut fruit biochemical composition and could lead to different nut yields and qualities. Tolerance of coconut germplasm to such natural calamities should be added to the descriptor list and existing databases

About the guidelines "Useful definitions of terms and nomenclature"

International cultivar names may evolve with time. For instance, researchers from Vanuatu, a Melanesian Archipelago, gave population names to the many Tall-type accessions they collected, under the cultivar "Vanuatu Tall": Pélé, Nipeka, Waluembue, Walanaro, etc. Researchers will observe in the genebank the characteristics of these populations, using morphological, productivity and molecular traits (DNA analysis). For instance, if the population "Vanuatu Tall Nipeka" proves to have distinct traits, its name will have to evolve: it will be renamed as a new cultivar, probably "Nikepa Tall". On the other hand, if the populations "Vanuatu Tall Waluembue" and "Vanuatu Tall Walarano" prove to be identical, these accessions or crosses between selected palms of these accessions could be merged under one name only, to be chosen by curators. When the accessions will have to be regenerated, the two accessions will be merged, as there is no need to conserve the same germplasm as two separate accessions.

Further prioritization on specific traits will be required under the coordination of COGENT. Pre-breeding activities, such as for instance selecting the best palms within accessions, should be supported so that advanced material can be made widely available to accelerate progress in breeding efforts. Once evaluated, pollen or embryos of selected progenies could be sent to quarantine centre(s) before being released in trust to breeders.

The manpower needed for characterizing accessions using standard descriptors was estimated in section 2.3.3. **This analysis led the COGENT secretariat to issue an international recommendation applicable to the coconut palm and any other crop: an evaluation of the manpower and equipment needed for observation of standard descriptors should be included as annex to all new versions of lists of standard descriptors.**

3.7.4 International breeding trials

As discussed in section 2.5.3, there is insufficient activity in practical coconut breeding. Many countries are still utilizing the same hybrids for over 20 years whilst farmers and exporters demand for new varieties that meet their needs. Breeding programmes are under-resourced in most countries. Coconut breeding itself is of no use if it is not followed by efficient programmes to multiply selected varieties, either in seed gardens (hybrid varieties) or using appropriate designs such as *Polymotu*. Plate 3.3 demonstrates the potential for wider future diversity from hybrids that could be incorporated into breeding programmes

Although past international surveys and experiments have been fruitful, a globally coordinated coconut breeding programme, as stated in the previous version of the Strategy has not been achieved. Coconut is used in a wide range of regions and countries, with a wide diversity of soils, climates, and pests and diseases, and for a great diversity of uses.

Plate 3.3

Progenies of hybrids between Malayan Dwarf-type Coconut Varieties

Wider future diversity

1. Natural selfing of the hybrid between the Malayan Yellow Dwarf and the Pilipog Green Dwarf.

2. Same progeny: inside the young fruits, some palms have a pink colour inherited from the Pilipog parent.

3, 4 & 10. Natural selfing of the hybrid between the Malayan Yellow Dwarf and the Tahiti Red Dwarf.

5, 6 & 8. Natural selfing of the hybrid between the Pilipog Green Dwarf and the Sri Lanka Green Dwarf.

7. Natural selfing of the hybrid between the Cameroon Red Dwarf and the Sri Lanka Green Dwarf, seen with researchers at the CNRA Marc Delorme research Centre (Côte d'Ivoire) and the COGENT coordinator.

9. Natural selfing of the hybrid between the Malayan Yellow Dwarf and the Sri Lanka Green Dwarf and researchers at the CNRA Marc Delorme research centre (Côte d'Ivoire).

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Risks of disease transmission and quarantine restrictions also limit the exchange of seednuts, although it remains possible to exchange pollen and embryos. It has proved difficult to engage the interest of both decision-makers and coconut breeders to collaborate on common genetic experiments. Breeders prefer to make their own choices, closely related to the specificities of their countries.

COGENT will no longer promote a globally coordinated coconut breeding programme. If some member-countries are interested in exchanging breeding progenies, COGENT will continue to support them. Such a possible exchange was recently discussed for Makapuno/Kopior varieties. The main challenge will be to obtain the commitment of researchers, their parent institutions and countries to exchange this sensitive material. Sending pollen is the fastest and the cheapest way to conduct such exchanges.

The role of COGENT in breeding activities will mainly focus on the following objectives:

- Help understand the genetic determinism of the two kinds of dwarfisms existing in the species by using field experiments and molecular approach.
- Evaluate the value of the seednuts harvested on Dwarf x Tall Hybrids, as many farmers are planting this material.
- Ensure that appropriate methods and equipments are available for conducting reliable controlled hand-pollination (breeders will benefit from the actions undertaken for regeneration of genebanks).
- Promote international exchanges of pollen between breeding programmes.
- Promote multi-location trials involving research centre, small farmers and the few existing large plantations, and increase interactions between these three categories of stakeholders. These experimentations will be devoted in priority to complex crosses between Dwarf types and search for tolerance to diseases caused by Phytoplasma.
- Help seednut producers to market their planting material.
- Promote the use of genomics in breeding, as discussed in section 3.9.2.

Conventional breeding is cumbersome in plantation crops. It involves many generations running for decades; it is expensive in terms of time, space and the large volume of individuals to be handled. Recent developments in molecular genetics and biotechnology are now accelerating the breeding process. Therefore, it is crucial to combine marker-assisted selection, genomics and genetic engineering techniques with classical breeding, as discussed in section 3.9.

The yields reached by the few large plantations and even small Brazilian farmers are often higher than those obtained by breeders in national research centres. New dynamic breeding programmes should be encouraged, technically strengthened and conducted in collaboration with private sector with technical assistance by COGENT and selected development partners. While some large companies in Brazil and India already have breeding programmes for their specific purposes, a more comprehensive breeding programme, which brings together information from existing varieties within companies, in research institutions and in farmers' fields, in a network model, would bring a great benefit. As stated in recommendation 7 from the 2012 COGENT SC, private companies and farmers need to be more involved in coconut breeding by hosting at least half of the field experiments under supervision of scientists from national institutions.

If breeding experiments are to be conducted with farmers, the past experience obtained from India must be fully taken into account. Protocols will integrate the fact that farmer's choices rely on the qualities of planting material as a cultural entity within a human community. COGENT will encourage large plantations to host new demonstration plots and to help training smallholders to modern cultivation practices.

Two of the ten recommendations developed during the 2012 SC COGENT meeting focused on establishing multi-location coconut breeding trials. One focuses on breeding Dwarf varieties in Latin America, the Caribbean and Africa; the other deals with conducting an international breeding trials in Asia.

3.7.5 Coconut clones, the next revolution?

As discussed in section 2.2.4, embryogenic callus from obtained from embryos plumules can be regenerated as in vitro plantlets. This technique has not yet been applied to producing planting material for farmers. *Cloning needs further study, as access to clones could greatly benefit farmers.*

In Brazil, large companies are already considering coconut cloning as a reality. Companies seek high and consistent productivity and standardization of the final product, which would be considerably improved with the advent of the cloning technique in scale, enabling the planting of clones over large area. For this technique to become economically viable and taken to scale, clone bio-factories should be established with the participation of private enterprises in financing, as well as for large-scale acquisition of clones. A partnership of private companies with Brazilian producers, who receive the cloned seedlings, will provide superior and uniform genetic material with guarantees from the private companies in terms of purchasing the fruits.

The availability of clones would have important consequences for both coconut conservation and breeding. The coconut cloning technique presently available has a particularity, in that the clones are not obtained from the vegetative parts of the palms. They come from embryos resulting from sexual reproduction. Breeding methods will need to be specifically adapted to identify and select the best 'sexual clones'.

A practical example will better illustrate such an evolution. In Colombia, CIAT has collected 300 embryos from 90 palms[129] that have survived recurrent waves of the Red Ring disease (caused by the nematode *Bursaphelenchus cocophilus*) during more than 40 years. Embryos are presently multiplied *in vitro* by using the technique of somatic embryogenesis from embryo plumules.

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[129] from local and imported Dwarf and Tall coconut varieties.

Nutless coconut varieties

There is an attractive potential market for nutless coconut varieties. The tourism industry and municipalities in Florida, Hawaii and other tropical areas are spending several million dollars per year only to remove coconut from the palms to avoid accidents due to falling coconuts. Globally, much more money is spent in removing these coconuts than for conservation of coconut genetic resources. This could be one of the first marketable applications of in vitro clonal propagation, although presently clones are generated mainly from embryos. Many customers would be prepared to pay a lot of money for a coconut palm with attractive fronds and no fruit at all. Such rare, nutless palms could quite easily be found in farmers' fields and genebanks, and they generally gain height more rapidly than conventional varieties.

The collected material will be tested for disease tolerance. From the genetic perspective, the samples presently multiplied do not have the same genotypes as the palms in the fields; they come from open-pollinated progenies. It is expected that the cause of tolerance in the parent palms is principally due to genetic factors. In this case, if the genes involved in tolerance are dominant, the tolerance will be transmitted to these progenies. But if these genes are recessive, only a very few of the progenies (those resulting from natural self-pollination) may express the expected tolerance to the Red Ring disease.

In the meantime, the embryogenic callus lineages obtained from embryos will need to be carefully preserved. They are the only material from which the best clones could be multiplied. The whole experiment, including field testing, will take 8 to 12 years to achieve full results. Thus, an efficient means of conserving these embryogenic calluses is vital. As discussed in section 3.3.4, cryopreservation could be the most effective way to conserve this material.

There is an evident interest to apply cloning both to the material existing in farmers' fields, and to breeders' best progenies. For instance, in the case of Colombia, it could be interesting to cross the putative tolerant Dwarfs with the putative tolerant Talls, and to use the resulting embryos for somatic embryogenesis and subsequent breeding work. It will probably take again time for scaling-out such a technique from the laboratories to the full-scale development stage.

Another application of coconut cloning could be to create bi-clonal seed gardens. This would allow releasing seednuts from the cross between two selected coconut palms (and no longer the crosses between two populations, as it is presently done).

The availability of clones would have strong consequences on both conservation and breeding of the coconut palm. Such a methodology will apply first to the selection of palms tolerant to phytoplasma diseases and to any other characteristics wanted by breeders and other stakeholders.

3.8 Improving databases and sharing of technical information

As pointed out in section 1.1.5, inadequate communication and dissemination of reliable information on coconut accessions held in genebanks significantly reduces the accessions' value to breeders, farmers and other users of the germplasm. *The existing germplasm information systems need more support* to improve accessibility and interpretation of the information available. The COGENT website[130] provides a single point of access for all the elements of the Coconut germplasm Information System.

3.8.1 Data management in genebanks

As seen in section 2.4.1 ('Local genebank management systems'), data loss in genebanks is a real threats. Therefore, it is imperative to make sure that all collected data remains available and securely stored for many years. Initiatives are needed in most genebanks to install and/or improve local information management systems to facilitate accession management and data sharing.

Characterization and evaluation data from ex situ *genebanks and breeding trials should be computerized and systematically duplicated* in another geographically different location. These may be two different national institutes, or a national institution cooperating with a specialized international research institute. The COGENT secretariat already played a role in safeguarding data, especially in Côte d'Ivoire. *This role could be extended with respect to intellectual property* of institutions and countries if appropriate resources are made available.

Given the rapid evolution of information technology, the software "Coconut Data Management" (CDM) is now becoming obsolete. *A more complete and modern software should be developed for managing palm-by-palm data*. The many technical operations linked with controlled hand-pollination need also to be computerized. Homemade basic software is sometimes used for this last purpose, but a more global and standardized approach would favour efficiency and quality in the management of controlled pollinations. Genebanks may hold collections of other crops; they are often spread over several locations, and coordination would require a significant amount of time or computer equipment. *The local genebank information system should be able to compute the average values for data obtained from specific trees in the field, that are stored as characterization data in the CGRD database.* This will facilitate the task of curators for documenting the international database.

A possible option could be to adopt a widely standardized system such as GRIN-Global[131]. However GRIN-Global was initially conceived for annual and seed crops and may need to be customized for managing coconut germplasm. This is exemplified

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[130] See the URL: www.cogentnetwork.org

[131] GRIN-Global is a project whose mission is to create a new, scalable version of the USDA's Germplasm Resources Information Network system (GRIN) suitable for use by any interested genebank in the world. It is being developed in a joint effort with the Crop Trust, Bioversity International, and ARS/USDA. The project's goal is to provide the world's crop genebanks with a powerful, flexible, easy-to-use global plant genetic resource (PGR) information management system. The database and interface(s) will be designed to accommodate both commercial and open-source programming tools, to be database-flexible, and to require no licensing fees for genebank use.

Plate 3.4

Spicata forms of coconut varieties

Wider coconut diversity

Spicata are forms in which most of the flowers are mainly attached to the inflorescence axis, instead of being attached to the spikelet. Such rare forms are found in many countries and varieties.

1. Spicata (left) compared with a normal coconut inflorescence (right) for Red Dwarf varieties.

2. Same for Green Dwarf varieties.

3. Some Spicata forms have also fewer spikelets.

4. Samoan Tall, Spicata inflorescence.

5. Terminal portion of a Spicata inflorescence with many male flowers in Fiji.

6. View of the central axis, Fiji. Many male flowers are hidden and squeezed between the female flowers, making the inflorescence difficult to emasculate for breeding purposes.

7. Papua New Guinea Red Dwarf Spicata.

R. Bourdeix, A. Kembu and A. de la Presa by exchanges with the Genesys multi-crop database, where coconut data transmitted more than 18 months ago is yet to be included in this database (2013). *So before engaging in GRIN-Global, COGENT must receive a clear commitment from the software providers and agree with them on detailed planning*. This should include training, with GRIN-Global experts carrying out this initial set-up in collaboration with genebank curators.

Research needs to be conducted regarding the techniques for numbering palms in the fields. Presently, numbers are painted on the stems but these last only four to five years. Missing or erased numbering was identified as a main source of error for field characterization and evaluation. Technologies such as Global Positioning Systems (GPS) and barcoding are currently not used in coconut collections, but these are becoming less expensive and more widely available, and likely to be increasingly important in managing genetic resources in the future. In some countries like Brazil, this process has already started: under a new law, all germplasm accessions of all species will have to be geo-referenced (GPS positioned). Another cheaper and simpler technique could be to carve numbers on the stems with basic precautions for avoiding diseases transmission.

For a fully efficient management of palm-by-palm data and controlled pollinations, it is expected to develop a new dedicated software. Curators of the coconut genebanks will need to be trained to its use. Already existing data will be carefully transferred under this new system, which will include a systematic data duplication, at least within countries.

3.8.2 International databases on *ex situ* conservation

The coconut genetic resources database (CGRD) is the database gathering specific data (passport and characterization using agreed standard descriptors) from all the genebanks of COGENT member-countries, be they national or international[132]. Given evolving computer standards, CGRD will become outdated. So there is a need to upgrade the CGRD. During the transition phase to upgraded software, where CGRD is no longer operating due to material constraints, Excel templates could be developed to help curators provide standardized information whenever possible.

The new CGRD will need to link to existing international databases (utilizing standardized variety identification codes), such as TropGENE (a multi-crop database storing data on molecular marker, genetic and physical maps, and phenotyping or genotyping studies), in order to access additional information of interest to potential users of the germplasm. This will take the form of either a direct link (taking the user to the other database) or a web service (where information is retrieved from another database, but integrated into the host's output). Users of these international databases will also be able to link back to CGRD to access information on individual accessions and their availability.

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[132] See http://www.cogentnetwork.org/cgrd-version-6-0-test-version

COGENT plans to develop a data-sharing agreement (DSA)[133] between each COGENT country-member as the data provider, and the COGENT Secretariat as the data receiver, to increase the level of legal protection of the data and to acknowledge the stake of each COGENT member-country. Targeted end-users concerning this DSA include genebank managers, plant breeders, taxonomists, policy-makers, educators, and students, as well as the broader scientific community. Sharing data encourages researchers, provides vital input and support for academic research, and renders the data available to other investigators. A Frequently asked questions (FAQ) section about DSA can be found on the COGENT website[134], together with the Database Portal Terms and Conditions of Use and a draft proposal for DSA.

Movement of material into and out of COGENT genebanks should be monitored and carefully recorded, including transfer for safety duplication. This would provide up-to-date information on the global management of accessions. The monitoring system would link to local genebank management systems to the future quarantine centre(s) and cryogenebank(s), providing up-to-date information on the location and availability (e.g. quarantine status) of the germplasm.

As is already in place for other crops, a likely future development for an information portal is the provision of a germplasm ordering system that would allow the user to select the most appropriate germplasm accessions in the collections accessible in the public domain based on passport, characterization and evaluation data. The germplasm ordering system would take account of the guidelines for safe movement of coconut germplasm and link accessions to an MTA or SMTA. The ordering system would also serve the purpose of tracking movement of germplasm in a similar way that the global information system for the International Treaty does.

COGENT envisions entrusting the global management of accessions data to one of the institutions linked to COGENT country-membership.

3.8.3 Databases for and of farmers

Farmers' access to appropriate and diverse planting material is an essential condition for sustainable coconut production. COGENT envisions an information management system for farmers that will provide comprehensive and updated information on coconut planting material, and on where and how to find it. Not all farmers will be able to directly access this online database, so simple and accurate documentation could also be made available (easily downloadable and printable) from the COGENT website, in conjunction with the websites of member-countries.

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133 A Data Sharing Agreement (DSA) comprises a number of regulations for managing shared data between the Data-provider and the Receiver in several specific domains and contexts. This is an official accord between the parties that distinctly establishes which type of data is being shared, the obligations involved, the permissions required and how the data can be used. It ensures the protection of the Data-provider and the Receiver, by establishing regulations and agreed terms and conditions of use in diffusion to third parties.

134 See http://www.cogentnetwork.org/index.php/faq/137-what-is

COGENT country-members should create and make available on line national databases "coconut planting material" that will include sources of coconut seednuts produced by national institutions, private companies, farmers and other stakeholders. Each extension service should also have a farmers' database facilitating the diffusion of information and innovation to farmers.

The national "coconut planting material" databases could be made accessible under a section "seednuts for farmers" added to the main page of the COGENT website. It will include two search options: by country, and by type of variety. This section will include coconut seednuts produced by national institutions, private companies, NGOs, farmers and other stakeholders at the national or global level, respectively.

Such a database will gather information about the planting material and also about people and sites involved in its production, with respect to intellectual property rights of the countries, farmers and other stakeholders. A significant amount of information already exists, even on the COGENT website, but this information is presently not sufficiently accessible[135].

The private sector is also very interested in contributing to such a database. Contacts recently initiated with private companies in Brazil, for instance, have highlighted the following issues: an interconnected network indicating producers of superior genetic seednuts, and the varieties most suitable for each purpose and environment, would be of great value for farmers and companies involved in coconut production.

The number of visits and downloads of technical documents from this online "Databases for and of farmers" will serve as an indicator for measuring the COGENT's success in communicating with coconut stakeholders.

3.9 Preparing the area of coconut genomics

As previously discussed in section 2.5.8, the range of techniques for genome study is rapidly expanding and coconut genomics information is quickly accumulating. Genotyping and sequencing approaches will continue to change rapidly. It is anticipated that some of the technical specifications given below will need to be revised to take into account the evolution of the methods and the decreasing cost and increasing reliability of high throughput methods. In particular, we believe that, even if microsatellite studies retain their usefulness, they will be quite quickly replaced by more powerful methods.

The coconut genomics approach is not only restricted to the *Cocos nucifera* genome. It also applies to associate pathogens such as the phytoplasmas involved in the lethal yellowing diseases. Meta-genomics analysis of soil samples collected at collection-evaluation sites could also help explain part of the prevailing phenotypic variation. Landscape genomics could also be helpful for a better understanding of the coconut climate adaptation in relation with climate change (e.g. higher global temperatures and sea-level rises). Genome wide association studies, when applied to environmental

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135 See for instance the illustrated descriptions of coconut hybrids available pages 115, 117,119 and 121 of the following document :http://www.cogentnetwork.org/images/publications/part4_CFCTechPaper42.pdf

factors, help to select and breed "adapted" genotypes. However, data management and analysis may become the weakest element of the chain to allow full exploitation of these technical advances. Both the conservation of coconut genetic resources and breeding efforts can significantly benefit from genomic approaches and become more effective and (cost-) efficient!

3.9.1 Sequencing coconut genome

Having a high-quality whole genome sequence was the first step in deciphering the organization of the coconut genome. It now provides the requested basis for mapping and characterizing key genes for economically and agronomically important traits such as fertility, flower and fruit development, oil production, dwarfisms or disease resistance. By unraveling evolutionary events such as sequence duplications or deletions, as well as chromosome rearrangements, whole-genome sequencing offers the possibility of benefiting from data obtained on related species such as oil palm or date palm.

The Malayan Yellow Dwarf, a highly homozygous variety already available in most COGENT genebank, was used as the first genotype to be sequenced. The transcriptome data, was also obtained for the Hainan Tall (variety from China). Both will be used as references for functional annotation.

New generation sequencing technologies will be used for genome wide association studies. The *de novo* sequence thus developed will become the future reference genome for coconut[136]. It will pave the way for rapid and much cheaper "resequencing"of extra genotypes (e.g. as parents in mapping populations, etc…) which will allow the development of marker-assisted breeding[137].

3.9.2 Preparing the era of marker-assisted breeding

In order to identify a large number of QTLs responsible for phenotypic differences, COGENT intend to focus experiments on four sets of populations: Indo-Atlantic Talls, Pacific Talls, Pacific Dwarfs and introgressed Talls. Each of these genetic groups will be represented by two cultivars with 25 individuals per population, so about one and half hectares of coconut plantation will be required. This set will have to be planted by the breeders interested in developing a genomics-based approach and who are ready to plant the field plots needed for this approach. Germplasm exchanges will have to be carefully monitored, preferably going through a quarantine centre having disease indexing facilities.

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136 Nuclear DNA will be sequenced using two complementary techniques, Illumina HiSeq2500 (~150 bp) with a ≈ 80 x coverage, Roche 454/454+ (coverage ≈15x). A new BAC library will be constructed for dwarf genotype and BAC clones will be sequenced to get the coverage of 4 x. Targeted re sequencing of the coconut genome for the specific loci will be done using solexa. A saturated map will be produced by anchoring a core set of SNP markers and available SSR markers to the existing map. Genotyping by sequencing will be followed for a minimum of 100 individuals each from a population created in Côte d'Ivoire (for saturated linkage map itself), and from a population created in the Philippines (for subsequent QTL mapping). These progenies and their parent palms will represent the global diversity of coconut. A progeny from China, derived from the cross between the Hainan Tall and the Malayan Yellow Dwarf, will also be integrated within a few years.

137 Functional annotation consists of attaching biological information to genomic elements to annotate their biochemical, biological, regulatory or interactive functions.

Phenotypic characterization will include:

- Phenology and biomass assessment (leaves, stem, roots and reproductive apparatus) which provides the net balance of the ontogenic development and the entire integration of the metabolism efficiency at plant scale.
- Measure of water use efficiency (WUE) and gas exchanges, possibly complemented by the carbon isotopic signature (13C/12C ratio) is liable to uncover variations between genetic groups and between individuals in the transpiration and photosynthetic processes.
- Assessment of leaf functional traits (leaf life-span, leaf area, specific leaf area, etc) are likely to shed light on the differences between Tall and Dwarfs.
- Finally, metabolomic analyses of biological samples (leaflets, inflorescence stalk, sap, fruits) will reveal variations of the amount of components, such as minerals, in relation with total non structural carbohydrates as well as metabolite profiling across cultivars.

In complement to this approach, collecting soil samples from the sites of these experiments for future metagenomics analysis will indicate if performance/ characteristics are related to soil microflora rather than genotype or epigenetics.

It is also essential to develop a genomic approach to identify and link molecular marker associations with disease resistance genes. This will allow marker-assisted selection (MAS) in segregating populations from various resistant or tolerant germplasm sources.

Large breeding experiments have been planted during the last decade in COGENT member countries. Most of these experiments devoted to improvement of hybrids are still alive in the fields. As field data are fully available, it It is proposed to sample them for further molecular analysis. Leaf samples will be collected and kept (or their DNA) extracted. Molecular analyses of these samples, combined with results of hybrid's performance recorded for several years during the field experiment will provide precious information

We intend to concentrate on four sets of populations corresponding to Indo-Atlantic Talls, Pacific Talls, Pacific Dwarfs and introgressed Talls respectively. Each of these genetic groups will be represented by two cultivars with 25 individuals per population, so about one and half hectares of coconut plantation will be required. *This set will have to be planted by the breeders interested in developing a genomics-based approach* and who are ready to plant the field plots needed for this approach. All germplasm exchanges will have to be carefully monitored, preferably going through a quarantine centre having disease indexing facilities.

In order to benefit from this opportunity, associated trait data characterization should be undertaken as early as possible. The targeted traits (e.g. oil or coconut water yield, quality etc) should be disaggregated into as many elementary factors as possible. The use of transcriptomics[138] and generation of expressed sequence tags (ESTs) when

138 The classification and analysis of RNA molecules with coded genetic information transcripts and their formation, structure, and function in an individual.

analyzing genetic activity (e.g. in pathogen - host interaction or the fatty acid conversion) can decipher genes involved in essential processes. As discussed in section 2.5, new phenotyping methodologies are likely to be introduced, based on increased understanding, knowledge and the underpinning genetics. These might include IRGA[139] measurements of water use efficiency, metabolite profiling, increased partitioning of phenotype components, or *in vitro* disease early screening.

As discussed in section 2.5.4, about 400 hybrids between traditional cultivars have been evaluated worldwide, and some of them were improved using half-sib family progeny tests. Planting of such experiments (improvement of best hybrids) was discontinued after 2000, especially in Côte d'Ivoire. Such large breeding experiments have not been planted elsewhere during the last decade. Most of these experiments devoted to improvement of hybrids are still alive in the fields. As field data are fully available, proposals *have been made to sample them for further molecular analy*sis. Leaf samples will be collected and kept, or their DNA extracted. When molecular breeding techniques will become fully available, analysis of these samples will provide precious information. Some more phenotypical/morphological observations could also be conducted on these trials, such as for instance additional fruit quality traits.

3.9.3 Improving conservation by DNA analysis in *ex situ* genebanks

The SSR microsatellite marker kit developed in 2002 is now widely used. The results of most analyses conducted in COGENT member-countries are kept in the TropGENE database. Within the next decade, the actual kit will evolve or even it will be replaced by another technique in order to have a more precise appraisal of the genetic diversity. The existing database will have to be updated by conducting additional analysis with the new technique, as the material newly sampled will need to be compared to the material previously studied.

Within the next decade, countrywide studies are envisioned in Sri Lanka and at least another COGENT member-country[140]. Locally collected accessions will be sampled in order to assess their inter-and-intra differentiation. This will help collection curators to optimize the sizes and numbers of accessions. At the global level, accessions that were previously analysed with an insufficient number of individuals will be further sampled. DNA analysis will also be used check the reliability of the controlled pollination process, as it has already been done in Côte d'Ivoire and India. Pollen will be increasingly exchanged and cryopreserved; thus developing a method for DNA analysis on pollen will be needed.

3.9.4 DNA analysis in farmers´ fields

As discussed in section 3.5, collecting about 500 new accessions is planned within the next decade. Molecular analysis will help to better understand the structure of genetic diversity and to efficiently select the most diverse germplasm to be included in *ex situ*

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[139] Infrared Gas Analyzer.

[140] It will be probably the Philippines, Indonesia or India, or another of COGENT member-country which collected many local accessions, such as for instance Bangladesh or Pakistan.

genebanks. Samples will have to be collected in some geographical zones that are insufficiently studied, and on specific biological material:

1. The contact zones between the Indo-Atlantic and Pacific coconuts.
2. The pattern of diversity in the Polynesian outliers (from Palau to the Marshall Islands and possible early Austronesian migrations.
3. The historically documented Polynesian migrations from Central Polynesia to Hawai'i.
4. The contribution of foreign influences to the build up of coconut diversity on the East African coast and Maldives.
5. The extent of the distribution of the Pre-Colombian coconuts on the Pacific coast of America.
6. A comparative analysis of spontaneous and sub-spontaneous coconut populations[141].
7. ... and possibly some other aspects as well.

Landscape genomics could also be helpful for a better understanding of the coconut climate adaptation in relation with climate change (e. g. higher global temperatures and sea-level rises). Genome wide association studies can be applied to environmental factors and QTLs to select and breed "adapted" genotypes.

Molecular analysis will also be particularly useful for analysing the surveys conducted in the islands most isolated[142] and/or endangered by climate change (see section 3.5.3) and in the framework of geographical gap filling (section 3.5.4).

3.10 Enhancing networking and partnerships for global collaboration

The global system for conservation and use of coconut genetic resources is based on safeguarding the unique and critical diversity, making it available to breeding programmes and other research institutes via a system for safe movement of germplasm. It aims to ensuring a safe and sustainable long-term conservation of this diversity and to facilitate its use to contribute to food security and farmers' livelihoods. The system therefore relies on a network of partners, including effectively-functioning and efficiently-managed international and national *ex situ* coconut collections.

Developing this Strategy has provided an extraordinary tool for strengthening relationships between COGENT researchers, and between these researchers and other coconut stakeholders. With more than 130 sections all co-authored by 2 to 5 contributors from all over the world, and the necessary adjustments between sections, it has created more than 400 opportunities to interact and co-publish (see Annex 3).

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[141] Plus some special varieties called Niu Afa in Samoa or Niu Kafa in Tonga, with long thick-husked fruit selected for making sennit from the fibre of the husk.

[142] Here the scientific question is to understand the effect of Island dispersal on the fragmentation on coconut diversity.

The creation of the COGENT International Thematic Action Groups (ITAGs, see section 1.1.6 and Annex 4) was extremely useful for building this Strategy. These groups will continue to evolve. The level of interaction between their members needs to be increased, as most of them never meet face-to-face. Each of the seven ITAG should meet at least once every four years. Thus, including the Steering Committee, about two COGENT meetings per year should be held on average. As indicated in section 1.1.6, piggybacking the APCC and COGENT meetings in the same location increase interactions with stakeholders from the coconut value chain and generate an economy of both time and financial resources. Once fully resourced, effectively led and operational, these ITAGs will also oversee the implementation of this Strategy.

Through an active participation in COGENT, all relevant national institutions will be able to ensure that the decisions made by the network are advantageous to their country in managing and using coconut diversity. Strengthening international cooperation under the auspices of the Treaty will facilitate the rationalization of existing and future coconut collections; it will reduce duplication of effort to address any gaps, and will greatly limit the risk of spreading diseases.

COGENT will engage with the International Plant Protection Convention (IPPC)[143] and its Regional Plant Protection Organizations to ensure that updated guidelines for safe movement of coconut germplasm will be widely available to those responsible for the phytosanitary systems in coconut-producing countries. Another important field of collaboration is risk analysis and policy making to avoid pest and diseases transmission by stakeholders coming from other countries or regions.

National public sectors are investing considerable resources in R&D coconut projects, but the cost-effectiveness of these efforts could be enhanced through clearer policies and strengthened global coordination. Capacity building, including training, is needed to allow genebank curators and breeders to adopt new conservation and breeding technologies.

Thus, COGENT Steering Committee and Secretariat, along with the ITAGs will continue to support and strengthen the following aspects:

1. Represent the 39 COGENT member-countries through one voice within the international community in order to inform and raise awareness on coconut genetic resources conservation and use.
2. Ensure effective long-term and cost-efficient conservation of important coconut genetic resources.

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[143] The IPPC works with Convention contracting parties, to develop phytosanitary measures that underpin the parties' ability to manage pest risks and the environmental, economic and social impacts of plant pests. Its Commission on Phytosanitary Measures (CPM) meets annually to review the state of plant protection, identifies action to control the spread of pests into new areas, develops and adopts international standards and establishes procedures for the sharing of phytosanitary information. The IPPC works with Regional Plant Protection Organizations and international organizations to build phytosanitary capacity, to identify and address risks that cross national borders.

3. Provide easy access to information and knowledge on coconut genetic resources worldwide, on quarantine regulations and precautions, on germplasm characterization and evaluation, and on genomics data.
4. Facilitate access to standardized protocols on characterization, evaluation, data management and long-term conservation of germplasm.
5. Facilitate access to technologies, procedures and methods to conserve, improve and breed coconut, such as genomics tools; cryopreservation; somatic embryogenesis, etc.
6. Provide pertinent legal information, assistance and advice, on germplasm access and benefit-sharing and help members in implementing dedicated regulations.
7. Help member-countries to identify funding sources, to build and implement regional and international projects, and to secure long term funding of the key elements of this Strategy.

Country-members and their representative institutions will continue to play a key role in the following aspects:

1. Provide international access to a wide range of diverse coconut genetic resources and information on these resources.
2. Build trust between country-members by providing information to facilitate rationalization.
3. Create national awareness of the importance of sharing responsibility for the conservation and use of coconut diversity.
4. Seek a dialogue with decision-making political and administrative bodies at the country-level.
5. Work towards the development and implementation of access and benefit-sharing national legislation that is conducive to COGENT's proposed policy.
6. Facilitate implementation of safe-movement guidelines and coconut quarantine regulations.
7. Seek funding opportunities, inform the COGENT Secretariat about it, and help develop international project proposals.

As discussed in section 1.2.1, COGENT coordination needs to be pursued on a sustainable, long-term basis rather than on a project basis. The COGENT Secretariat needs contractual continuity for all its research and administrative functions. At the end of 2017, the Australian Department for Foreign Affairs and Trade (DFAT) and the Australian Centre for Agricultural Research (ACIAR) provided support to finalize and publish this Strategy. They have also expressed a willingness to support the transfer of the COGENT secretariat from its long-standing CGIAR host to the Asia Pacific Coconut Community (APCC) as soon as it becomes a global organization the International Coconut Community (ICC)- a move endorsed by COGENT's Steering Committee. Subject to satisfactory genebank audits, it is hoped that genebank support may also be available from other key organizations such as the Global Crop Diversity Trust and the International Treaty.

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4. Annexes

Annex 1. COGENT-member-countries and linked national institutions

This list will be regularly updated on the COGENT website.

Country	Institution name (s)	Contact
Bangladesh	Horticulture Research Centre (HRC) Bangladesh Agriculture Research Institute (BARI)	Joydebpur, Gazipur-1701, Bangladesh Tel: +880 29252529
Benin	Institut National des Recherches Agricoles du Bénin (INRAB)	01 BP 884 Cotonou, Benin Tel: +229 95369014
Brazil	Empresa Brasileira de Pesquisa Agropecuaria – EMBRAPA, Centro de Pesquisa Agropecuaria dos Tabuleiros Costeiros	Av. Beira Mar, 3250 Atalaia 49025040 Aracaju, SE Tel: +55 79 40091332 Fax: +55 79 40091374
China	Coconut Research Institute- Chinese Academy of Tropical Agriculture Sciences (CRICATAS)	496, Wenqin Road 571339 Wenchang City, Hainan Province, China Tel: +86 89863330184
Colombia	CORPOICA - Centro de Investigación Palmira	Calle 23 Carrera 37 Continuo al Penal Palmira, Valle, Colombia Tel: + 57 3311058
Cook Islands	Ministry of Agriculture Research Division Ministry of Agriculture	PO Box 96 Rarotonga, Cook Islands Tel:+682 28711/25403
Costa Rica	Ministerio de Agricultura y Ganaderia	Frente Servicentro Siquirres – Limón, Costa Rica Tel: +506 7186092/7688403
Côte d'Ivoire	Station de Recherche Marc Delorme, Centre National de Recherche Agronomique (CNRA)	07 B.P. 13 Abidjan, Côte d'Ivoire. Tel: +225 01135852 Fax: +225 23472411

Country	Institution name (s)	Contact
Cuba	Instituto de Investigaciones en Fruticultura Tropical	Avenida 7a. No. 3005, entre 30 y 32, Miramar Playa Havana 1600, Cuba Tel: +53 72025526/28
Fiji	Koronivia Research Station	PO Box 77, Nausori, Fiji Tel: + 679 3477044
Ghana	Oil Palm Research Institute	Council for Scientific and Industrial Research PO Box 74 Kade, Ghana Tel:+233 244526566
Haiti	Ministry of Agriculture, Centre de Recherche et de Documentation Agricoles (CRDA) Institute	PO Box 1441 Damien, Port-au-Prince Haiti HT 6125 Tel: +509 22 4503/4592/4705
India	Central Plantation - Crops Research Institute, Indian Council of Agriculture Research (ICAR)	Kasaragod, Kerala 671 124, India Tel: +91 4994232893
Indonesia	Indonesian Coconuts and Palm Research Institute (ICOPRI)	Jl. Raya Mapanget, Kotak Pos 1004 Manado 95001 North Sulawesi Indonesia Tel: +62 431812430
Jamaica	Coconut Industry Board	18 Waterloo Road, PO Box 204, Jamaica Tel: +1876 9261770
Kenya	Kenya Agricultural Research Institute	PO Box 57811 City Square 00200 Nairobi, Kenya Tel: +254 204183323/344
Kiribati	Department of Agriculture, Ministry of environment, Lands and agricultural development (MELAD)	Bikenibeu Tarawa PO Box 267, Kiribati Tel: + 686 92951/98014
Madagascar	Directeur Général Société SOAVOANIO	PO Box 36 Sambava, Madagascar Tel: +261 320514575
Malaysia	Rice and Industrial Crop Research Division Malaysian Agricultural Research and Development Institute (MARDI)	PO Box 12301, General Post Office 50774 Kuala Lumpur, Malaysia Tel: +60 389437218 / 6489242

Country	Institution name (s)	Contact
Mexico	Centro de Investigación Científica de Yucatán (CICY)	Calle 43 No. 130, Colonia Chuburna de Hidalgo, 97200 Merida, Yucatán, Mexico Tel: +52-999-9813923
Nigeria	Plant Breeding Division, Nigerian Institute for Oil Palm Research (NIFOR)	Benin-Akure Road, PMB 1030 Benin City, Edo State, Nigeria Tel: +234 8037033231
Pakistan	Coastal Agriculture Research Station (CARS)	Post Box 9028, Quaidabad, Landhi, Karachi 75120 Pakistan Tel: +92 219248621
Papua New Guinea	Cocoa Coconut Institute Stewart Research Station Madang	PO Box 642, Madang, Papua New Guinea Tel: +675 9839208
Philippines	Agricultural Research & Development Branch, Philippine Coconut Authority (PCA)	7th/f PCA Bldg., Elliptical Road, Quezon City, Philippines Tel: +63 29284501 to 10 Fax: +63 29267631
Samoa	A/CEO for Crops Division Ministry of Agriculture and Fisheries	PO Box 1874, Apia, Samoa Tel: +685 20605 Fax: +685 20607
Seychelles	Seychelles Agricultural Agency	PO Box 166, Grand Anse, Victoria, Mahe, Seychelles Tel: + 248 4378252
Solomon Island	Under Secretary Technical Department of Agriculture and Livestock	PO Box G13, Honiara, Solomon Islands Tel: +677 27987
Sri Lanka	Genetics & Plant Breeding Division Coconut Research Institute (CRI)	Bandirippuwa Estate Lunuwila 61150, Sri Lanka Tel: + 94 313127954
Sultanate of Oman	Agricultural & Livestock Research Stations (ALRS)	Salalah, Dhofar, Sultanate of Oman Tel :+968 23290186
Tanzania	Mikocheni Agricultural Research Institute Ministry of Agriculture, Food Security and Co-operatives	P O Box 6226, Dar es Salaam, Tanzania Tel: +255 754298946 Fax: +255 222775549

Country	Institution name (s)	Contact
Thailand	Horticulture Research Institute Department of Agriculture	Phaholyothin Road, Chatuchak 10900 Bangkok, Thailand Tel :+66 25792759
Tonga	Research & Extension Division, Ministry of Agriculture, Food, Forests & Fisheries	PO Box 14 Nuku'alofa, Tonga Tel :+676 23038/32125 Fax: +676 32132/24271/23093
Trinidad & Tobago	Ministry of Agriculture, Land and Marine Resources Research Division	Central Experiment Station Centeno via Arima Post Office Centeno, Trinidad & Tobago Tel : +868 6426008 Fax: +868 6461646
Vanuatu	Vanuatu Agricultural Research and Training Centre (VARTC)	P.O. Box 231, Espiritu Santo, Vanuatu Tel: +678 36320/36420
Vietnam	Planning & International Cooperation Department Research Institute for Oils and Oil plants (IOOP)	171-175 Ham Nghi St. District 1 Ho Chi Minh City, Vietnam Tel :+84 88297336/8243526/

Annex 2. Contributors to the Strategy and their parent

Name	Email	Institution	Country
Adkins Stephen	s.adkins@uq.edu.au	The University of Queensland - School of Agriculture and Food Sciences and Centre for Plant Science, Brisbane Queensland QLD 4072	Australia
Allou Kouassi	kouassi_allou@yahoo.fr	Station Cocotier Marc Delorme, Centre National de Recherche, Agronomique (CNRA), 07 BP 13, Port Bouet	Côte d'Ivoire
Andreas Claude	claude.andreas@gmail.com	Société SOAVOANIO PO Box 36, Sambava	Madagascar
Arachchi V R M V	vijitharma@yahoo.com	Coconut Research Institute (CRI), Tissue Culture Division, Bandirippuwa Estate, 61150 Lunuwila	Sri Lanka
Arunachalam Vadivel	vadivelarunachalam@yahoo.com arun.ceo.innovations@gmail.com	Indian Council of Agricultural Research (ICAR), Research Complex for Goa	India
Bourdeix Roland	roland.bourdeix@cirad.fr	CIRAD, TA A-10/03 Avenue Agropolis 34398 Montpellier Cedex 5	France
Canja Liberty	lhcanja@yahoo.com	Philippine Coconut Authority Davao Research Center, Bago Oshiro, Davao City	Philippines
Chong Fasan dit Jean Kape	kape@mail.pf	Académie des Pa’umotu BP 43768 Papeete-Tahiti, 98713	French Polynesia
Collins Samantha	s.collins@cgiar.org	Bioversity International, Via dei Tre Denari, 472/a 00057 Maccarese (Fiumicino), Rome	Italy
Coppens Geo	geo.coppens@cefe.cnrs.fr	CIRAD, Biological Systems Department UMR CEFE, Montpellier	France
Cueto Cristeta A.	cacueto@yahoo.com	Philippine Coconut Authority Albay Research Center (PCA-ARC), Tissue Culture Division, Banao, Guinobatan Albay 4503	Philippines

Name	Email	Institution	Country
De la Mata de la Isla Diana		ex-Bioversity	France
De la Presa Ane		ex-Bioversity	France
De Lima Araujo Silvia	s.delima@cgiar.org	Bioversity International, Parc Scientifique Agropolis II, 34397 Montpellier Cedex 5	France
Devakumar Krishnamoorthy	k_devakumar@yahoo.com	Indian Council of Agricultural Research (ICAR)	India
Dollet Michel	michel.dollet@cirad.fr	CIRAD, Etiologie UPR 29, Campus International de Baillarguet, 34398 Montpellier	France
Dona Fologo Danièle	info@ivoiredd.org	Ivoire Développement Durable, 04 BP 2733 Abidjan 04	Côte d'Ivoire
Duong Ngo Thi Kieu	ngokieuduong@yahoo.com	Research Institute for Oils and Oil plants (IOOP), Perennial Oil Crops Dpt,171 - 175 Ham Nghi Street, District 1, Ho Chi Minh City	Vietnam
Engelman Florent	florent.engelmann@ird.fr	Institut de Recherche pour le Développement (IRD), 911 av. Agropolis, BP 64501 34394, Montpellier	France
Er-rachiq Leila	leila.er2@wanadoo.fr	ex-Bioversity	France
Foale Mike	m.foale@uq.edu.au	School of Land Crops and Food Sciences, Level 4, Hartley Teakle Building, University of Queensland	Australia
Goirand Renaud	renaud.goirand.rci@gmail.com	Cocopack Enterprise 06 BP 2897 Abidjan 06	Côte d'Ivoire
Gouigou Marie Astrid		ex-Bioversity	France

Name	Email	Institution	Country
Gunn Bee	bee.gunn@anu.edu.au	Division of Evolution, Ecology and Genetics. Research School of Biology, The Australian National University Bldg. 116, Gould Wing	Australia
Guarino Luigi	luigi.guarino@croptrust.org	The Crop Trust Platz Der Vereinten Nationen 7 53113 Bonn	Germany
Haeng-hoon Kim	h.kim@cgiar.org cryohkim@korea.kr	Bioversity International, Regional Office for Asia, the Pacific and Oceania. PO Box 236, UPM Post Office, 43400 Serdang, Selangor	Malaysia
Haikuo Fan	vanheco@163.com	Coconut Research Institute, Chinese Academy of Tropical Agriculture Sciences (CRICATAS), No. 496 Wenqing Road	China
Hamelin Chantal	chantal.hamelin@cirad.fr	CIRAD, Biological Systems Department (UMR CEFE), Campus CNRS, CEFE 1919, Route de Mende 34293, Montpellier	France
Hegde Vinayaka	hegdev64@gmail.com	Central Protection Crops Research Institute (CPCRI), Kasaragod 671 124, Kerala	India
Heslop-Harrison John S.	phh4@le.ac.uk	Department of Biology, University of Leicester, Adrian Building, Leicester LE1 7RH	United Kingdom
Issali Auguste Emmanuel	issaliemma@yahoo.com	Station Cocotier Marc Delorme, Centre National De Recherche Agronomique (CNRA) 07 BP 13, Port Bouet	Côte d'Ivoire
Johnson Vincent	v.johnson@cgiar.org	Bioversity International. Parc Scientifique Agropolis II, 34397 Montpellier Cedex 5	France
Kanniah J.	K.Jayashree@cgiar.org		SE Asia

Name	Email	Institution	Country
Karun Anitha	anithakarun2008@gmail.com	Central Plantation Crops Research Institute (CPCRI), Indian Council of Agriculture Research, Kasaragod Kerala 671124	India
Kembu Alfred	kembua@ymail.com	Papua New Guinea Cocoa Coconut Institute Stewart Research Station Madang PO Box 642, Madang	Papua New Guinea
Kete Tevita	tevita.kete@gmail.com	Centre for Pacific Crops and Trees (CePaCT), Secretariat of the Pacific Community (SPC) Private Mail Bag, Suva	Fiji
Konan Konan Jean-Louis	konankonanjeanlouis@yahoo.fr	Station Cocotier Marc Delorme, Centre National de Recherche Agronomique (CNRA) 07 BP 13, Port Bouet	Côte d'Ivoire
Konelio Misa	misa.konelio@maf.gov.ws	Crops Division Ministry of Agriculture and Fisheries, PO Box 1874, Apia	Samoa
Kumar Vijendra	vijenkumarcida@gmail.com	Coconut Industry Development Authority (CIDA), PO Box 5160, Raiwaqa	Fiji
Laliberté Brigitte	brig.lalib@gmail.com	Bioversity International Via dei Tre Denari, 472/a 00057 Maccarese (Fiumicino), Rome	Italy
Lobo David J.	davidlobo@deejayfarm.com	DEEJAY Group, 3rd floor, St. Patrick's Complex, Brigade Road Bangalore, Karnataka 560025	India
Lusty Charlotte	charlotte.lusty@croptrust.org	The Crop Trust Platz Der Vereinten Nationen 7 53113 Bonn	Germany
Manimekalai R.	rmanimekalaiicar@gmail.com	Central Plantation Crops Research Institute (CPCRI), ICAR, Kasaragod, Kerala	India

Name	Email	Institution	Country
Martinez Dorine	martinezdorine@hotmail.fr	ex-Bioversity	France
Maskromo Ismail	is_maskromo@yahoo.com	Indonesian Palm Research Institute (Balit Palma), Jl. Raya Mapanget PO Box 1004, Manado 95001	Indonesia
Masumbuko Linus.I	linusmasumbuko@yahoo.ie	Mikocheni Agricultural Research Institute, PO Box 6226, Dar es Salaam	Tanzania
Mirisola Luiz Angelo	mirisola@terra.com.br	Grupo Regon Brazil, Rua Centauro, 241 - 3° andar, Bairro Santa Lucia Belo Horizonte MG 30360-310	Brazil
Myrie Wayne	cocomax@cwjamaica.com	Coconut Industry Board, 18 Waterloo Road, Kingston 10 PO Box 204	Jamaica
Naresh Kumar Soora	nareshkumar.soora@gmail.com	Indian Agricultural Research Institute, Centre for environment and climate resilience, New Delhi	India
Niral Vittal	niralv@yahoo.com	Central Plantation Crops Research Institute (CPCRI), ICAR) Kudlu PO Kasaragod, Kerala, 671124	India
Odewale Joshua	olusesanodewale@yahoo.com	Plant Breeding Division, Nigerian Institute for Oil Palm Research (NIFOR), Benin-Akure Road, PMB 1030, Benin City	Nigeria
Ollivier Jean	jean.ollivier@cirad.fr	CIRAD, Biological Systems Department UMR CEFE, Montpellier	France
Omuru Eric	eeomuru@gmail.com	Cocoa Coconut Institute, Stewart Research Station, PO Box 642, Madang	Papua New Guinea
Oropeza Carlos	coscicy@gmail.com cos@cicy.mx	Centro de Investigación Científica de Yucatán (CICY), Biotechnology Unit, Colonia Chuburna de Hidalgo, 97200 Merida, Yucatán	Mexico

Name	Email	Institution	Country
Parra Pedro Pablo	p.p.parra@cgiar.org	International Center for Tropical Agriculture (CIAT) Km 17 Recta Cali-Palmira CP 763537 Apartado Aéreo 6713, Cali	Colombia
Pereira Messias Gonzaga	messiasgpereira@gmail.com	Universidad de Estadual do Norte Fluminense (UENF), Av. Alberto Lamego, 2000, Parque California Campos dos Goytacazes RJ 28013-602	Brazil
Perera Lalith	kanthaperera@yahoo.com	Coconut Research Institute (CRI), Genetics & Plant Breeding Division Bandirippuwa Estate, 61150, Lunuwila	Sri Lanka
Perera Prasanthi	p.perera@cgiar.org	Coconut Research Institute (CRI), Tissue Culture Unit, Bandirippuwa Estate 61150, Lunuwila	Sri Lanka
Perera SACN	chandrikaperera2003@yahoo.com	Coconut Research Institute (CRI), Genetics & Plant Breeding Division Bandirippuwa Estate, 61150, Lunuwila	Sri Lanka
Persley Gabrielle	G.Persley@cgiar.org	The Doyle Foundation 41 St Germains, Bearsden, Glasgow, G61 2RS	United Kingdom
Petraglia Marcia	m.petraglia@cgiar.org	Bioversity International. Parc Scientifique Agropolis II, 34397 Montpellier Cedex 5	France
Picq Claudine	claupicq@gmail.com	Ex-Bioversity	France
Pilet Fabian	fabian.pilet@cirad.fr	CIRAD, UMR Peuplements Végétaux et Bioagresseurs en Milieu Tropical (PVBMT) Station de Ligne Paradis, Pôle de protection des plantes 7, chemin de l'IRAT F-97410 Saint-Pierre	La Réunion France
Planes Serge	planes@univ-perp.fr	Centre de Recherche Insulaire et Observatoire de l'Environnement (CRIOBE), Labex «Corail», USR 3278 CNRS-EPHE, Moorea	French Polynesia

Name	Email	Institution	Country
Pokou Désiré N'Da	pokoudesire@yahoo.fr	Centre National de Recherche Agronomique (CNRA), Laboratoire Central de Biotechnologie, 01 BP 1740 Abidjan 01	Côte d'Ivoire
Pole Finyange	finyange@gmail.com	Kenya Agricultural Research Institute, PO Box 57811 City Square 0200 Nairobi	Kenya
Prades Alexia	alexia.prades@cirad.fr	CIRAD, Département PERSYST, Unité Mixte de Recherche "QUALISUD", TA B 95 16 73, Rue JF Breton, 34398 Montpellier	France
Ramos Semiramis Rabelo Ramalho	semiramis@cpatc.embrapa.br semiramis.ramos@embrapa.br semiramis.ramos@gmail.com	EMBRAPA Coastal Tablelands, Av. Beira Mar, 3250, Bairro, Jardins, Aracaju	Brazil
Rivera Ramon I.	rlrivera_pca@yahoo.com.ph	Zamboanga Research Center (PCA-ZRC) Breeding and Genetics Division, San Ramon, PO Box 236, 7000 Zamboanga City	Philippines
Ruas Max	m.ruas@cgiar.org	Bioversity International, Parc Scientifique Agropolis II, 34397 Montpellier Cedex 5	France
Samosir Yohanes	ysamosir@yahoo.com	University of Queensland, Integrated Seed Research Unit, School of Agriculture and Food Sciences, St Lucia, Queensland	Australia
Santos Gerardo A.		Zamboanga Research Centre (PCA-ZRC), Breeding and Genetics Division, San Ramon, PO Box 236, 7000 Zamboanga City	Philippines
Sebastian Leocardio	l.sebastian@irri.org	Bioversity International, Regional Office for Asia, the Pacific and Oceania, PO Box 236, UPM Post Office Serdang Selangor 43400	Malaysia

Name	Email	Institution	Country
Sentoor Kumeran Govindasamy	sentoor@mardi.gov.my	Rice and Industrial Crop Centre Stesen MARDI Hilir Perak Peti Surat 25, 36307 Sg Sumun, Perak	Malaysia
Sileye Tiata	tiatas@vanuatu.com.vu sileye.tiata@gmail.com	Vanuatu Agricultural Research and Technical Centre (VARTC), PO Box 231, Espiritu Santo	Vanuatu
Stoian Dietmar	d.stoian@cgiar.org	Bioversity International Parc Scientifique Agropolis II, 34397 Montpellier Cedex 5	France
Sundaramari M.	sundaramari@yahoo.co.in	Faculty of Agriculture & A.H., Gandhigram Rural University, Gandhigram 624 302, Dindigul Dt., Tamil Nadu	India
Thakshan Kumara Gamini Ranasinghe	tkgrana@gmail.com	TBC	Sri Lanka
Thampan P.K.	pkthampan@yahoo.com	Peekay Tree Crops Development Foundation, Kochi, Kerala 682020	India
Thomas George V.	georgevthomas@yahoo.com	Central Plantation Crops Research Institute (CPCRI), Indian Council of Agriculture Research (ICAR), Kasaragod, Kerala 671 124	India
Tuia Valérie Saena	valeriet@spc.int	Centre for Pacific Crops and Trees (CePaCT), Genetic Resources Unit	Fiji
Tulalo Meiti	mtulalo@yahoo.com	Indonesian Coconuts and Palmae Research Institute (ICOPRI), Jl. Raya Mapanget,Kotak Pos 1004 95001 Manado, Sulawesi Utara	Indonesia
Tutwiler Ann	a.tutwiler@cgiar.org	Bioversity International Via dei Tre Denari, 472/a 00057 Maccarese (Fiumicino), Rome	Italy
Ullivari Álvaro		ex-Bioversity	France
Weise Stephan	s.weise@cgiar.org	Bioversity International Via dei Tre Denari, 472/a 00057 Maccarese (Fiumicino), Rome	Italy

Name	Email	Institution	Country
Wilson Menezes Aragão	aragaowilsonmenezes@hotmail.com	Embrapa, Rua Celi Prado de Oliveira, 94 Aracaju Sergipe 49.025-050	Brazil
Yaodong Yang	ydyang@tocri.com yangyd@tocri.com	Tropical Oil Crops Research Institute (TOCRI), Chinese Academy of Tropical Agricultural Sciences (CATAS), Wenchang, Hainan, 571339	China

Annex 3. Contributors to the strategy by chapters and sections

Participation in drafting and refining the Strategy was done on a voluntary basis. All coconut stakeholders were invited to participate. The COGENT secretariat has taken in account the effective involvement of each contributor and his/her willingness to synthesize not only personal views, but also those of the wider coconut community.

Region colour codes for contributors	
	Southeast Asia and Middle East
	South East Asia
	South America and the Caribbean
	Pacific region
	Africa and Indian Ocean
	Cogent Secretariat
	Experts from Europe and North America

Chapter and section	Contributors (main contributor in bold)
Chapter 0	
Cover page	A de la Presa
Disclaimer	V Johnson, C Picq
Acknowledgements	R Bourdeix, V Johnson
Contents	R Bourdeix, V Johnson
Preface	V Johnson
Foreword	G Persley
Outline	R Bourdeix, V Johnson*GV Thomas
Coconut glossary	V Johnson, R Bourdeix*C Picq
Acronyms	C Picq, V Johnson
Chapter 1. Introduction to the Global Coconut Strategy	VS Tuia
1.1 The coconut, a tree of many lives	*R Bourdeix, V Johnson*GV Thomas*
1.1.1 Origin, history and dynamics of coconut cultivation	B Gunn, WW Myrie* L Baudouin
1.1.2 Cultivation and current production of coconut	C Liberty, M Foale*R Arancon
1.1.3 Importance of coconut genetic diversity	L Baudouin, VS Tuia*M Tulalo
1.1.4 Constraints linked to the biology of the plant	R Bourdeix, E Issali*VS Tuia
1.1.5 Major threats to coconut genetic resources	V Hegde, F Pilet*E Omuru

Chapter and section	Contributors (main contributor in bold)
1.1.6 The International Coconut Genetic Resources Network – COGENT	R Bourdeix, GV Thomas*K Allou
1.1.7 The urgent need for a revised Global Strategy	R Bourdeix, GV Thomas*S Weise
1.2 Global Strategy vision, goal, objectives, outputs and outcomes	*R Bourdeix*
1.2.1 Vision and goal	R Bourdeix, B Laliberté*K Allou
1.2.2 Objectives	R Bourdeix, V Johnson*GV Thomas*A Tutwiler
1.2.3 Outputs	R Bourdeix, D Stoian*V Johnson
1.2.4 Expected outcomes	V Johnson, R Bourdeix*D Stoian
1.2.5 Links with outcomes of CGIAR research programs	R Bourdeix, L Snook*D Stoian
1.3 Process for developing the Global Strategy	*R Bourdeix, B Laliberté*VS Tuia*
2. Where we are today	SRR Ramos
2.1 The genetic diversity of Coconut	*B Gunn*
2.1.1 The coconut genepool	L Baudouin, L Perera*M Tulalo
2.1.2 Coconut domestication	G Coppens, B Gunn*L Baudouin
2.1.3 International Coconut nomenclature	R Bourdeix, L Baudouin*GA Santos
2.2 Methodologies for conserving coconut genetic resources	*JL Konan*
2.2.1 *Ex situ* conservation methods	JL Konan, RI Rivera*R Bourdeix
2.2.2 *In situ* and on-farm conservation	VS Tuia, L Sebastian*R Bourdeix
2.2.3 Revisiting the classical delineation between *in situ* and *ex situ* conservation	R Bourdeix, VS Tuia*JL Konan
2.2.4 *In vitro* culture and cryopreservation	C Oropeza, F Engelman*CA Cueto*PIP Perera
2.3 The current global ex situ *conservation system*	*R Bourdeix*
2.3.1 Content of *ex situ* collections	R Bourdeix, C Hamelin*M Ruas
2.3.2 Mandate of institutes managing *ex situ* collections	GV Thomas, R Bourdeix*S Weise
2.3.3 Cost of *ex situ* collections	R Bourdeix, JL Konan*NTK Duong
2.3.4 Collecting germplasm	R Bourdeix, K Devakumar*F Pole
2.3.5 *Ex situ* collection management	SRR Ramos, V Niral*JL Konan
2.3.6 Germplasm identification and characterization	E Issali, M Tulalo*V Kumar
2.3.7 Safety duplication of germplasm	CA Cueto, R Bourdeix*JL Konan
2.4 Genetic resources information management	*M Ruas*
2.4.1 Local genebank management systems	R Bourdeix, V Arunachalam*C Hamelin
2.4.2 Managing international coconut databases	M Ruas, C Hamelin*R Bourdeix
2.4.3 Geographic Information Systems	G Coppens, NTK Duong*A Ullivarri
2.5 Utilization of coconut genetic resources	*MG Pereira*
2.5.1 Planting material for farmers	E Omuru, L Perera*D Lobo*RA Castillo* RI Rivera
2.5.2 Involvement of farmers in breeding and seednut	R Bourdeix, M Konelio*PK Thampan

Chapter and section	Contributors (main contributor in bold)
production	
2.5.3 Past and contemporary coconut breeding	MG Pereira, R Bourdeix*JO Odewale
2.5.4 Breeding for yield	E Issali, T Sileye*R Bourdeix
2.5.5 Breeding for pest and disease resistance	V Hegde, LI Masumbuko*PPG Parra
2.5.6 Breeding for quality traits	MA Wilson A Prades*A Kembu
2.5.7 Breeding for drought and other abiotic stresses	Fanhaikuo R Bourdeix*TKG Ranasinghe
2.5.8 Genomics and DNA markers	R Manimekelai, Y Yaodong L Baudouin*
2.5.9 Coconut, climate change and coastal areas	S NareshKumar, J Ollivier*R Bourdeix
2.5.10 Coconut conservation, tourism and ecotourism	Y Samosir, VS Tuia*R Bourdeix
2.6 Coconut germplasm exchange	*CA Cueto*
2.6.1 Benefits of sharing coconut genetic resources	GV Thomas, JL Konan*M Tulalo
2.6.2 Safe movement of germplasm	CA Cueto, V Hegde*F Pilet
2.6.3 International germplasm transfers	JL Konan, L Perera*E Omuru
2.7 Partnerships and networking	*V Johnson, S Weise*R Bourdeix*
2.8 Facing emergency situations: an overview	*JL Konan, E Omuru*R Bourdeix*
3 Where we need to be to secure diversity and promote use	L Perera
3.1 Strengthening communication and commitment to conservation and use of coconut genetic resources	*R Bourdeix*
3.1.1 Targeted audience	L Perera, D DonaFologo*N Chomchallow
3.1.2 Concepts for communication	T Kete, D DelaMatadelaIsla*R Bourdeix
3.1.3 Implementing the communication strategy	V Johnson, A Delapresa*C Picq
3.2 Revisiting the concept of the Global COGENT Coconut Collection	*R Bourdeix*
3.2.1 Crucial importance of field genebanks	RI Rivera, K Allou**V Niral*
3.2.2 Diversification of coconut genebanks	JL Konan, T Sileye**V Niral*
3.2.3 Geostrategy: doubling the number of International genebanks	VS Tuia L Perera**C Andreas**RI Rivera E Issali
3.2.4 Sharing international resources between genebanks	L Perera K Allou*RI Rivera
3.2.5 Towards a concept of a "networked" or "virtual" coconut collection	R Bourdeix, L Guarino*C Lusty
3.3 Securing existing ex situ *Coconut genetic resources*	*K Allou*
3.3.1 Business plans for genebanks	L Perera, JL Konan*M Tulalo
3.3.2 Extending the duration of accessions in the fields	NTK Duong, M Tulalo*JL Konan
3.3.3 Duplication of germplasm in distinct geographical sites	R Bourdeix, K Allou*E Omuru
3.3.4 Cryogenebanking	K Haeng-hoon, F Engelman
3.4 Strengthening conservation beyond ex situ *genebanks*	*VS Tuia*
3.4.1 Conservation through use	V Kumar, R Goirand*J Kanniah

Chapter and section	Contributors (main contributor in bold)
3.4.2 Multifunctional landscape management	R Bourdeix, D DonaFologo*S Planes* N Chomchallow
3.4.3 Botanists, ecologists and the coconut palm	F Chong, E Issali*T Kete
3.4.4 Coconut reproduction patterns	R Bourdeix, Planes*KG Sentoor
3.5 Collecting and filling gaps in ex situ collections	*SACN Perera*
3.5.1 Compact Dwarfs and other special varieties	V Kumar A Prades*SACN_Perera*MG Pereira
3.5.2 Collecting for pest and disease tolerance	SACN Perera, JO Odewale*E Omuru*L Mirisola
3.5.3 Filling geographical gaps	G Coppens, P Komba*A Ullivarri
3.5.4 Islands most isolated and/or endangered by climate change	R Bourdeix, F Chong**I Maskromo*
3.6 Strengthening the distribution and the safe movement of germplasm	*A Karun*
3.6.1 Policies for international germplasm transfers	R Bourdeix, GV Thomas*F Pilet
3.6.2 Transfer of germplasm via embryo culture and pollen	A Karun, K Haeng-hoon
3.6.3 Disease indexing and quarantine centres	M Dollet, A Karun*VRMV Arachchi
3.7 Promoting the use of coconut genetic resources	*T Kete*
3.7.1 Global objectives in terms of planting material	R Bourdeix, G Yace*T Sileye
3.7.2 Promoting farmer-made planting material	M Konelio, J Kanniah*T Sileye
3.7.3 Germplasm characterization and evaluation	A Prades, MA Wilson*R Goirand
3.7.4 International breeding experiments	NTK Duong, G Yace*MG Pereira
3.7.5 Coconut clones, the next revolution?	PPG Parra , JL Verdeil*L Mirisola
3.8 Improving databases and sharing of technical information	*M Ruas*
3.8.1 Data management in genebanks	R Bourdeix, V Arunachalam*C Hamelin*M Ruas
3.8.2 International databases on ex situ conservation	M Ruas, C Hamelin*R Bourdeix
3.8.3 Databases for and of farmers	R Bourdeix, J Kanniah*L Mirisola
3.9 Genome studies for effective management and utilization of coconut genetic resources	*L Baudouin*
3.9.1 Sequencing coconut genome.	R Manimekelai, Fanhaikuo* L Baudouin
3.9.2 Preparing the era of marker-assisted breeding	L Baudouin , P Heslop Harrison*MG Pereira
3.9.3 DNA analysis in *ex situ* genebanks	DN Pokou, R Manimekelai*Fanhaikuo
3.9.4 DNA analysis in farmer's fields	SACN Perera, B Gunn*RI Rivera
3.10 Enhancing networking and partnerships for global collaboration	*V Johnson, L Perera*VS Tuia*
4. Annexes	
Annex 1. COGENT-members countries, linked national institutions	R Bourdeix M Petraglia*S de Lima
Annex 2. Contributors to the Strategy including their parent institution(s)	R Bourdeix M Petraglia*D DelaMatadelaIsla

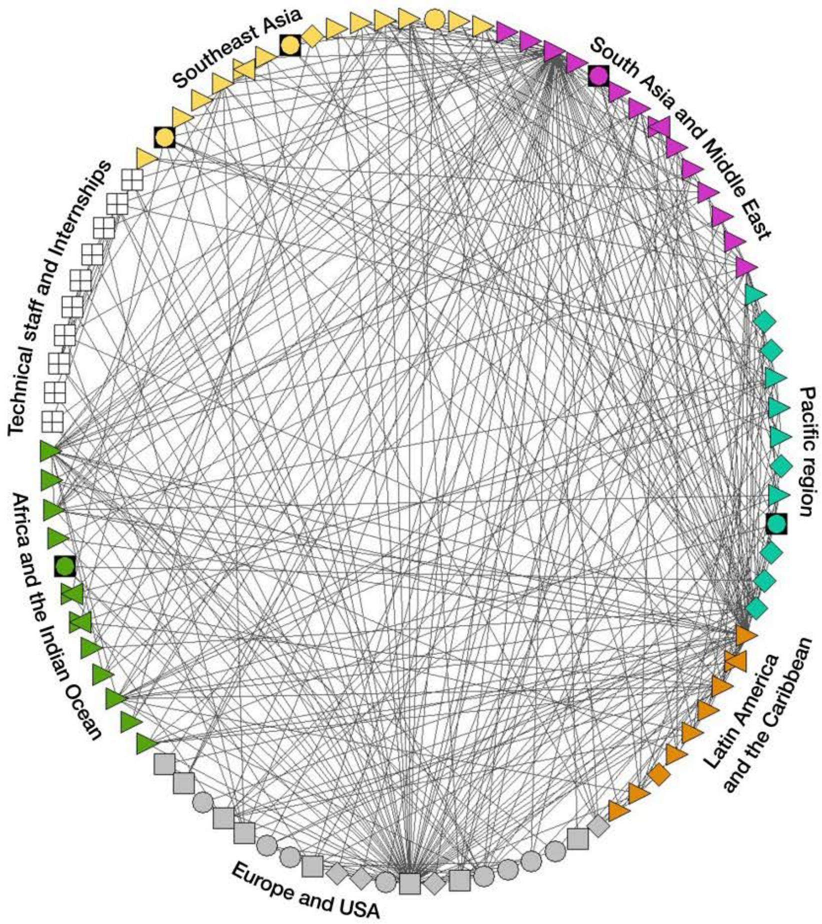
Chapter and section	Contributors (main contributor in bold)	
Annex 3. Contributors to the strategy by chapters and sections	**R Bourdeix**	M Petraglia*MA Gouigou
Annex 4. Reorganization of the Cogent Network	**R Bourdeix**	M Petraglia*D Martinez , V Johnson
Annex 5. List of the projects facilitated or coordinated by COGENT and Bioversity International	**R Bourdeix**	M Petraglia*V Johnson
Annex 6. Global survey template (2012) and list of responding institutions.	**R Bourdeix**	D DelaMata delaIsla*V Johnson
Annex 7. Standard costs for the preparation of coconut germplasm	R Bourdeix	JL Konan*RI Rivera
Annex 8. Schedule of gathering characterization data for a Tall-type coconut accession	**R Bourdeix**	JL Konan*M Tulalo
Annex 9. Conserving each cultivar in three countries: what does it means?	**R Bourdeix**	M Petraglia*V Johnson
Annex 10. Costs summary of the Global COGENT collection	**R Bourdeix**	M Petraglia
Annex 11. Useful web links	L Er Rachiq	R Bourdeix*C Picq

Plate 3.1

Networking for coconut conservation and research

Network representations of the interactions between the contributors to the Global Strategy for Conservation and Use of Coconut Genetic Resources

The writing and compiling of this strategy generated 434 unique interactions between the 90 contributors of the 132 sections and the 5 chapters of the Strategy. Each section was authored by 2 to 5 contributors, specialists in their fields of competences and preferably working in different geographical regions



Caption:

COGENT researchers

Bioversity researchers

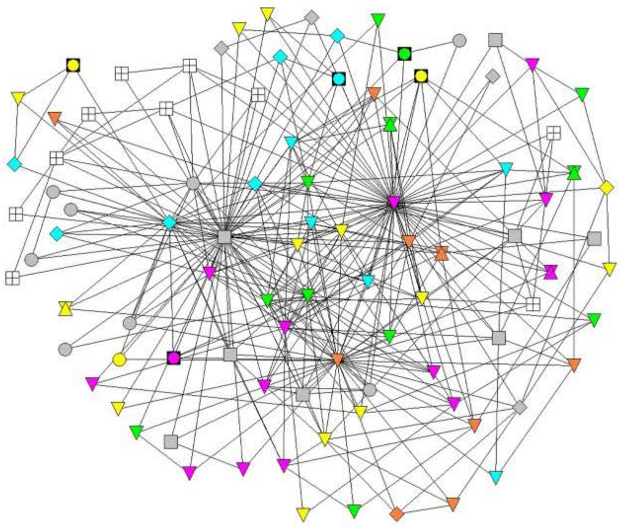
CIRAD researchers

Interns and technical staff (COGENT Secretariat)

Researchers from other institutions

Experts from NGOs

Experts from private companies



A. Ullivarri, R. Bourdeix and A. de la Presa

Annex 4. Reorganization of the COGENT Network

In 1991, acting on the suggestion of the CGIAR, representatives of 15 coconut-producing countries recommended establishing an international coconut genetic resources network. Based on the results of this consultation process, CGIAR decided to include coconut in its research portfolio, in response to studies indicating that international support and global coordination of research in coconut is essential to make the crop more productive and beneficial to smallholder coconut farmers.

In 1992, endorsed by CGIAR and its donors, the International Plant Genetic Resources Institute (IPGRI) now Bioversity International, established the International Coconut Genetic Resources Network (COGENT) to promote an international collaborative programme on genetic resources conservation and use. Coconut-producing countries lack both human and material resources to conduct expensive and time-consuming research that could address many of the challenges that face the crop. Conservation and improvement of genetic resources were identified as the most urgent and strategic areas to strengthen for increasing productivity and yield security.

Currently, only coconut producing countries can become COGENT members. To apply for free membership, an authorized government official should write to the COGENT Secretariat and provides dedicated information[1].

Between 1992 and 2017, 18 meetings of the Steering Committee (SC) have been held. (Table 4.1) gives the location and composition of the SC meetings held from 1997 to 2014. This illustrates how COGENT has aimed to maintained equitable representation of countries, regions and continents in its deliberations and support. The SC meetings were regularly held from 1997 to 2007 (except 2006). No meeting was held from 2007 until 2012, when an important reorganization of the network was achieved.

Until 2012, each country member was represented in COGENT by a single national Official representative, chosen by the country. Two regional coordinators from each of the five regional networks constituted the Steering Committee[2].

Upgrading COGENT's organization was initiated in 2012 by conducting two organizational assessments and two participative meetings. Since 2012, each member country has to nominate two COGENT representatives:

- An Official Country Representative. She/he can be a staff member of the Ministry of Agriculture supervising coconut research, the director of an institute involved in coconut research, the head of a national coconut research programme or the curator of a coconut genebank.
- An Alternative Representative. She/he can be the director of an institute involved in coconut research, the head of a national coconut research programme or the curator of a coconut genebank.

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[1] To be eligible for COGENT membership, a country must meet a number of criteria that have recently been articulated and published on the COGENT website. (see http://www.cogentnetwork.org/faq/34-membership)

[2] The Chair and Vice-Chair of the Steering Committee are elected for a two-year term and each must come from a different regional network. The members are also elected for a two-year term.

Table 4.1. Location and composition of the COGENT Steering Committee Meeting from 1997 to 2014

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008 2009	2010 2011	2012 2013	2014
Location of SC meeting	CIV	PNG	VNM	IND	TZA	THA	MEX	MYS	IND		PHL			IND	LKA
Africa Indian Ocean	CIV	**CIV**	**CIV**	**CIV**	**CIV**	CIV	CIV	CIV	CIV		CIV	**CIV**	**CIV**	CIV	CIV
	TZA	TZA	TZA	TZA		**TZA**	**TZA**	TZA	TZA		TZA*			TZA	KEN
Latin America & Caribbean	**JAM**	JAM	CUB	CUB		MEX	MEX	**MEX**	**MEX**	**MEX**	**MEX***			MEX	MEX
	BRA	BRA	BRA	BRA		BRA	BRA	BRA	BRA		BRA			**BRA**	**BRA**
South Asia	IND	IND	IND	IND		IND	IND	IND	IND		IND			**IND**	IND
	BGD	BGD	LKA	LKA		LKA	LKA	LKA	LKA	**LKA**	**LKA**	**LKA**		LKA	LKA
Southeast & East Asia	PHL	PHL	PHL	**PHL**	**PHL**	**PHL**	**PHL**	**PHL**	**PHL**		PHL		**PHL**	PHL	PHL
	THA*	**THA**	IDN	IDN		IDN	IDN	IDN	IDN		IDN			IDN	IDN
South Pacific	FJI	FJI	**FJI**	FJI		FJI	FJI	FJI	FJI		Vacant			VAN	VAN
	PNG	PNG	Vacant	Vacant		WSM	PNG	PNG	PNG		PNG			PNG	PNG

* Absent Member

(1) In **red bold**, chairman; in **green bold**, vice-chairman

Country code ISO 3166-1: Bangladesh (BGD), Brazil (BRA), Côte d'Ivoire (CIV), Cuba (CUB), Fiji (FJI), Kenya (KEN), France (FRA), India (IND), Indonesia (IDN), Jamaica (JAM), Malaysia (MYS), Mexico (MEX), Papua New Guinea (PNG), Philippines (PHL), Samoa (WSM), Sri Lanka (LKA), Tanzania (TZA), Thailand (THA), Viet Nam (VNM).

Engaging two people (one official and one alternative representatives) in COGENT instead of only one (as before 2012) for each member-country makes communication much more efficient and sustained.

The composition and role of the SC were modified in order both to increase its stability and to allow other member-countries to fully participate in decision-making. It was decided that any country hosting an international genebank will be *de facto* member of the SC and involved in the coordination of its respective regional networks.

All COGENT member-countries are now invited to join the SC meetings, by sending their official or alternative representatives, or any other delegate mandated by the above. All stakeholders and NGOs involved in the coconut value chain and all donors agencies involved in funding coconut research are also invited to apply for participating in the meeting[3].

All the member-countries' representatives who attend the SC meeting now fully participate in decisions and votes implemented during the meeting. Decisions will be ratified by consensus (as it was done during the 2012 SC meeting for this important change in decision-making) or by a majority of participating member-countries, taking account one vote per member country.

In 2012, the venue of COGENT SC meetings was fixed as biennial and linked to the COCOTECH[4] meeting of the APCC. Organizing the two meetings back to back in the same location allows increased interactions with stakeholders from the coconut value chain, generates economies of scale, and proves more environmentally friendly in reducing the number of international flights. Furthermore it is no longer necessary to wait for separate decisions on the venue of the SC meeting. A remote decision-making process was endorsed, using two distinct processes, remote consensus and remote voting.

Another important innovation introduced in 2012 was the creation of seven permanent International Thematic Action Groups (see Table 4.2 for composition). ITAGs are not decision-making bodies. Their objectives are:

- to gather the best specialists in order to strengthen communications between researchers working in different countries in the same thematic field,
- to provide useful recommendations and new research ideas to the COGENT SC (the decision-making body and to the COGENT secretariat),
- to help to protect the specific research interests of COGENT member-countries.

To enable effective hosting for the COGENT Secretariat, ongoing funding is needed for IT support, finance, administration, HR, communications, fundraising and other associated services. CIRAD has supported COGENT by providing technical expertise

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[3] In 2012, all the stakeholders who applied were welcome and participated in the meeting: three representatives of private companies located in India and Brazil, a professor from a Brazilian University, and representatives from APCC, SPC and the Coconut Development Board of India. A representative from the Global Crop Diversity Trust also attended the meeting.

[4] COCOTECH is the permanent panel on coconut technology of the APCC. This gathering of coconut development workers, researchers, farmers, processors, importers, exporters and government policy makers in APCC member countries is held once every two years. For more information, visit the URL: http://www.apccsec.org/meeting.html

and coordination for Secretariat, whereby two researchers were successively seconded to Bioversity for coordination support from 2011 to 2016

In the wake of CGIAR systemic changes (since 2011) Bioversity has reduced access to funds to continue its current hosting support for the COGENT Secretariat. Furthermore, Bioversity does not have core research expertise in coconuts (although offers farming-systems expertise linked also to other palm spp.)

For these reasons, COGENT and Bioversity have identified a new arrangement for hosting the Secretariat to keep network effective and ensure implementation of this Global Coconut GR Strategy. Different hosting options were considered by COGENT and Bioversity. Any Secretariat host must have global reach, embracing all regions (LAC, Africa/Indian Ocean; Asia - Pacific), to be able to support the network of 39 member countries, and the 24 national and 5 International Coconut Genebanks. The final decision was made by COGENT through its Steering Committee, at its 18th SC meeting in Fiji in 2017 to transfer the Secretariat to the APCC as soon as it is formally renamed as the international coconut community (ICC) in September 2018. Bioversity will also transfer article 15 obligations under the Treaty, regarding ICGs in PNG and Côte d'Ivoire, as these obligations may transfer to another organization in any new hosting arrangement.

As articulated in Recommendation 4 issued at the COGENT 18th SC meeting[5] in November 2017, the SC also voted for COGENT members to update the International Thematic Action Groups (ITAGs - see table 4.2 next page for current ITAGs), in terms of leadership and composition, and nature (adding ITAGs if a new thematic area is deemed appropriate). The SC also recommended that a COGENT Strategy Implementation Taskforce (SIT) be established, by remote voting, composed of the ITAG leaders, the COGENT Coordinator, Chair and Vice-chair, along with representatives of the ICGs and external observers. The ITAG teams will then develop appropriate sections of the strategy implementation timeline and budget for those activities relevant to their thematic area, with reference to the work plan developed by Dr Bourdeix, and updating this after the ITAGs leaders have been appointed. This also will require a fundraising task force being established and proposals developed via the ITAG team task force (essentially ITAG team members and COGENT Secretariat).

[5] See the URL: http://www.cogentnetwork.org/images/COGENT_-Recommendation_1-10-_2017-_COGENT_interim_coordination-signed.pdf

Table 4.2. Actual composition of COGENT International Thematic Action Groups.

Name of the ITAGs	# senior members	# junior researchers	# countries involved	Leadership country
Ex situ Coconut conservation and related methodologies	5	3	5	Côte d'Ivoire
Phytopathology and coconut germplasm movements	5	1	6	Côte d'Ivoire
Ethnobiology and socioeconomics	13		8	None
Coconut breeding	7	1	5	Brazil
Coconut genomics	13		9	India
Coconut *in vitro* culture	12		11	Mexico

Annex 5. List of the projects facilitated or coordinated by COGENT and Bioversity International

Table 4.3. Fund generation and financial support to member countries and partner institutions.

Name of the project	Dates	Number of countries involved	Budget donor only (KUSD)	Funding agency/ donor
Regional technical assistance for the establishment of a coconut genetic resources network for Asia and the Pacific Region	1994-1997	13	800	ADB
Regional technical assistance for a coconut genetic resources and human resource strengthening for Asia and the Pacific Region	1998-2000	20	1,200	ADB
Developing sustainable coconut-based income generating technologies in poor rural communities	1998-2000	8	1,000	ADB
Sustainable use of coconut genetic resources to enhance incomes and nutrition of smallholders in the Asia-Pacific Region	1997-2000	14	907	IFAD
Cryopreservation technical support , Korean Associate Scientist	2001- 2015	1	170	South Korea
Overcoming poverty in coconut growing communities	2005-2008	19	1,000	IFAD
Coconut-based product diversification to reduce poverty in coconut-growing communities	Jan 2005 – Dec 2009	1	62.4	Philippines (DA-BAR)
Coconut germplasm utilization and conservation to promote sustainable coconut production	1997-2002	6	1,199	CFC

Name of the project	Dates	Number of countries involved	Budget donor only (KUSD)	Funding agency/ donor
Project regeneration Côte d'Ivoire Regeneration of Accessions in the International Coconut Genebank for Africa and the Indian Ocean	2004 - 2011	1	262	Global Crop Diversity Trust
Establishment of the International Coconut Genebank for South America and the Caribbean	June 2006 – Dec 2011	1	200	Brazil (EMBRAPA)
Training and research workshop: 'Coconut embryo culture to improve collecting and safe movement of germplasm'	Sep-Dec 2008	14	63	Global Crop Diversity Trust
Project Upgrading international coconut genebanks and evaluating accessions	Jan 2011 - March 2012	6	35	Global Crop Diversity Trust
Project COGENT Steering Committee Meeting 2012	May 2012 to Oct 2012	17	19.9	Global Crop Diversity Trust
Project Validation of a coconut embryo culture protocol for the international exchange of germplasm	October 2009 April 2012	4	295.6	Global Crop Diversity Trust
Project Developing cryopreservation protocols for sub-tropical crops and establishing cryogenebank at RDA, Korea	Nov 2015 – October 2018	2	338.2	South Korea
Project Upgrading and broadening the new South-Pacific International Coconut Genebank	June 2016- May 2019	3	494.5	UK, Darwin Initiative
Project Coordinating the conservation of coconut diversity in the Asia-Pacific region and globally	Oct 2017-March 2018	27	64.7	Australia
Total			8,111.3	

Annex 6. Global survey template (2012)

COGENT survey on cost and long-term sustainability of the coconut genebanks for COGENT representatives and alternative representatives[6]

(Please note that the narrative below dates from 2012)

The International Coconut Genetic Resources Network is updating a global strategy for the conservation and use of coconut genetic resources. In order to describe the current situation as accurately as possible, we need updated information and your opinions on the status of coconut collections.

As a COGENT representative or alternative representative, we kindly request you to complete this questionnaire. Your opinion will be a key factor for convincing donors and other stakeholders to invest more in coconut research and conservation. The questionnaire can be filled on internet at the following address:

http://www.surveymonkey.com/s/COGENT-Survey

At the global level, coconut conservation is presently facing an emergency situation. We will probably need to rethink and modify the global organization of coconut conservation. We have learned, from researchers of the CNRA "Marc Delorme" research station, that a Lethal Yellowing Disease was identified for the first time in Côte d'Ivoire, in the Grand-Lahou region, at about 150 km from the International Coconut Genebank for Africa and Indian Ocean. In Papua New Guinea, the International Genebank for the Pacific Region is also strongly threatened by a new Phytoplasma disease (see the video at: http://www.cogentnetwork.org/bogia-syndrome-disease).

In 2012, the COGENT secretariat released an important report which gives an overview of coconut conservation and provides an evaluation of several genebanks. This report may help you to articulate an opinion. It is available on line at: http://www.cogentnetwork.org/network-projects/past-projects/upgrading-genebanks

If you do not succeed to connect or use the Internet version of the survey, we also provide a Word version of the questionnaire. Please return this questionnaire by 1st July 2013, even if it is not fully completed.

For all quantitative data, we do not need very precise data but a rough estimated average. We prefer to have now your opinions on strategically important points than to wait a long time for having a full set of quantitative data.

The feedback received will contribute to the Global Strategy and you will have an opportunity to review its content and provide further feedback. Your participation in the development of this initiative is highly valued. If you have any questions or difficulties, please do not hesitate to contact Dr Roland Bourdeix, COGENT coordinator, or Diana De la Mata, COGENT Communications.

Yours sincerely,

Dr Roland Bourdeix

COGENT Coordinator

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[6] A list of respondents is available on request. Please contact v.johnson@cgiar.org

INSTITUTIONAL INFORMATION

1. Name and address

Name and address of institution holding the collection	
Name of institution	
Address	

2. Please give your information details

Last name (family name)	
First name	
Position	
Institute	
Address	
Email:	

3. Please indicate the type of institute that holds the collection:

☐ Public-funded institute (government institute, university, public-funded research institute)

☐ Private institute

☐ Other, please specify:

4. Please indicate what responsibility the institute has in maintaining the collection (only one tick per row):

	Yes	No	Don't know
Does the institute own the collection?			
Does the institute have an official mandate from the government to conserve Coconut?			
Does the institute have an official mandate from the government to carry out research on Coconut?			
Does the institute have an official mandate for conserving Coconut at the regional or global level?			
Does the institute have sole responsibility for management decisions concerning the collection?			
Does the institute provide most or all of the recurrent costs for the collection?			

5. If you have answered "no" to any of these questions, please specify, where possible, who is the responsible institute(s):

LONG-TERM SECURITY OF THE COLLECTION

The responses to the following questions are important in providing baseline information to estimate the costs of supporting Coconut conservation at a global level.

6. What is the current status of the collection with respect to the following factors?

Factors	Very good / Good / Average / Poor / Very poor / I don't know
Funding for maintenance	
Number of trained staff	
Status of buildings, facilities and equipment	
Funding for collecting germplasm	
Funding for research on the collection	
Level of use by breeders, researchers or growers	

7-8. Who funded the genebank activities during the last (in USD per year, yearly average)?

Factors	Total amount per year
Self-funding (resources generated by the genebank from raw coconut products excluding planting material)	
Self-funding (selling germplasm and planting material)	
Self-funding (selling high value coconut products processed in the genebank)	
Self-funding (selling other products than coconut)	
National Government	
National Private companies	
International Private companies	
International agencies	
Other (______________________________)	
Total	

9. Please estimate the annual costs in US$ per accession of the following activities carried out on the collection

	US$ / accession / year
Field collection maintenance	
Morphological characterization	
Molecular characterization	
Agronomic evaluation	
Germplasm health (indexing & eradication)	
Information management	

10. Please provide the details of any other major costs related to your activity(ies)

11. Location and surface of coconut genebanks

How many locations are devoted to *ex situ* conservation of coconut palms in your country?	
Under your institution, how many locations are devoted to *ex situ* conservation of coconut palm?	
What is the total area of centers from your institution where are located *ex situ* coconut genebanks? (rough estimation, hectares)	
What is the total area devoted to *ex situ* coconut genebank(s) in your institution? (rough estimation, hectares)?	

12. Typology of coconut genebanks

Are all the locations devoted to coconut *ex situ* conservation in your country under the same institution?	
Are the coconut palms from the genebank under-planted with other crops, and which one?	
Under your institution, are the sites for *ex situ* coconut conservation also serving for *ex situ* conservation of other crops?	

13. Please provide the average production of the genebank (estimation on adult palms, average last five years)

Number of fruits per palm per year	Average weight of the mature coconuts (g)	Average weight of kernel per mature coconut (g)	Average coconut water per young coconut (ml)	Average planting density (Palms per hectare)

14. What are the main factors presently threatening the genebank?

15. Please describe the major concerns threatening the long-term sustainability of the collection in your country

Land pressure	
Lack of budget	
Lack of profitability of the genebank	
Lack on manpower	
Lack of infrastructure	
Pest	
Disease	
Drought	
Low agronomic management	
Geographical isolation of the genebank Scientific isolation of researchers working at the genebank	
Researchers do not want to stay working at the genebank	
Low commitment to coconut conservation at local level	
Low commitment to coconut conservation at national level	
Low commitment to coconut conservation at international level	
Other	

If other (please specify):

PLANTING MATERIAL FOR FARMERS

16. Links between the genebank and production of planting material

	Yes / Mostly/ Neutral / Not really / No
The coconut genebank and the seed gardens are under the same institution	
Seed gardens are located in the same locations as the coconut genebanks	
The institution in charge of *ex situ* coconut conservation is also the main producer of coconut seednuts	
The private sector plays an important role in managing seed garden for mass production of coconut planting material	
The genebank provides good planting material to farmers at national level	
The genebank provides a sufficient amount of good planting material at national level	
Farmers are reluctant to pay for coconut seednuts	
The cost of seednuts released by the institution is affordable to farmers	
Genebank help farmers to produce good planting material by themselves	
Coconut farmers are well organized regarding the availability of good planting material	
Most of the planting material is produced by the farmers themselves.	

If other (please specify)

17. Please provide the average production of the seed gardens from your institution (rough estimation on adult palms, per year, average of last years)

Type of seednuts	Number of mother palms	Total area (hectares)	Number of fruits per palm per year	Number of seednuts produced per year	Number of seednuts released to farmers	Number of seedlings released to farmers
Dwarf						
Tall						
Tall x Tall hybrids						
Dwarf x Tall hybrids						
Composite varieties						
Other						

18. Please tell us anything else about planting material

COMMUNICATION ASPECTS

19. How does the genebank from your country interact with stakeholders on the importance of conservation and use of coconut genetic resources?

	From 1 (very effecively) to 5 (very weak) 0 = Don't know
The website of the institution provide accurate information on the genebank	
The website of the institution provide information on germplasm descriptors and yield characteristics	
The website of the institution provide pictures of the conserved germplasm	
The website of the institution provide videos on conservation and use of coconut germplasm	
Books and paper catalogues on coconut germplasm are available at national level	
The links between the genebank and the coconut stakeholders (farmers, industrials) are satisfactory	
The links between the genebank and the citizens are satisfactory	

20. How many people are visiting the genebank? (Rough estimation, yearly average for the last five years). If you do not have a gender estimation, please fill only the column "Total"

	Female	Male	Total
Total number of people			
Students for primary school			
Students for secondary school			
Students from university			
Students for internships on coconut research			
Farmers and other coconut stakeholders			
Researchers from other institutions			
Local tourists			
International tourists			
Other			

If other, please specify:

21. Do you think the genebank should be visited by more people? Why and by whom?

22. Do you have any advice to improve the communication aspects?

GLOBAL ORGANIZATION OF COCONUT GENEBANKS

23. International genebanks are effectively playing their role in:

	Strongly agree / Agree / Neutral / Disagree / Strongly disagree / I don't know
Conserving germplasm of their region	
Conserving germplasm from other regions	
Distributing germplasm at national level	
Distributing germplasm at international level	
Capacity building at national level	
Capacity building at regional level	
Enhancing commitment to conservation and use of coconut genetic resources	

24. Do you think that the present global organization, with only five genebanks classified as International, should be modified?

	Strongly agree / Agree / Neutral / Disagree / Strongly disagree / I don't know
The number of international genebank should be increased (two per region instead of one, for instance the Philippines and/or Sri Lanka could also become international genebanks)	
The number of international genebanks should be maintained (one per region only)	

Add a comment if necessary

25. What changes to the present situation would you consider to be essential for the long-term conservation of Coconut at a national or global level?

RULE AND EFFICIENCY OF NATIONAL COCONUT GENEBANKS

26. Please answer this question, ONLY if the coconut genebank in your country does not have the status of international genebank

	From 1 to 5 1: strongly agree 5: strongly disagree 0= Don't know
The national genebank is effectively playing its role in:	
1. conserving germplasm from the country	
2. conserving germplasm from other country	
3. distributing germplasm at the local level (100 km around the genebank)	
4. distributing germplasm at the national level	
5. capacity building at local level (100 km around the genebank)	
6. capacity building at National level	
7. enhancing commitment to conservation and use of coconut genetic resources	

27. How the COGENT network can help to strengthen the genebank in your country?

28. How the COGENT network can help to increase commitment at local, national and International level to conservation and use of Coconut Genetic Resources?

Thank you for completing this questionnaire

Annex 7. Standard costs for the preparation of coconut germplasm

Standard costs for the preparation of coconut germplasm for international movements between the countries members of the COGENT network

These costs apply from 2012 to 2014 for quantities superior to 200 units sent in the same package. Prices include the harvest and preparation of the germplasm, the required chemical treatments, obtaining the phytosanitary certificates in the country sending the material, and the packaging. These costs do not include the cost for sending the germplasm and obtaining the phytosanitary certificates in the receiving country.

In the case of an international project involving a national research institute from a COGENT country and other partners such as farmer's organizations or private companies, these prices apply to all the partners. In the case of direct negotiation between genebanks and private partners, these prices do not apply. Costs are given in US$.

Material	Seednuts treated with appropriate chemicals	Sterile embryos in albumen cylinders in bulk	Embryos stored *in vitro* and tagged individually with parent palm numbers	Desiccated pollen, per gr	Leaf or root samples for DNA analysis
From open pollination (no bagging of the inflorescence)	2	2.5	2.5	2	0.5
From assisted pollination (emasculation of the female parent without bagging)	3	3	3	Not applicable	0.5
From controlled pollination (bagging of the inflorescence)	8	8	10	3.5	0.5

The Secretariat of the COGENT Network
Dr R. Bourdeix
COGENT coordinator

Annex 8. Schedule of gathering characterization data for a Tall-type coconut accession

Section	Reference from the STANTECH manual[1]	Sample	Periodicity	Age to make measurement (years)	Manpower (per accession)	RCI[2] Tech. staff (hours)	RCI Field worker (hours)	Indonesia Tech. staff (hours)	Indonesia Field worker (hours)	Total No. of data to be recorded	Time data entry (hours)
Germination speed and rate	§ 7, p 25 *form 1*	All nuts	Weekly, during 4 months	Before planting	1 technician + 1 field worker	8	8	16	168	300	0.2
Vegetative observations before flowering	§ 7, p 26 *form 3*	30 palms	Every 6 months, during 3 to 5 years	Before flowering	1 technician	32	0	48	0	600	0.4
Flowering distribution	§ 7, p 27 *form 5*	each palm	Monthly, during 1 to 2 years	During flowering	1 technician	36	36	48	48	72	0.1
Floral biology	§ 7, p 28	12 palms	3 time a week (RCI) or every day (Indonesia) during 1 year	8 to 10	1 technician	250	0	864	0	7500	5
Inflorescence morphology	§ 2, p 6	12 palms	One measurement	8 to 10	1 technician + 1 worker	2	2	6	6	100	0.1
Leaf measurement	§ 7, p 29 form 4	12 palms	One measurement	8 to 10	2 hours 1 technician + 1 worker	2	2	2	2	72	0.1
Stem height	§ 7, p 28 form 11	30 palms	Two measurements	8 and 12	1 technician + 1 worker	5	5	10	10	60	0.1

[1] Available on line at: http://www.cogentnetwork.org/images/publications/StantechManual.pdf

[2] RCI: Republic of Côte d'Ivoire

Section	Reference from the STANTECH manual	Sample	Periodicity	Age to make measurement (years)	Manpower (per accession)	RCI Tech. staff (hours)	RCI Field worker (hours)	Indonesia Tech. staff (hours)	Indonesia Field worker (hours)	Total No. of data to be recorded	Time data entry (hours)
Stem morphology	*§7, p 28 form 10*	30 palms	One measurement	10	1 technician + 1 field worker	3	3	6	6	120	0.1
Fruit component analysis.	*§7, p 30 form 8*	30 palms	Every other month during 4 years	6 to 9 or 8-12	1 technician 2 field workers	60	240	60	120	5760	4
Bunch and fruit numbers	*§7, p 29 form 7*	30 palms	Every other month for Tall-type accessions	From beginning to 12 years	1 technician 1 field worker	350	350	480	480	4320	3
Transfer of data into CGRD						0	0	0	0	0	2
Total (hours)						748	646	1,540	840	18,904	15.1

Annex 9. Conserving each cultivar in three countries: what does it mean?

As discussed in Section3.3, the easiest way to explain which system curators would like to adopt is to give practical examples:

1. The Salak Green Dwarf (SKD) is a cultivar conserved under international mandate by Indonesia[7]. Presently there are six living accessions of SKD, all located in Indonesia. SKD is a very interesting Malayan Dwarf type: it starts flowering after one year, about one year before similar kinds of Dwarfs. It is self-pollinating so it can be exchanged, but using seeds or embryos from open pollination.

   Thus we need to consider: a) For an efficient global conservation, SKD must be planted in two more countries; b) Which countries are interested to obtain SKD?[8]; c) Among these countries, which ones are ready to place the received accession under international mandate?[9]; d) Which ones have really shared coconut germplasm during the last 20 years? e) Which ones provide the most secure conservation?

   Then, negotiations at COGENT level will designate the two reviving countries. It is expected that the international system will cover the cost of the two required international transfers.

2. The Nicobar Tall (NCT) is a cultivar conserved under international mandate only in India. There are six populations of NCT, namely Auck Chung, Campbell Bay, Katchal, Kimios, Kimmai and Tamaloo. All are conserved as living palms numbering between 36 and 45; per accession, which is less than the recommended size but sufficient enough to conduct a controlled hand pollination programme. At least one population of Nicobar Tall must be conserved at international level, meaning conserving three accessions in three distinct countries. Does COGENT need to conserve more than one population of NCT at the international level? Curators will have to make a decision on this point according to available data. As an allogamous Tall-type, NCT must be reproduced by controlled hand-pollination (CHP). CPCRI has access to good skills in CHP although some minor points need improvement. How can the international system help CPCRI to improve its CHP technique? Which are the most interesting populations of NCT? Then the process (a, b, c, d, e) described in the previous paragraph will be applied to at least one NCT population. Negotiation within COGENT will designate the two receiving countries. It is expected that the international system will help CPCRI to improve its CHP method and find ways of covering the cost of the required international transfers[10].

3. The Brazilian Tall (BRT) is a cultivar under international mandate conserved only in Brazil with more than 10 populations. At least one population of BRT must be conserved at international level. Does COGENT need to conserve more than one

[7] This means that, in the Memorandum of Agreement signed by Indonesia, the Salak Green Dwarf (SKD) is one of the cultivar listed as available for the coconut community.

[8] Probably more than 20.

[9] Probably more than eight.

[10] At the rate of US$500 per cultivar.

population of BRT at the international level? Curators will have to make a decision on this point according to available data. As an allogamous Tall-type, BRT must be reproduced by CHP. Unfortunately, the International Genebank in Brazil does not currently have adequate skills, climbing methods and the manpower needed to conduct CHP. Could the international system help the Brazil genebank to overcome this constraint? Is it possible to come back to the collecting site and get BRT seednuts from open pollination? Yes, it would become possible to transfer BRT to other countries by developing skills for CHP technique in Brazil or by coming back to collection site for getting BRT seednuts,. Then the process (a, b, c, d, e) described in earlier paragraph will be applied to at least one BRT population. Negotiation within COGENT will designate the two receiving countries. It is expected for the international system to help Brazil genebank to improve its CHP method and to cover the cost of the required international transfers.

4. The Rennell Island Tall (RIT) is a very useful cultivar already well conserved in 15 countries. The international system will no longer fund RIT international transfers. Negotiation with COGENT will have to designate three RIT accessions in three countries which will be considered as part of the global coconut collection. This process will not only take into account the present international mandates. It will also take into consideration the real involvement of countries in international exchanges during the past 20 years, and their willingness to place RIT accessions under international mandate. Then, the international system is expected to cover part of the cost of conserving these three accessions. Of course, RIT will remain fully available for the other genebanks which want to acquire it. This acquisition process will be greatly facilitated by the existence of three accessions of RIT conserved preferably under international mandate by three distinct countries.

Annex 10. Estimated costs summary of the Global COGENT collection

Operation (as described in Annex 7)	Estimated No. of accessions	FN*	Cost per accession	FN*	Capital cost	FN*	Total cost	Periodicity
Acquisition	20	1	255	2	520	3	5,620	Annual
Field genebank	2,500	4	38	5	7,678	6	102,678	Annual
Characterization – morphological	200	7	21	8	800	9	5,000	Annual
Characterization – molecular	200	10	101	11	1,800	12	22,000	Annual
Regeneration	200	13	105	14	1,600	15	22,600	Annual
Health testing	200	16	292	17	9,200	18	67,600	Annual
Maintenance of *in vitro* collection	250	19	28	20	1,000	21	8,000	Annual
Introduction/ multiplication of accession *in vitro*	75	22	231	23	3,300	24	20,625	Annual
Maintenance of the cryopreserved accessions	300	25	18	26	1,200	27	6,600	Annual
Safety duplication (or security duplication)	300	31	25	32	1,500	33	9,000	Annual
Distribution	200	34	74	35	1,000	36	15,800	Annual
Identification of duplicates and integrity	200	43	155	44	10,200	45	41,200	Annual
Information management	2,500	37	15	38	2,500	39	40,000	
General management	2,500	40	8	41	2,500	42	22,500	Annual
Total			1366					Annual
	Total of annual costs						389,223	Annual
Introduction of accessions into cryopreservation	300	28	1,557	29	79,200	30	546,300	One-off
	Total of one-off costs						546,300	One-off

* Footnotes (FN) for the table

1 Estimated annual acquisition of new accessions

2 Average based on acquisition activities of Bioversity (banana), CIAT (cassava) CIP (Andean roots and tubers, potato and sweetpotato) and IITA (cassava) for a total of 631 accessions with total cost of 161,048 USD

3 Estimated at 26 USD per accession based on capital costs of CIP (Andean roots and tubers, potato and sweetpotato) and IITA (cassava) for a total of 631 accession with total cost of 16,323 USD

4 Estimated size of the CNCC

5 Average based on field genebank activities of CIP (Andean roots and tubers, potato and sweetpotato) and IITA (banana and cassava) for a total of 12,770 accessions with total cost of 483,718 USD

6 Estimated at 3 USD per accession based on capital costs of CIP (Andean roots and tubers, potato and sweetpotato) and IITA (banana and cassava) for a total of 12,770 accession with total cost of 39,221 USD

7 Estimated number of accessions to be introduced and/or regenerated every year

8 Average based on basic characterization activities of Bioversity (banana), CIAT (cassava), CIP (Andean roots and tubers) and IITA (yam) for a total of 5503 accessions with total cost of 114,259 USD

9 Estimated at 4 USD per accession based on capital costs of CIP (Andean roots and tubers) and IITA (cassava and yam) for a total of 3978 accession with total cost of 15,562 USD

10 Estimated number of priority accessions per year

11 Average based on molecular characterization activities of Bioversity (banana), CIAT (cassava), CIP (potato and sweetpotato) and IITA (cassava) for a total of 2608 accessions with total cost of 263,027 USD

12 Estimated at 9 USD per accession based capital on costs of CIP (potato and sweetpotato) and IITA (cassava) for a total of 2583 accession with total cost of 23,773 USD

13 Estimated number of accessions regenerated per year

14 Average based on regeneration activities of CIP (Andean roots and tubers) and IITA (yam) for a total of 1526 accessions with total cost of 159,761 USD

15 Estimated at 8 USD per accession based on capital costs of CIP (Andean roots and tubers) and IITA (cassava and yam) for a total of 1526 accessions with total cost of 11,692 USD

16 Estimated number of coconut accessions tested every year (for distribution, acquisition and regeneration)

17 Average based on activities of health testing (virus pre-indexing, indexing and therapy) of Bioversity (banana) for a total of 135 accessions with total cost of 39,450 USD

18 Estimated at 46 USD per accession based on capital costs of CIAT (cassava) for a total of 553 accessions with total cost of 25,663 USD

19 Estimated number of coconut accessions expected to be distributed from the CNCC every year

20 Average based on activities of maintaining accessions *in vitro* of CIAT (cassava), CIP (Andean roots and tubers, potato and sweetpotato) and IITA (banana and cassava) for a total of 21,257 accessions with total cost of 603,534 USD

21 Estimated at 4 USD per accession based on capital costs of CIP (Andean roots and tubers, potato and sweetpotato) and IITA (banana and cassava) for a total of 21,257 accessions with total cost of 74,116 USD

22 Estimated number of new coconut accessions requested for distributed from the CNCC every year

23 Average based on activities of introducing accessions *in vitro* of Bioversity (banana), CIP (Andean roots and tubers, potato and sweetpotato) and IITA (banana and cassava) for a total of 814 accessions with total cost of 188,342 USD

24 Estimated at 44 USD per accession based on capital costs of Bioversity (banana), CIP (Andean roots and tubers, potato and sweetpotato) and IITA (banana and cassava) for a total of 814 accessions with total cost of 35,723 USD

25 Estimated number of accessions to be maintained in cryopreservation

26 Average based on activities of maintenance of the cryopreserved accessions of Bioversity (banana) for a total of 800 accessions with total cost of 14,655 USD

27 Estimated at 4 USD per accession based on capital costs of Bioversity (banana) for a total of 800 accessions with total cost of 3442 USD

28 Estimated number of accessions to be introduced into cryopreservation

29 Average based on activities of introduction of accessions into cryopreservation of Bioversity (banana) for a total of 35 accessions with total cost of 54,495 USD

30 Estimated at 264 USD per accession based on capital costs of Bioversity (banana) a total of 35 accessions with total cost of 9250 USD

31 Estimated number of accessions for security duplication in a distant location (in addition to the accessions in cryopreservation).

32 Average based on activities of security duplication of CIAT (cassava), CIP (Andean roots and tubers,) and IITA (cassava and yam) for a total of 4141 accessions with total cost of 105,572 USD

33 Estimated at 5 USD per accession based on capital costs of Bioversity (banana), CIP (Andean roots and tubers, potato and sweetpotato) and IITA (banana and cassava) for a total of 4141 accessions with total cost of 19,447 USD

34 Estimated number of accessions distributed every year

35 Average based on activities of distribution of CIAT (cassava), CIP (Andean roots and tubers, potato and sweetpotato) and IITA (banana, cassava and yam) for a total of 4911 accessions with total cost of 361,274 USD

36 Estimated at 5 USD per accession based on capital costs of CIP (Andean roots and tubers, potato and sweetpotato) and IITA (banana, cassava and yam) for a total of 4911 accessions with total cost of 22,739 USD

37 Estimated number of accessions of the CNCC

38 Average based on activities of information management of Bioversity (banana), CIAT (cassava), CIP (Andean roots and tubers, potato and sweetpotato) and IITA (cassava) for a total of 27,742 accessions with total cost of 422,461 USD

39 Estimated at 1 USD per accession based on capital costs of Bioversity (banana), CIP (Andean roots and tubers, potato and sweetpotato) and IITA (cassava) for a total of 27,742 accessions with total cost of 39,633 USD

40 Estimated number of accessions of the CNCC

41 Average based on general management of collection of Bioversity (banana), CIAT (cassava), CIP (Andean roots and tubers and sweetpotato) and IITA (banana, cassava and yam) for a total of 43,707 accessions with total cost of 344,388 USD

42 Estimated at 1 USD per accession based on capital costs of Bioversity (banana), CIAT (cassava), CIP (Andean roots and tubers and sweetpotato) and IITA (banana, cassava and yam) for a total of 43,707 accessions with total cost of 39,940 USD

43 Estimated number of accessions verified for identification of duplicates and integrity

44 Average based on activities of identification of duplicates and integrity of CIAT (cassava) for a total of 233 accessions with total cost of 36,180 USD

45 Estimated at 51 USD per accession based on capital costs of CIAT (cassava) for a total of 233 accessions with total cost 11,795 USD

46 Estimated number of new germplasm collected annually

47 Estimated cost per sample of collecting based on pers. communication

48 Estimated cost of travel and equipment per year.

Annex 11. Useful web links

ACIAR	www.aciar.gov.au
Bioversity	www.bioversityinternational.org
CABI	www.cabi.org
COGENT	www.cogentnetwork.org
Caobisco	www.caobisco.eu
CATIE	www.catie.ac.cr/en
CBD	www.cbd.int
CEPICAFE	www.cepicafe.com.pe
CEPLAC	www.ceplac.gov.br
CFC	www.common-fund.org
CGIAR	www.cgiar.org
CIRAD	www.cirad.fr; http://www.cirad.fr/en/home-page
CNRA	www.cnra.ci
COPAL	www.copal-cpa.org
CPCRI	www.cpcri.gov.in
CPQP	www.idhsustainabletrade.com/CPQP
CRIN	www.crin-ng.org
CRU/UWI	www.sta.uwi.edu/cru
FAO	www.fao.org
FHIA	www.fhia.org.hn
GPA	www.fao.org/agriculture/crops/core-themes/theme/seeds-pgr/gpa
ICA	www.ica.gov.co
ICCO	www.icco.org
ICCRI	www.iccri.net
ICT	www.ict-peru.org
IDIAF	www.idiaf.gov.do
IDH	www.idhsustainabletrade.com
IICA	www.iica.int
IITA	www.iita.org
INGENIC	http://ingenic.cas.psu.edu
INIA	www.inia.gov.ve
IPPC	www.ippc.int
IRAD	www.iradcameroun.org
IT IS	www.itis.gov
ITPGRFA	www.planttreaty.org
MCB	www.koko.gov.my
Trust	www.croptrust.org
WIEWS	http://apps3.fao.org/wiews/wiews.jsp

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