Food and Agriculture Organization of the United Nations

Convention on Biological Diversity

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SPREP
Secretariat of the Pacific Regional Environment Programme

MAINSTREAMING ECOSYSTEM SERVICES AND BIODIVERSITY INTO AGRICULTURAL PRODUCTION AND MANAGEMENT IN THE PACIFIC ISLANDS

TECHNICAL GUIDANCE DOCUMENT

BIODIVERSITY & ECOSYSTEM SERVICES IN AGRICULTURAL PRODUCTION SYSTEMS

MAINSTREAMING ECOSYSTEM SERVICES AND BIODIVERSITY INTO AGRICULTURAL PRODUCTION AND MANAGEMENT IN THE PACIFIC ISLANDS

TECHNICAL GUIDANCE DOCUMENT

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
SECRETARIAT OF THE CONVENTION ON BIOLOGICAL DIVERSITY
SECRETARIAT OF THE PACIFIC REGIONAL ENVIRONMENT PROGRAMME
SECRETARIAT OF THE PACIFIC COMMUNITY

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FOREWORD

The international community is increasingly aware of the link between biodiversity and sustainable development and its direct impact on wealth, health and well-being. Biodiversity is the origin of all crops and domesticated livestock. It is also the source of vital ecosystem services and functions, including soil conservation, water cycling, pollination, pest and disease regulation, carbon sequestration and nitrogen fixation. Biodiversity and the ecosystem services it supports are thus key to nutritional diversity and to agricultural productivity and resilience. The Convention on Biological Diversity (CBD) Strategic Plan for Biodiversity 2011–2020 and its 20 Aichi Biodiversity Targets provide a framework for countries to develop national targets and policies for sustaining biodiversity for a healthy planet.

To meet rising global food demands, agricultural systems need to produce greater quantities of more diverse and nutritious food in a sustainable way. This progress can and must be achieved without driving biodiversity loss. It must come through gains in the efficiency of resource use, through sustainable intensification and a landscape perspective in agricultural production. By contributing to the conservation and sustainable use of biodiversity, agriculture will be a key driver for eliminating poverty, improving human health and providing energy, food and clean water for all while maintaining natural ecosystems.

Islands are particularly vulnerable to the consequences of biodiversity loss. The Pacific Islands include some of the most diverse and richest terrestrial and marine ecosystems on our planet, with a large number of endemic species. In this subregion, commercial and semi-commercial agriculture represents a significant activity. Unsustainable production systems, including, for example, excessive use of pesticides, are a source of concern, having direct and indirect impacts on wildlife populations and the ecosystems they depend on.

This document has been produced to assist Pacific Island countries in finding synergies in their policies for sustainable management of chemicals and biodiversity conservation and use. It will especially guide them in revising or implementing their National Biodiversity Strategies and Action Plans (NBSAPs) to help them meet the relevant Aichi Biodiversity Targets.

Reconciling the aims of agricultural production with those of biodiversity conservation requires coherent policies, the mainstreaming of biodiversity in agriculture and significant efforts to reduce greenhouse gas emissions and to achieve land degradation neutrality. This publication will help Pacific Island countries move in that direction, by helping them to implement the Strategic Plan for Biodiversity fully, in the context of the Sustainable Development Goals, to achieve human well-being in harmony with nature.

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FAO implemented the first phase of the project focusing on the elimination of obsolete pesticide stockpiles and capacity development for improved pesticide management. This second phase continues some of the pesticide-related activities addressed in Phase 1, but also includes activities related to additional MEAs, focusing on synergies between MEAs related to chemicals/waste and biodiversity, and their relevance and application within the agriculture sector. The Convention on Biological Diversity (CBD), the implementation of relevant Aichi Biodiversity Targets and the preparation and implementation of National Biodiversity Strategy and Action Plans (NBSAPs) are a key focus.

This document is the result of a fruitful partnership over many years among FAO, CBD, the Secretariat of the Pacific Regional Environment Programme (SPREP) and the Secretariat of the Pacific Community (SPC), geared towards promoting a sustainable ecosystem-based approach to agriculture in the Pacific Islands. The document was prepared through collaboration with experts on a range of topics related to ecosystem services management at technical, institutional and policy levels. The contributors are listed at the end of the publication. The publication was edited by Andrea Perlis, Francesca Mancini and David Colozza. Colleagues from regional partner organizations, in particular Easter Chu Shing-Galuvao (SPREP) and Fereti Atumurirava (SPC) greatly supported the production of the document.

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ACRONYMS

ACIAR Australian Centre for International Agricultural Research

ACSE Adapting to Climate Change and Sustainable Energy

BoA Bureau of Agriculture, Palau

Bt *Bacillus thuringiensis*

CBD Convention on Biological Diversity

COP Conference of the Parties

DSAP Development of Sustainable Agriculture in the Pacific

EIA environmental impact assessment

EU European Union

EWM ecological weed management

GDP gross domestic product

GEF Global Environment Facility

GIZ German Agency for International Cooperation

HHP highly hazardous pesticide

IES incentives for ecosystem services

IFOAM International Federation of Organic Agriculture Movements

IFAD International Fund for Agricultural Development

INTEGRE Pacific Territories Initiative for Regional Management of the Environment

IPM integrated pest management

IPPC International Plant Protection Convention

ITPGRFA International Treaty on Plant Genetic Resources for Food and Agriculture

IUCN International Union for Conservation of Nature

IWM integrated weed management

MA Millennium Ecosystem Assessment

MAL Ministry of Agriculture and Livestock, Solomon Islands

MEA multilateral environmental agreement

NASP National Agriculture Sector Plan

NBSAP National Biodiversity Strategies and Action Plan

NCSA National Capacity Self Assessment

NGO non-governmental organization

NISSAP National Invasive Species Strategy and Action Plan

PAPP Pacific Agriculture Policy Project

PES payment for ecosystem services

PGS participatory guarantee system

PICTs Pacific Island countries and territories

PIFON Pacific Island Farmers Organization Network

POETCom Pacific Organic and Ethical Trade Community

POP persistent organic pollutant

SDG Sustainable Development Goal

SIDS Small Island Developing States

SOM soil organic matter

SPC Secretariat of the Pacific Community

SPREP Secretariat of the Pacific Regional Environment Programme

TDA Tetepare Descendants Association

UNCED United Nations Conference on Environment and Development

UNDP United Nations Development Programme

USAID United States Agency for International Development

WIBDI Women in Business Development Inc.

Part I

Context

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1 INTRODUCTION

David Colozza, Francesca Mancini and Randy Thaman

The Pacific Islands subregion comprises the islands of Melanesia, Polynesia and Micronesia in the tropical Pacific Ocean and extends from Papua New Guinea and Palau in the far west to Kiribati, French Polynesia and Hawaii in the east. The subregion, where land makes up less than 2 percent of the total area, includes some of the richest and most diverse terrestrial and marine ecosystems on Earth. Ecosystems on the high continental and oceanic islands range from montane and cloud forests that harbour high levels of endemism to some of the most extensive mangrove forest and coral reefs on Earth, whereas the low-lying limestone islands and atolls have among the poorest terrestrial flora and fauna on Earth (Thaman, 2008a; SPREP, 2016a). The high species richness and high levels of endemism on the high islands are reflected by the presence of three of the 35 global biodiversity hotspots, whereas the low-lying islands and atolls are considered to be among the world's biodiversity cool spots. Pacific Island peoples in both the biodiversity hotspots and coolspots are strongly connected by longstanding spiritual and cultural traditions to their terrestrial, coastal and marine ecosystems and biodiversity, including their rich agricultural biodiversity.

Pacific Island countries and territories (PICTs) are clearly on the front line in the battle against the loss of biodiversity due to the impact of humans (Kolbert, 2014). A disproportionate number of all extinctions of plants and animals on Earth have historically occurred in this subregion, mainly as a result of human overexploitation, habitat degradation and invasive alien species. PICTs are also highly vulnerable to climate change; extreme weather and tidal events and other natural disasters; food dependency and nutrition-related non-communicable diseases; increasing import dependency; and the loss of ethnobiodiversity – the indigenous and local knowledge that Pacific peoples had regarding biodiversity (Thaman, 2009; UNEP, 2014).

While countries across the subregion and their economies are diverse, they all rely heavily on the agricultural sector, which is largely dependent on smallholder producers. Agriculture represents a major source of livelihood for the rural population and is vital to food, health and energy security; it is the fundamental basis along with wild terrestrial and marine foods for healthy diets and avoidance of obesity and other nutrition-related non-communicable diseases due to increased consumption of imported, highly processed and energy-dense food (FAO, 2016a). In addition, sustainable agricultural practices can assist crop adaptation to new environmental conditions and improve resilience through crop diversification (UN, 2014).

In most PICTs, especially on atolls and other small highly populated islands, at lower elevations and near urban areas where there is little or no remaining forest, the most well-known and useful biodiversity is found in tree-rich rural and urban agroforestry systems, which are the basis of the subregion's traditional agriculture. As the forests and wild lands are increasingly being replaced by intensive industrial farming, much of the biodiversity and ecosystem services traditionally provided by forest ecosystems is now delivered by agricultural land-use systems (Thaman, 2008a).

The Melanesian islands (including Fiji, Papua New Guinea, Solomon Islands and Vanuatu) are the largest in size in the subregion and account for 90 percent of the population and 85 percent of the total land mass. They are the best placed in terms of agricultural resources, having fertile soils that are able to support a wide variety of species. Agriculture across these islands is mostly subsistence oriented, but some production is also for export (e.g. sugar, copra, ginger, coconut oil and other products in Fiji). The Polynesian islands (including Tonga and Samoa) are not as large as the Melanesian islands, but they also have fertile soils and agricultural economies oriented to both local needs and the export of key cash crops such as squash, coconuts and other tropical crops. Islands in Micronesia are smaller. While some islands are specialized in growing cash crops for export, the economies of most of them rely mainly on other sectors (FAO, 2009a).

PICTs share common challenges in their smallholder farming systems. These include drought and lack of water for agriculture; salinity on atolls; irregular supply of seeds and other agricultural inputs; pests, diseases, weeds and invasive species; and natural disasters (SPC, 2016a). More recently, commercial farming has expanded, often coupled with logging, land clearing, forest conversion for plantation agriculture or monocultural cash-crop production and use of agrochemical inputs, resulting in severe localized impacts on water and soil resources as well as on nearshore coral reefs and coastal ecosystems. In addition, increased ease of transportation and international trade has led to a rise in a number of invasive alien species across the Pacific Islands, with severe impacts on endemic biodiversity as well as on key economic sectors such as agriculture, tourism, trade and human health (SPREP, 2016b).

These challenges to natural ecosystems represent an opportunity, however, for a shift in production paradigms, towards ecological management of agricultural production systems based on documented best practices, both science-based and building on indigenous local knowledge and methods. In this way agriculture, rather than being a threat to the environment, will become a key instrument in conserving or strengthening natural ecosystems and biodiversity bases, with production maintained or increased in a sustainable way.

Defining biodiversity, ecosystems and ecosystem services

In this document the term "biodiversity" refers to the diversity of natural and cultural ecosystems, including island types and different habitats and the species and genetic diversity within these island and ecosystems, as well as the ecosystem services that biodiversity delivers. The definition also includes "ethnobiodiversity" – the indigenous and local knowledge, uses, beliefs, management systems, taxonomies and language that both indigenous and local communities and modern scientists have regarding their islands, ecosystems, species and genetic diversity (Thaman, 2008b, 2013a). It is stressed that within PICTS, ethnobiodiversity must be seen as an integral part of the definition of biodiversity because traditional Pacific societies did not see their knowledge and cultural traditions as separate from their environment and plants and animals.

The Convention on Biological Diversity (CBD) considers agricultural biodiversity or biodiversity for food and agriculture – also referred to as agrobiodiversity – in a broad way, to include all components of biological diversity of relevance to food and agriculture and all components of biological diversity that constitute the agro-ecosystem (crops, pastoral systems, forest, fishery and aquaculture systems): "the variety and variability of animals, plants and microorganisms, at the genetic, species and ecosystem levels, which are necessary to sustain key functions of the agro-ecosystem, its structure and processes" (CBD, 2000). These functions and processes include nutrient cycling, pest and disease regulation, pollination and other ecosystem services. Agricultural biodiversity has been managed or influenced by farmers, pastoralists, forest dwellers and fisherfolk for hundreds of generations and reflects the diversity of both human activities and natural processes. Making use of this biodiversity and these ecological processes to enhance the productivity of agro-ecosystems is sometimes described as ecological intensification.[1]

The CBD defines an ecosystem as "a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit" (UN, 1992). The Millennium Ecosystem Assessment (MA, 2005) highlighted that humankind benefits in diverse ways from ecosystems. Collectively, these benefits are known as ecosystem services. Daily (1997) described ecosystem services as "the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life".

Different typologies of ecosystem services have been proposed. The most common includes the following categories.

» Regulating services are defined as the benefits obtained from the regulation of ecosystem processes such as climate regulation, natural hazard regulation, water purification and waste management, pollination and pest control.

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1 Ecological intensification is an approach to agricultural production that aims to match or increase yields while minimizing negative impacts on the environment and on agricultural productivity, by integrating the management of ecosystem services delivered by biodiversity into production systems (Bommarco, Kleijn and Potts, 2013).

» Supporting services are those that support the delivery of other services (such as soil formation and supplying habitat for species) which enable ecosystems to continue to supply provisioning and regulating services.
» Provisioning services refer to the goods and physical products obtained from ecosystems such as food, freshwater, wood, fibre, genetic resources and medicines.
» Cultural services include non-material benefits that people obtain from ecosystems such as spiritual enrichment, intellectual development, recreation and aesthetic values.

Ecosystem approaches to agriculture for conservation of agrobiodiversity and ecosystem services

Agrobiodiversity constitutes the most well-known, culturally useful and accessible type of biodiversity in most PICTs, and the main foundation for food, health, energy and livelihood security. In PICTS, ecosystem goods and services, conservation of biodiversity and adaptation to climate, environmental and economic change depend to a great extent on the conservation, restoration and enrichment of agrobiodiversity.

This rich agrobiodiversity heritage – including the indigenous and local knowledge on which its survival depends – is, however, threatened from increasing environmental, social and economic pressures coming from the farming sector. These pressures arise from the increasing pace of transition from traditional, biodiverse and integrated systems to more industrial paradigms of production, based on monocultures of a few, selected cash crops, overexploitation of existing agricultural land, uncontrolled clearing of forest land and increased use of, and dependency on, agrochemicals.

Ecosystem-based approaches to agricultural production and management, which build on – rather than deplete – natural ecosystem services and biodiversity, offer a viable option for sustainable growth of agricultural productivity. Examples of good agricultural practices that can decrease pressure on natural ecosystems and biodiversity include sustainable management of soils to increase their organic matter content (e.g. through composting, mulching or application of manure); and protection of pollinators and pest predators by planting flower strips and hedgerows on farms and in the landscape. Ecosystem-based approaches to agriculture such as agroforestry and agro-ecology also strengthen the resilience of production systems and landscapes to the adverse effects of climate change and are key components of adaptation strategies.

Sustaining healthy agro-ecosystems requires efforts at multiple spatial scales – on and around the farm, but also at the broader landscape level. In addition, it is important to take into account interactions among ecosystem services to fully harness their potential. An ecosystem perspective to farming recognizes that the regenerative aspects of agriculture occur on the level of the whole farming system, at the watershed, landscape or community level, with the traditional knowledge and experience of farmers and the empowerment of communities at its base.

Economic assessment of ecosystem services in agriculture

To sustain the provision of multiple ecosystem services from biodiversity, their value and contribution to agricultural production, livelihoods and food security must be reflected in policies and initiatives for managing agro-ecosystems (TEEB, 2010). The value of agricultural practices in enabling and sustaining ecosystem services must also be recognized, and assessment of this value will serve as a basis for supporting farmers in a transition towards more sustainable practices.

Economic valuation of natural resources and their use is an important tool to support policy- and decision-makers in promoting management and conservation of ecosystem services and biodiversity (Laurans *et al.*, 2013; Lal, 2003). Understanding the benefits of ecosystem services and the costs of their degradation and loss can provide clear arguments for their efficient and sustainable use. Valuation therefore provides a useful tool to justify better investment and policies for managing ecosystem services for, and from, agriculture. (For valuation methods, see e.g. Emerton and Bos, 2004; van Beukering *et al.*, 2007; for results from the Pacific, see MACBIO, n.d.).

For example, economic valuation of mangrove ecosystem services in Vanuatu (Pascal and Bulu, 2013) indicated that these ecosystems may contribute about US$8 500 per hectare per year. This value can provide a basis for regulations and policies affecting mangrove use and compensation for their damage or removal. The figure was obtained from a combination of valuation methods including:

- catch and consumption of fish from household surveys and market prices for fisheries;
- calculation of replacement cost for fuelwood, timber and medicinal uses;
- the cost of seawall construction as a proxy for the value of natural coastal protection;
- carbon production and market price for carbon sequestration;
- value transfer for the relative importance of subsistence versus commercial fisheries;
- the proportion of tourism spending that can be assigned to the presence of mangroves.

Through a similar set of studies, authorities in Rarotonga, Cook Islands, became aware that they could potentially avoid costs of 2 900 New Zealand dollars (NZD) per household per year (values from 2006, currently approximately US$2 000) if watershed pollution were prevented. The costs of pollution included healthcare and illness, upstream public water filters, bottled water business and lost tourism income (Hajkowicz and Okotai, 2006). The authors noted that effective management of watersheds to recover at least some part of these costs would require a combined government, industry and community response to address, among others, herbicide, pesticide and fertilizer runoff, livestock and animal waste contamination and soil erosion and stream sedimentation.

In the PICTs, where data may be insufficient and understanding of the complex relationship between biodiversity, ecosystem services and human welfare may be poor, it is important to implement valuation methods that are context specific and accessible for those involved.

Further, cultural values should be incorporated into any valuation, in light of the extensive traditional ecological knowledge within the region (Christie *et al.,* 2012). Understanding the social, economic and ecological value of ecosystem services and biodiversity can guide policy- and decision-makers to work with communities to provide sufficient incentives to support the transition to more sustainable practices and the integration of these biodiversity values into cross-sectoral policies.

About this guidance document

Policies targeting the mainstreaming of ecosystem approaches in agriculture need to look beyond a single sector. They must bring together varied stakeholders from areas such as environment, health, planning and agriculture, and they must embrace multiple spatial perspectives (local, subnational, national, regional and international).

This guidance document is produced to assist PICTs in finding synergies between two important realms of policies and conventions: sustainable management of chemicals and biodiversity conservation and use. The document draws upon work that has been carried out with a similar scope in Kenya and other countries of the East African Community. It focuses specifically on the context and national policy processes of PICTs where commercial and semi-commercial agriculture represents a significant activity and the excessive use of agrochemicals is a source of concern.

The document will be useful to countries revising any of their strategies or policies related to the two realms, but in particular it is oriented towards assisting revision or implementation of their National Biodiversity Strategies and Action Plans (NBSAPs) to help attain a number of relevant Aichi Biodiversity Targets (see Chapter 2). It is intended to indicate where important synergies can be harvested, but it is not meant to be prescriptive.

This guidance document primarily considers the regulatory services and how they may be promoted and enhanced to support more sustainable production (provisioning services) and reduce externalities detrimental to biodiversity by reducing reliance on chemical inputs. Other services, however, such as the cultural values of agriculture and related indigenous knowledge systems, are also important in supporting efforts towards an improved ecological foundation of agriculture.

Chapter 2 introduces the international framework for chemical management and biodiversity conservation. Part II then addresses a number of technical aspects related to mainstreaming ecosystem services and biodiversity management in agricultural production in the Pacific Islands, with the objective of reducing the use of agrochemicals and increasing overall sustainability of farming systems across the subregion. It covers the key challenges to sustainable agricultural production in the subregion – the role of ecosystem services and biodiversity in relation to soil fertility, biological pest control, ecological weed management, management of invasive alien species, integrated farming systems, organic agriculture and ecotourism – and examples of the types of production systems and best practices that are best placed to preserve and enhance agrobiodiversity and ecosystem services.

Part III looks at the policy context. In particular, it identifies relevant entry points for policy instruments that stakeholders across the subregion can use to achieve the final goal of mainstreaming an ecosystem approach in agricultural production and management. This section especially looks into NBSAPs as policy instruments that are ideally placed for achieving this goal, considering their scope and their cross-sectoral and “living” nature. Case studies from the subregion explore issues related to the use of incentives for ecosystem services as a mechanism for funding best ecosystem management practices.

2
INTERNATIONAL FRAMEWORKS SUPPORTING ECOSYSTEM SERVICES IN AND FOR AGRICULTURE

Monica Kobayashi and Francesca Mancini

Multilateral environmental agreements (MEAs) are the main instruments available under international law for countries to work together on specific global environmental issues. MEAs are agreements between States that include obligations which may vary from adherence to general principles about a particular environmental issue to definitive actions to be taken to achieve an environmental objective. Through the ratification of international conventions, governments accept obligations to incorporate them into national policies. When these obligations require changes in behaviour, they are generally incorporated into domestic policies and laws.

Conventions on chemical management

Pesticide use is likely to rise under intensification of agricultural production as well as with global warming, which many studies have concluded will increase the abundance of insect pests and diseases.

Since their introduction into agriculture, pesticides have generally been used inefficiently. Prophylactic applications of broad-spectrum pesticides suppress natural pest control mechanisms and exacerbate pest problems, resulting in additional chemical applications. Health issues are widely associated with intensive pesticide use, especially in developing countries, and concern applicators, farmers, field workers and consumers. Contamination of drinking water, river systems and aquifers with pesticides poses a particular concern for its adverse effects on human health and the environment.

The effects of pesticides on wildlife and biodiversity are both direct, through exposure, and indirect, through reduction in food availability and loss of natural and semi-natural habitats, including the habitat of some pollinators and other insects relevant to pest control (IPBES, 2016). Pesticide use has caused losses in the regional biodiversity of aquatic insects and other freshwater invertebrates in Europe and Australia (Beketov *et al.*, 2013). It has also reduced global populations of insects (van Lexmond *et al.*, 2015) and insectivorous birds (Hallmann *et al.*, 2014). Studies have shown that certain systemic insecticides (some neonicotinoids) can trigger the collapse of bee colonies, thus reducing their function as pollinators (Lu, Warchol and Callahan, 2014). Widespread and continued herbicide application eliminates plant species in fields and bordering areas that provide food and shelter to beneficial insects, spiders and birds. Unfortunately, the current ecological risk assessment of pesticides, even in the most resourceful countries, seems to fall short of protecting biodiversity, and new approaches linking ecology and ecotoxicology are needed.

It is today widely recognized that the role of pesticides has to be seen in the broader context of sustainable pest management. Integrated approaches to crop management, such as integrated pest management (IPM), are emphasized. Within an IPM context, natural biological control mechanisms are enhanced to reduce reliance on pesticides. Only IPM-compatible pesticides are applied as supplementary control measures based on actual field conditions (FAO, 2010).

Three international conventions on chemical management, the Basel, Rotterdam and Stockholm (BRS) Conventions (Box 1), have an important role in improving the management of hazardous chemicals and minimizing the risks associated with them.

Box 1. **BRS Conventions**

The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal aims to reduce hazardous waste generation and promote environmentally sound management of hazardous wastes; to restrict transboundary movement of hazardous wastes except where it is perceived to be in accordance with the principles of environmentally sound management; and to regulate transboundary movements in those cases where they are permissible.

The Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade covers international trade in hazardous chemicals (mostly pesticides) with the aim of protecting human health and the environment. If all parties agree that a specific pesticide constitutes a severe health or environmental hazard it can be listed for prior informed consent procedures, which require exporting countries of these chemicals to prevent export to those countries that do not wish to receive them any more and to notify importing authorities on data of known hazards. As of October 2016 the convention lists 33 pesticides.

The Stockholm Convention on Persistent Organic Pollutants aims to eliminate or restrict the production and use of persistent organic pollutants (POPs), some of which are pesticides. Based on a specified review process, pesticides that fulfil the criteria for POPs can be listed for elimination or restriction.

Convention on Biological Diversity

The CBD is a key instrument for sustainable development, with three objectives: the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising from the use of genetic resources. The CBD addresses a number of overarching as well as thematic and cross-cutting areas on biodiversity which are important for food and agriculture. For the purposes of this guidance document, two are of particular relevance: the Programme of Work on Agricultural Biodiversity, and the Strategic Plan for Biodiversity 2011–2020 and its Aichi Biodiversity Targets.

Programme of Work on Agricultural Biodiversity

The Conference of the Parties (COP) to the CBD established the Programme of Work on Agricultural Biodiversity in 1996 (CBD, 1996) and subsequently adopted a Plan of Action for it, centring on four elements: assessment, adaptive management, capacity building and mainstreaming (CBD, 2000). The Programme of Work on Agricultural Biodiversity includes three international initiatives, on pollinators, soil biodiversity and food and nutrition.

Strategic Plan for Biodiversity 2011–2020, including the Aichi Biodiversity Targets

Global Biodiversity Outlook 3 (CBD, 2010a) reported that the target agreed by the world's governments in 2002 – "to achieve by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national level as a contribution to poverty alleviation and to the benefit of all life on Earth" – had not been met, and spelled out the need to address the drivers and pressures of biodiversity loss as a complement to biodiversity policies that focus on conservation and protection measures. Therefore, the Strategic Plan for Biodiversity 2011–2020, adopted in 2010 by the Parties to the CBD (CBD, 2010b), emphasizes addressing causes and reducing pressures.

The Strategic Plan for Biodiversity comprises a shared vision, a mission, strategic goals and 20 ambitious targets, collectively known as the Aichi Biodiversity Targets. The Strategic Plan serves as a flexible framework for the establishment of national and regional targets and promotes the coherent and effective implementation of the three objectives of the CBD. This plan provides an overarching framework on biodiversity, not only for the biodiversity-related conventions, but for the entire United Nations system and all other partners engaged in biodiversity management and associated policy development. The Strategic Plan has been recognized as a common platform for action among a number of biodiversity-related MEAs, the United Nations General Assembly and other stakeholders.

The fourth edition of *Global Biodiversity Outlook* (CBD, 2014a) reviewed midterm progress towards achievement of the Strategic Plan for Biodiversity 2011–2020. It concluded that significant progress had been made towards meeting some components of most of the Aichi Biodiversity

Targets, but that in most cases this progress was not sufficient to achieve the targets set for 2020, and additional action is required to keep the Strategic Plan for Biodiversity 2011–2020 on course. Further, it concluded that under a business-as-usual scenario, the projected losses of terrestrial and freshwater biodiversity by 2050 would be driven to a large extent by escalating pressures from food systems and agricultural expansion. Achieving sustainability in food systems and agriculture will thus be an important pathway for halting the loss of biodiversity.

The Strategic Plan for Biodiversity 2011–2010 and the Aichi Biodiversity Targets explicitly consider ecosystem services. The rationale is that biological diversity underpins ecosystem functioning and the provision of ecosystem services, contributing to human well-being by supporting, for example, food security, human health, local livelihoods, economic development and poverty reduction. As a recognized overarching framework on biodiversity for all stakeholders, the Strategic Plan is intended to apply not only to environmental goals and institutions, but also to other sectors, including agriculture (CBD, 2014b).

A number of the Aichi Biodiversity Targets are directly relevant to agricultural biodiversity, including those addressing sustainable production and consumption, sustainable agriculture, aquaculture and forestry, pollution, invasive alien species, genetic diversity and ecosystem services (Box 2). Most of the other Aichi Biodiversity Targets are indirectly linked to agricultural biodiversity either because they address issues related to the sustainability of agriculture or because they address the pressures on biodiversity generated in part by agricultural activities. However, few agricultural stakeholders are directly involved in the implementation of the CBD, although many might be undertaking some measures consistent in practice with the CBD. In this context, National Biodiversity Strategies and Action Plans offer a major opportunity for mainstreaming biodiversity and ecosystem services into the agricultural sector.

Box 2. **Aichi Biodiversity Targets relevant to agriculture and biodiversity**

Each of the 20 Aichi Biodiversity Targets, in some way and to some extent, can be relevant to the agriculture sector, but the following are the most pertinent:

» **Target 4:** By 2020, at the latest, governments, business and stakeholders at all levels have taken steps to achieve or have implemented plans for sustainable production and consumption and have kept the impacts of use of natural resources well within safe ecological limits.

» **Target 7:** By 2020 areas under agriculture, aquaculture and forestry are managed sustainably, ensuring conservation of biodiversity.

» **Target 8:** By 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity.

» **Target 9:** By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment.

CONTINUES →

- **Target 13:** By 2020, the genetic diversity of cultivated plants and farmed and domesticated animals and of wild relatives, including other socio-economically as well as culturally valuable species, is maintained, and strategies have been developed and implemented for minimizing genetic erosion and safeguarding their genetic diversity.
- **Target 14:** By 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods, and well-being, are restored and safeguarded, taking into account the needs of women, indigenous and local communities, and the poor and vulnerable.

National Biodiversity Strategies and Action Plans

NBSAPs are the principal instruments for implementing the CBD at the national level, as stated in Article 6 and supported by Article 10(a), which calls for integrating consideration of the conservation and sustainable use of biological resources into national decision-making. Under the CBD, countries have an obligation to develop an NBSAP and to ensure that this strategy is mainstreamed into the planning and activities of all sectors whose activities can have impact (positive and negative) on biodiversity. More specifically, Article 6 calls for countries to: "(a) develop national strategies, plans or programmes for the conservation and sustainable use of biological diversity or adapt for this purpose existing strategies, plans or programmes…; and (b) integrate, as far as possible and as appropriate, the conservation and sustainable use of biological diversity into relevant sectoral or cross-sectoral plans, programmes and policies".

National Biodiversity Strategies are meant to reflect how a country intends to fulfil the objectives of the CBD in light of specific national circumstances, and the related Action Plans constitute the sequence of steps to be taken to meet these goals. Currently, however, major challenges remain, and there is a need to enhance national capacity for implementation.

The main COP decisions that provide direct guidance for NBSAPs are Decisions IX/8 (CBD, 2008) and X/2 (CBD, 2010b). Parties are encouraged to review these decisions for consolidated guidance on the NBSAP process, substance, components, support systems and monitoring and review systems. In Decision X/2, the COP calls on countries to:

- develop national and regional targets, using the Strategic Plan for Biodiversity 2011–2020 and its Aichi Biodiversity Targets as a flexible framework;
- review, revise and update NBSAPs in line with the Strategic Plan;
- integrate national targets into revised and updated NBSAPs, adopted as a policy instrument;
- use revised and updated NBSAPs as effective instruments for integrating biodiversity targets into national development and poverty reduction policies and strategies, national accounting as appropriate, economic sectors and spatial planning processes, by government and the private sector at all levels;
- monitor and review NBSAP implementation in accordance with the Strategic Plan and national targets, making use of the set of indicators developed for the Strategic Plan as a flexible framework;

» support the updating of NBSAPs as effective instruments to promote the implementation of the Strategic Plan and mainstreaming of biodiversity at the national level, taking into account synergies among the biodiversity-related conventions in a manner consistent with their respective mandates.

To this effect, the CBD provides comprehensive information and guidance on NBSAPs (CBD, 2016a). Furthermore, other COP decisions provide guidance on specific issues. For example, on agricultural biodiversity, Decision X/34, Paragraph 7 "Invites Parties to incorporate, as appropriate, relevant elements of the programme of work on agricultural biodiversity into their National Biodiversity Strategy and Action Plans as well as into their relevant sectoral and inter-sectoral policies and plans" (CBD, 2010b). Parties are in various stages of revising their NBSAPs in accordance with Decision X/2. This guidance document is therefore designed to inform the revision of an NBSAP and/or to support implementation of an existing NBSAP in relevant policy areas.

Agricultural instruments

The international agricultural treaties most relevant to the intersection of agriculture, biodiversity, ecosystem services and chemical management include, but are not limited to:

» the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA);
» the International Plant Protection Convention (IPPC);

The objectives of ITPGRFA are the conservation and sustainable use of all plant genetic resources for food and agriculture and the fair and equitable sharing of the benefits arising from their use, in harmony with the CBD, for sustainable agriculture and food security. The IPPC is an international treaty that aims to secure coordinated, effective action to prevent and to control the introduction and spread of pests of plants and plant products.

In addition, Global Plans of Action on animals, plants and forest genetic resources for food and agriculture (FAO 2007a, 2011, 2014a) were adopted by the relevant governing bodies of FAO to create an efficient system for the conservation and sustainable use of genetic resources for food and agriculture. These Global Plans of Action are intended as comprehensive frameworks to guide and catalyse action at the community, national, regional and international levels through better cooperation, coordination and planning and by strengthening capacities.

Sustainable Development Goals

The 2030 Agenda for Sustainable Development (UN, 2015) sets out 17 Sustainable Development Goals (SDGs) and 169 associated global targets, which take into account different national realities, capacities and levels of development and respect national policies and priorities. In adopting this agenda, countries made a commitment to adopt policies, among others, for increased productive capacities and sustainable agriculture. Each government is at liberty to set its own national targets, guided by the global level of ambition but taking into account national circumstances; and each government will also decide how the aspirational and global targets should be incorporated into national planning processes, policies and strategies.

While the goals and targets are integrated and indivisible, several in particular could guide and support the formulation of policy measures that promote integration of ecosystem services and biodiversity with agriculture and minimizing the use of agrochemicals (Box 3).

Box 3. Key Sustainable Development Goals and targets supporting integration of ecosystem services and biodiversity with agriculture

Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture.

- **Target 2.4:** By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality.
- **Target 2.5:** By 2020, maintain the genetic diversity of seeds, cultivated plants and farmed and domesticated animals and their related wild species, including through soundly managed and diversified seed and plant banks at the national, regional and international levels, and promote access to and fair and equitable sharing of benefits arising from the utilization of genetic resources and associated traditional knowledge, as internationally agreed.

Goal 3. Ensure healthy lives and promote wellbeing for all at all ages.

- **Target 3.9:** By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination.

Goal 12. Ensure sustainable consumption and production patterns.

- **Target 12.4:** By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment.

Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

- **Target 15.9:** By 2020, integrate ecosystem and biodiversity values into national and local planning, development processes, poverty reduction strategies and accounts.

Biodiversity mainstreaming in the 2030 Agenda for Sustainable Development and other international strategies and agreements

Achieving food security is a complex global challenge, and food security and biodiversity conservation should be seen as mutually supportive objectives. It is broadly agreed that biodiversity is essential not only for food production, but also for increasing resilience and nutritional diversity in diets, achieving food security, ending hunger and addressing disease and premature mortality in the Pacific Islands, including through traditional medicinal plant diversity. The Strategic Plan for Biodiversity 2011–2020, the 2030 Agenda for Sustainable Development and its 17 SDGs, the FAO Strategic Objectives and the Paris Agreement on Climate Change all recognize in some way that food and nutritional security and biodiversity cannot be dissociated. Each calls for a coherent and integrated approach for increasing productivity through ecological intensification and achieving sustainability across agricultural and food systems.

To be effective, this integrated approach must be applied to policies, plans and actions at all levels that lead to maintaining ecosystem functions and services. These initiatives should also lead to the sustainable use of resources and to a reduction of the pressures on biodiversity and ecosystem services caused by current agricultural practices. Therefore, increasing cooperation between biodiversity and agriculture is critical to achieving both the SDGs and the Aichi Biodiversity Targets. Along these lines, the thirteenth meeting of the COP (December 2016) aims to promote actions to support the implementation of the Strategic Plan 2011–2020 and the Aichi Biodiversity Targets through a central theme: the integration of the conservation and sustainable use of biodiversity in the plans, programmes and sectoral and intersectoral policies, with emphasis on the agriculture, forestry, fisheries and tourism sectors.

Part II

Agrobiodiversity and ecosystem services in the Pacific Islands

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3
ORGANIC FARMING SYSTEMS

Robert Bishop

Organic farming systems favour agricultural production and management practices that are beneficial to natural ecosystems over the use of chemical inputs which might be unavailable and can have adverse effects. Organic farming systems build on and enhance ecological processes, biodiversity and natural cycles attuned and/or adapted to local conditions (Box 4). These systems are highly integrated and recognize soil health as the basis for healthy plants, animals and people (Box 5). Organic agriculture combines traditional knowledge and science to benefit the shared environment and synergistic relationships that sustain the health of plants, soils, water, air, ecosystems, cultures and people. It represents a valid tool for halting and reversing biodiversity loss because it secures environmental conservation through the use of agro-ecological methods of production. Land managed in this way can host up to 30 percent more species of all kinds and 50 percent more individuals of the species relative to land in non-organic farms, and provides more semi-natural habitats (POETCom, 2015).

Box 4. **Certified organic agriculture in the Pacific Islands**

Organic agriculture in the Pacific Islands is much more than the substitution of agrochemicals. It is a system that encourages a respectful relationship with the land, crops, livestock, farmhands, micro-organisms in the soil, ecosystems, patrons, the community and its cultural values. Organic agriculture is a holistic production, distribution and value system with the following guiding principles.

- Health: Organic agriculture sustains and enhances health.
- Ecology: Organic agriculture is based on and builds on living ecological systems.
- Fairness: Organic agriculture fosters relationships that ensure fairness.
- Care: Organic agriculture is managed in a precautionary and responsible manner with an ethos of sharing.
- Culture and traditions: Organic agriculture recognizes the value of and validates traditional agriculture and Pacific cultures.

These principles demonstrate a natural fit between organic principles and Pacific cultural philosophies (POETCom, 2012).

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In the Pacific Islands, organic production is both traditional and new. It is traditional in the sense that most producers to this day use tried and tested practices handed down from generation to generation that are generally in harmony with the environment and with modern organic principles. It is new in that PICTs are starting to recognize the benefits of certification for obtaining access to markets and the need for research and training to develop the sector and generate much-needed livelihood benefits. More importantly, organic management is bringing new knowledge to increase the resilience of farming systems and increase the quality of produce for international markets.

Organic agriculture is practised in most PICTs. In 2014, the Pacific Islands had four approved organic participatory guarantee systems, 74 organic certification licensees, 19 000 certified growers and 70 000 ha under organic production. In 2015, the subregion had more than 40 types of organic inputs available; 42 demonstration farms established; 1 766 farmers trained and 72 training courses and resources (POETCom, 2015). Organic agriculture is now poised to be a great resource for building social and natural capital across the Pacific Islands.

Box 5. Integrated farming systems for sustainability, resilience and ecosystem services

Integration is the action of striving to make a farm system whole by bringing all elements together, as distinguished from intensification, which is the action of increasing productivity per unit of land of the farm system by greater employment of “improved” or “smart” techniques, capital and/or labour. Intensification strains the system, particularly where there is a small resource base, which is the situation of many family farms in the Pacific Islands. Since most family farms in the subregion are multipurpose, intensification is a mismatch, as it concentrates resources in land productivity at the expense of other purposes. Intensification of agricultural production is usually achieved through specialization, involving large-scale production of single crop species and/or varieties (monoculture) and intensive animal (livestock) farming. It is increasingly evident that the ecosystem services provided by monoculture systems are greatly insufficient to compensate for the heavy costs of inputs and their pollution damage to the ecosystem (SPC, 2008).

The simplest type of integrated system consists of synergistic crop associations commonly referred to as a mixed cropping system. When this basic system is improved by the incorporation of trees and other perennials it is referred to as an agroforestry system. When an agroforestry system is improved by the incorporation of livestock, it is referred to as a tree–crop–livestock system or agrosilvipastoral system. Similarly, when a mixed cropping system is improved by the incorporation of aquaculture it is referred as an aquaculture–crop–livestock system. This system may be further improved by the incorporation of trees, which results in a tree–aquaculture–crop–livestock system. The more elements are integrated in the basic system, the more sustaining, sustainable, resilient and viable the system becomes, and the more ecosystem services are provided.

Organic farming practices

Organic farming systems rely on a wide range of techniques and methods that share the common aim of maintaining or increasing the quantity and quality of production while maximizing conservation of the natural environment and human health benefits. Although this chapter cannot cover the whole suite of management practices available, the following are some key elements.

» **Using manure, compost or other organic materials (including biological fertilizers) to preserve and enhance soil resources.** Benefits from employing these practices include reduced environmental pollution caused by synthetic fertilizers; recycling of organic waste (i.e. on-farm production of biological fertilizers); positive externalities from increased quality of soils, including improved soil structure – which allows for better retention of water and higher capture of noxious compounds – and increased soil organic matter, which increases the quantity of nutrients available to crops and the amount and types of soil biodiversity (Photo 1).

» **Providing habitat for beneficial insect species, for example by planting wildflower strips, establishing hedgerows on and around farmland and planting relevant crop and tree species.** Such interventions can be employed at both the farm and landscape scales to help conserve pollinator species and natural enemies of pests that are present in the area.

» **Pest management practices that do not entail the use of chemicals, such as cover crops, crop rotation and push-pull methods.** Ecological management strategies for pests and weeds avoid reliance on agrochemicals.

Photo 1. *A Niue organic farmer at his farm planted with mucuna (*Mucuna pruriens*), used in the Pacific Islands as a cover crop to improve soil health through nitrogen fixation, regulate weeds, improve moisture retention and prevent soil erosion and damage (e.g. by reducing the impact of rainwater)*

- **Optimizing interactions between herbivores and perennials.** Ensuring the sustainability of livestock systems is key to maintaining landscapes, the biodiversity of species and ecosystems and the provision of healthy livestock-derived foods.
- **Diversifying farming system components and species.** Diversification not only presents a useful economic buffer against the failure of individual crops, but also assists the natural environment, both directly (e.g. by increasing habitat opportunities for native species, improving soil resources, supporting water retention) and indirectly (by offering farmers alternatives to chemical-based management of soil fertility, pests and weeds).

Socio-economic benefits of organic farming systems in the Pacific Islands

Organic agriculture benefits the broader socio-economic systems in the Pacific Islands in the following ways.

- It represents a more climate-friendly agricultural paradigm, beginning with an increase in soil carbon through green manuring, mulching and wise temporal and spatial plant–animal associations. The use of natural inputs and management techniques that boost resilience to local conditions leads to increased conservation of soil, water and forest resources, in turn leading to increased soil organic matter, prevention of soil erosion and enhanced soil moisture and water percolation.
- It supports food security and human health by increasing the availability of safe and nutritious food. Reduced use of agrochemicals limits the risk of non-communicable diseases related to the cumulative effect of chemical residues in food while protecting the rural population from pesticide spray hazards. In addition, diversification and the use of adapted local varieties (necessary to prevent pests and diseases) and the use of non-synthetic inputs result in enhanced nutrient and energy flows and more diverse diets. Organically grown crops and pasture-raised animals have been demonstrated to have increased micronutrient contents, such as more vitamin A in plants and more omega-3 fatty acids in meat, milk and eggs (Benbrook, 2009; Benbrook *et al.*, 2013).
- When integrated production is linked to the market, it not only provides a means of livelihood generation for smallholder farmers, but also supports spillover benefits in other sectors of the local economy (e.g. the processing, packaging and distributing industries, further along in the food chain). It can help reduce the share of imported food produce and is in net contrast with export-oriented, monoculture-based agriculture, which exploits local resources while generating income that often benefits a few, often outside the country of production.
- It preserves indigenous local knowledge and culinary culture by supporting integration of traditional practices in the production system, conservation of local varieties and the production of traditional food produce.

Ecosystem services of organic farming systems

If managed through an ecosystem-based, sustainable approach, organic farming systems can provide a wide array of agro-ecosystem services benefitting local communities and the environment (Table 1).

Regulating services

The high degree of diversification in organic farming systems results in a high capacity for controlling pests and invasive species and in reduced risks for individual crops. The combined growing of diverse crop and tree species also contributes to regulation of broader processes such as soil formation, soil carbon sequestration and water filtration and purification. Organically managed systems incorporate by-products from agricultural production, effectively recycling waste and biomass.

Supporting services

Organic farming systems support the conservation of pollinator species which are key to agricultural production. They enhance soil organic matter content (through practices such as composting, mulching [Photo 2] and on-farm recycling of organic waste) and consequently below-ground biodiversity. Diversified systems, especially those that include animal and tree species, can also favour increased plant root development and hence nutrient uptake and soil carbon sequestration. In particular, managed grazing significantly enhances biodiversity in pastures (Jordan, Müller and Oudes, 2009).

Table 1. **Ecosystem services from organic agricultural systems**

ECOSYSTEM SERVICE TYPE	ROLE OF ORGANIC FARMING SYSTEMS
Regulating	> Pest and invasive species control > Reduction of risks to crops through diversification of production > Carbon sequestration and air purification through growing of crop and tree species > Increased resilience to extreme climate events (e.g. droughts, floods, wind) > Recycling of agricultural residues > Detoxification/purification/filtration and regulation of water resources
Supporting	> Conservation and enhancement of key pollinator species > Conservation and enhancement of soil organic matter and soil micro-organisms > Enhanced uptake of nutrients by crops through inclusion of trees and animals
Provisioning	> Production of food, organic matter/manure, timber, plant materials for traditional remedies
Cultural	> Preservation of aesthetic values > Spiritual enrichment > Historical preservation > Preservation of and support to traditional local practices

Photo 2. *Thick mulch around papaya, Marshall Islands*

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Provisioning services

Organically managed systems offer the opportunity to increase not only the quantity but also the quality of food produce, in terms of nutritional value and absence of agrochemicals (Lairon, 2009). Where these systems include trees (agroforestry), additional benefits come from the provision of forest products such as timber and fuelwood. Plant and tree crops and livestock are also a vital source of organic matter (manure and green manure) that can be recycled within the farm system, reducing both environmental impacts from agrochemicals and costs to farmers. The overall resilience of the system reduces land users' risk of crop failure and damage from extreme climatic events. Finally, diversification supports the provision of a variety of traditional remedies and medicines prepared using plant and tree products.

Cultural services

A number of cultural services are linked to organic farming systems. A diversified and organically managed agricultural landscape best conserves the aesthetic values of the natural environment, in turn offering possibilities for spiritual enrichment, inspiration and reflection. A well preserved landscape also facilitates the preservation of historical sites and local traditions and practices, which are often deeply embedded in the local environment.

Challenges for enhancing ecosystem services from organic farming systems

A number of systemic constraints hinder the mainstreaming of organic agricultural practices, making it difficult to increase their share in agricultural production and keeping conventional agriculture the most widespread agricultural paradigm at the global level.

Conventional agriculture receives the largest share of subsidies and funding for research and development. The ease of access to subsidies has historically led to externalization of the environmental and socio-economic costs of production, usually at the expense of the natural environment and of other land users. These costs include pollution of air, soil and water resources from agrochemicals and the loss of locally important biodiversity (in both agricultural and environmental terms) from plantation-based agriculture. Smallholder producers are particularly affected, because they often lack the means and/or knowledge to respond to the changed balance in the natural resource base associated with increased used of external inputs.

Among the main challenges is the need to restructure extension systems for the shift away from conventional agriculture to ensure high productivity and quality of produce from organic farming. Agricultural extension services traditionally tend to follow conventional agriculture, as it relies more on distribution and application of external inputs than on increasing the level of technical knowledge. Conventional agriculture has articulate, vocal, influential, resourceful and well-connected champions including supranational corporations, international and regional bodies and national governments. On the other hand, champions of organic agriculture in the Pacific Islands are relatively sparse; except for a few notable examples (e.g. the Pacific Organic and Ethical Trade Community [POETCom] and the Pacific Island Farmers Organization Network [PIFON]), farmer associations are non-existent, struggling and/or in need of strengthening (Damiani, 2002).

In the Pacific Islands, commercialization and increased production are priorities and precede efforts to establish farmers' markets (Bishop and Fakava, 2015). The results of projects in Palau indicate that:

» efforts to improve production and marketing will need to go hand in hand to have lasting impact;
» reversing the equation, i.e. using marketing to guide production, or in other words using demand to drive supply, would be more resource wise;
» for most family farms, which are multipurpose and do not have profit as their primary purpose, commercialization with a focus primarily on profit is a poor fit.

Examples of current policy instruments supporting organic agriculture across the Pacific Islands

Policy instruments, both at the national and subregional levels, offer an excellent entry point for overcoming the challenges described above, so as to improve environmental sustainability and offer additional livelihood opportunities for producers, and smallholders in particular.

Cross-sectoral coordination in policy action is essential, as food production (whether conventional or ecological/organic), involves a broad range of actors, and efforts to change the course of the current paradigm must involve all stakeholders in the food chain. Existing initiatives specifically relating to the mainstreaming of organic agriculture at the national, subregional and international levels can help in identifying policy examples for uptake in NBSAPs and other national and regional agricultural and/or environmental policies.

Subregional policies and programmes

POETCom (Box 6) developed the Pacific Organic Standard, working in a multistakeholder partnership with government agencies, the private sector and the International Federation of Organic Agriculture Movements (IFOAM), with the assistance and support of the Secretariat of the Pacific Community (SPC) and funding from the International Fund for Agricultural Development (IFAD). This regional standard is the first organic standard that includes culture and climate change considerations. It covers organic production and processing and is tailored to the unique social, cultural, environmental and agricultural conditions of PICTs.

In the framework of the SPC Pacific Agriculture Policy Project (PAPP), with funding from the European Union (EU) and in collaboration with IFOAM, POETCom has developed the Toolkit for Developing Supportive Organic Policy. This toolkit is now being used as a model for developing an international toolkit (SPC, 2016b). Cook Islands, the Federated States of Micronesia, Fiji, Samoa, Solomon Islands and Vanuatu have requested to use it.

Organic agriculture is also included in the agricultural sector policy documents (or their nearest equivalent) of 12 of 14 PICTs (PAFPNet, 2016).

National policies and programmes

As discussed above, conventional agricultural production externalizes the environmental costs of production. This has made it possible to offer conventionally produced foodstuffs at below-market prices. It is difficult if not impossible to produce organic produce at a cost that is lower, equal to or only slightly above the cost of equivalent conventionally produced or imported foods. While organics are in some cases a niche market that may yield higher profits to farmers, organic certification costs are beyond most smallholder farmers.

A number of governments across the islands have initiatives in place to enable organics to compete better on non-price attributes such as freshness, taste and other quality measures and through “know your farmer” magnets. The Governments of Niue, Samoa and Tonga provide financial support to organic family farmers for obtaining organic certification. The Government of Niue was the first in the world to target 100 percent organic production by 2020: It provides substantive financial support in the form of a salary for a certification manager, office accommodation, transport for auditing and certification as well as an operational budget for assistance from field officers when needed. The Governments of Samoa and Tonga each provide financial assistance to an organics association (in Tonga by funnelling bilateral aid).

Box 6. The Pacific Organic and Ethical Trade Community (POETCom)

POETCom – the unified voice for the organic and ethical trade movement in the Pacific Islands – is a not-for-profit membership organization housed at SPC. It counts 43 active members (farmers' associations, farmer support organizations, non-governmental organizations (NGOs), private-sector entities and research institutions) across 14 PICTs. POETCom spearheads efforts to mobilize resources for, establish and assist in implementation and monitoring of regional projects advancing organic products. Such efforts have resulted in, among others:

» the Pacific Organic Standard, adopted in 2008 and officially recognized by IFOAM in its list of international standards in 2012;
» a regional participatory guarantee system (PGS) (developed in 2013 and evolving);
» the Pacific Organic Tourism and Hospitality Standard (2016).

The Pacific PGS provides a certification methodology used by family farmers to help them access organic markets. The Pacific PGS seal (Figure 1) serves as a marketing tool. The PGS provides support for collaboration among farmer groups and other stakeholders in the production, processing and often collective marketing of their products.

Figure 1. **Organic certification seal obtained through the participatory guarantee system, ensuring that the Pacific Organic Standard has been used as the production standard**

The Governments of French Polynesia and New Caledonia fund their respective Chambers of Agriculture, and the former also provides financial support to the local participatory guarantee system Bio Fetia (SPG Bio Fetia, 2016). The Government of Vanuatu is considering the possibility of making Vanuatu an "organic" nation.

Local governments at the island and village level are increasingly supporting and promoting organic agriculture. Islands in Fiji, Kiribati and Vanuatu have elected to be fully organic. Some have received organic certification.

Pacific Island territories are leading the development of organic agriculture in the subregion through adoption of relevant laws and programmes. Examples include subsidized conservation practices and certification costs in American Samoa, French Polynesia, Guam, Hawaii, New

Caledonia and Northern Mariana Islands. French territories have developed participatory guarantee systems and regularly share training in organic agriculture within the subregion. The Pacific Territories Initiative for Regional Management of the Environment (INTEGRE) is a sustainable development project designed for and implemented by the four European Pacific overseas countries and territories, with funding from the tenth European Development Fund. It is implemented by SPC through a series of workshops on organic agriculture.

The Government of Cook Islands assists organic farmers through:

- special soft (low-interest) loans (5 percent) for up to 30 000 New Zealand dollars (NZD) (US$21 470) to support farmers that venture into organic farming, especially for vanilla growing (for which the government allocated and transferred a total of NZD150 000 [US$107 300] for 2016 and 2017);
- allocation of 30 medium-sized mulching machines, each worth NZD4 000 (US$2 860), for organic growers of vegetables, maire (*Microsorum commutatum*, an aromatic fern) and vanilla, distributed to organic growers organizations with assistance from the Government of China.

The Government of Fiji, through the Ministry of Agriculture, Ministry of Industry, Trade and Tourism and Ministry of Health, is facilitating the development of an organic agricultural industry by developing organic standards for Fiji. To promote production and consumption of organic products, the government is in the process of forming a "Fijian Organic" brand under the "Fijian Made – Buy Fijian" campaign. Demand for organic produce is also transforming Fiji's hospitality industry, with increasingly numerous organic resorts or hotels offering locally produced organic food, toiletries and cosmetics.

In Palau, an organics consortium consisting of the Palau–Taiwan Farmer's Association, Palau Organic Growers Association, Bureau of Agriculture (BoA), BoA–FAO Organic Project, Palau Chamber of Commerce, Palau Conservation Society, Division of Environmental Health and Sanitation, Environmental Quality Protection Board and key government officials was able to successfully graft organics into Palau's policies for climate and food security. As a result, organics is now assigned a prominent role in the best management practices and implementation of the Strategy and Action Plan for Resilient Agriculture and Aquaculture, a national policy for strengthening food security in Palau as a priority climate change adaptation measure. This policy notes: "Farming activities can also negatively impact ecosystem health if best management practices, especially organic practices, are not employed… Organic agriculture has been shown to lower soil erosion and build up soils… Organic agriculture has demonstrated success in lowering greenhouse gas emissions" (PACC, 2015). Objectives of the policy include:

- the development and implementation of tested and cost-effective protocols for climate-proof, organic and sustainable agriculture, integrated pest management and nutrient recovery;
- the use of aquaculture and agriculture using climate-proof state-of-the-art sustainable land management practices and organic practices and maximizing local inputs and renewable energy to produce 80 percent of Palau's food needs by 2025;
- by 2018, a 25 percent increase in existing farms practising environmentally sound IPM and organic plant protection methods.

Palau's policy is a key priority intervention of the Five-Year Action Plan of the broader, recently endorsed Palau Climate Change Policy for Climate and Disaster Resilient Low Emissions Development.

In 2015, 16 national strategic development plans included organic agriculture and ethical trade; 19 national environmental plans included organic agriculture; and 41 organic projects or programmes were ongoing in the subregion (POETCom, 2015).

Several foreign aid institutions channel their support to organic agriculture and fair trade through national and regional institutions, including the EU–German Agency for International Cooperation (GIZ) Adapting to Climate Change and Sustainable Energy (ACSE) Programme, FAO, the Global Environment Facility (GEF) Small Grants Programme, IFAD, New Zealand, Oxfam, the United Nations Development Programme (UNDP) and the United States Agency for International Development (USAID) Pacific-American Climate Fund.

International policies and programmes

The partnership "Organic Islands: Growing our Future", formed as part of the Small Island Developing States (SIDS) Accelerated Modalities of Action (S.A.M.O.A.) Pathway (UN, 2014), was created to raise awareness of the potential for organic agriculture to contribute to addressing development issues for SIDS. It was formed in a bottom-up fashion by grassroots organizations committed to promoting organic agriculture as a means for improving environmental sustainability, livelihoods and food security. It includes 30 member organizations across 13 Island States.

In June 2016, the forty-sixth meeting of the Committee of Representatives of Governments and Administrations of SPC reviewed a proposed initiative on the development of the organic sector (Organic Islands: Growing our Future through Organic and Ethical Trade) for inclusion in the Framework for Pacific Regionalism. The committee urged SPC to integrate organic agriculture fully into relevant strategies and agreed on the need to identify options for sustainable financing of an organic agriculture programme in SPC. It also acknowledged the complementary roles of SPC and POETCom in the development of organic agriculture for improved environmental, cultural, social and economic development outcomes (SPC, 2016c).

FAO addresses organic agriculture at the regional level in its Pacific multi-country programming framework for 2013–2017 (FAO, 2012a); organic agriculture is also considered at the national level in the FAO country programming frameworks of 9 of the 14 Pacific Island member countries.

To date, organic agriculture has a direct role in the NBSAPs of seven Pacific Island countries. It also contributes to efforts of countries in the subregion to meet broader international commitments, such as several of the SDGs: Goal 1: No To Poverty; Goal 2: Zero Hunger; Goal 3: Good Health and Well-being; Goal 6: Clean Water and Sanitation; Goal 12: Responsible Production and Consumption; Goal 13: Climate Action; and Goal 15: Life on Land (POETcom, 2015).

Recommendations for mainstreaming ecosystem services and biodiversity through organic agriculture in Pacific Island countries' NBSAPs

Since the agricultural sector is often one of the main drivers of biodiversity loss (as described in the introduction to this volume), organic agriculture is well placed to help increase environmental sustainability and reduce biodiversity loss across the Pacific Islands. NBSAPs in turn represent an excellent tool for mainstreaming these and other ecosystem-based approaches and practices into agricultural production and management across the subregion, as they can serve as a bridge between the national environmental and agricultural sectors and policies.

The following recommendations are categorized in two groups, those pertaining to agricultural practices and those relating to knowledge and education.

Incentivizing organic practices

NBSAPs and other agricultural and environmental policies at the subnational, national and regional levels should focus on promoting and incentivizing those practices that are able to preserve natural ecosystems and biodiversity while at the same time maintaining or improving viability of production at the farm level (Table 2).

Overall, diversification in farming systems – to include any combination of mixed crops, trees, livestock and aquaculture – must be encouraged to harness the benefits to local communities and ecosystems outlined above.

Broader-level policies could also be implemented at the national or regional/subregional levels, including, for example, the phasing out of highly hazardous pesticides and the reduction and phasing out of all noxious synthetic agrochemicals. Unregistered products should be removed from sale, and stricter controls are required on those that are illegally imported and or produced.

In terms of supply, governments could implement food procurement policies for schools and other government-managed institutions that focus increasingly on procurement of local organic food.

A "barrel tax" on each barrel of imported petroleum, oil and lubricants could be used to fund agricultural sustainability and vitality initiatives including organic production, permaculture and bio-dynamic and agricultural parks (Brower, 2010). An example is the Sunol AgPark, a collaborative farm that promotes sustainable agricultural practices in California, United States of America (SAGE, 2015).

Table 2. **Recommendations for supporting integrated farming practices that conserve biodiversity and ecosystem services**

FARMING PRACTICE	MEANS OF PROMOTION	POTENTIAL FUNDING SOURCE
Incorporation of legumes in crop rotations, alley crops, cover crops, riparian zones, inoculation of soil or crops with beneficial organisms	Collection, multiplication and dissemination of open-pollinated landraces of legumes and inocula of beneficial indigenous organisms Extension efforts	Duty on imported seeds, plants and organisms
Application of various forms of mulching (e.g. lasagna, deep layer and the use of diverse mulching materials such as cardboard or palm leaves)	Research and training on mulching on farms and at schools, universities and community health centres	Duties on plastic and other non-ecological packaging and pallets
Composting and proper application of manure on farmland	Improve local capacity through the establishment of composting facilities (as has been done in the Cook Islands [Photo 3]) at hamlet, village, municipal and national levels	Levies on solid waste and/or fines on the possession and use of prohibited agrochemicals
Local production of farm inputs	Incentive programmes, including technical, financial, management and marketing assistance and a five-year tax reduction	Duty on imported synthetic agrochemicals and fines for possession and use of prohibited substances
Farm-level water harvesting and conservation	Research and training on water harvesting and water conservation practices on farms and at schools, universities and community health centres	Voluntary contributions, including from commercial water and soda bottlers and breweries

Photo 3. *Cook Islands composting facility*

Knowledge and education

National extension systems and farmer-centred research. Mainstreaming sustainable practices in agriculture will require a solid evidence base to counter the common arguments that organic and ecosystem-based approaches are not fit to produce a sufficient amount of food in an increasingly populated world. Building knowledge on organics in the subregion will have to focus on preserving, documenting, disseminating, valuing and especially revitalizing traditional knowledge and skills in food production, consumption, preservation and processing.

Furthermore, individual countries should facilitate farmer-led research in farmers' fields (Wright *et al.*, 2016) as well as farmer-to-farmer approaches to dissemination of knowledge on agricultural production and management. These innovations should parallel a restructuring of agricultural extension approaches towards a model that increasingly encourages sustainable practices over external inputs. Current research, development and investment efforts in input-based technologies must also be redirected towards further exploration of the potential of process-based technologies, integrated systems and holistic approaches (Mulvaney, 2008). Finally, public investments and resources should be made available and directed to restoring and revitalizing traditional Pacific food production systems such as ancient fishponds, taro patches (Brower, 2010), as well as to developing local food produce and cuisine (FAO, 2009a).

Promotion of agriculture as a rewarding field for newer generations. Efforts are needed to improve the image of agriculture if young people are to be attracted into farming and agricultural professions. This can be achieved through education and advocacy at all levels. Examples include:

» a coordinated media campaign to promote a positive image of farmers (e.g. "farming as a noble profession", "farmers feed the world", "farmers nourish traditions");
» awards ("green ribbons" or "green badges"), e.g. for sharers, mentors, champions, leaders, enhancers of the environment, carers of livestock and "nurses" of wildlife;
» training of producers in social marketing, relationship marketing and public relations;
» a "rapid rebuttal unit" to respond to any antagonistic news stories quickly and effectively and to debunk and combat the fallacies of the prevalent negative views of farming;
» apprenticeship schemes such as "earning while learning";
» field tours and other showcasing of successful farms and farmers (e.g. "heroes who feed us");
» publicity and validation for on-farm research through various media.

4 AGROFORESTRY SYSTEMS

Randy Thaman

Agroforestry systems come in many forms and shapes, but generally speaking, they entail the planting and growing of woody perennials (e.g. trees and shrubs) in and/or around farmland, or the conservation of those plants and associated animals and micro-organisms that are already there. Agroforestry systems are diverse and dynamic production systems relying on the marriage of natural and cultural ecosystems and diversification as a basis for optimizing social, economic and environmental benefits for land users (FAO, 2016c). These benefits stem from, among others, the biological nature of tree roots – as they are deeper than those of most agricultural crops and thus able to make increased use of soil nutrients – and the supply of food and non-food products and other provisioning, regulating and cultural ecosystem services. Trees and other plants in agroforestry systems are also among the most culturally useful of all plants.

Agroforestry systems in the Pacific Islands

In the Pacific Islands, traditional agriculture is based on tree-rich agroforestry systems. Traditional agro-ecosystems across the islands had hundreds of cultivated and wild multipurpose trees and other plants and animals that were deliberately planted, raised and protected in rural and urban garden lands (Thaman, 2008b; Clarke and Thaman, 1993; Thaman, Elevitch and Wilkinson, 2000). This is especially true in Melanesia, Polynesia and the larger islands of Micronesia, where rural agroforestry systems traditionally had numerous staple and non-staple food crops, often represented by numerous distinct cultivars, more than 100 multipurpose tree or tree-like species, and countless other useful plants and animals (Thaman and Clarke, 1993) (Photo 4). Even in the extreme conditions of the atolls of Kiribati, Marshall Islands and Tuvalu, a single garden area commonly has more than 40 useful tree or tree-like species, a limited number of ground crops and other useful non-tree plants (Thaman, 2008b; Thaman and Whistler, 1996). It is stressed that home gardens in villages, urban areas and rural agricultural areas, such as in the Fiji sugar-cane belt, are also biodiverse agroforestry ecosystems. For many families, these gardens are the only insurance against worsening poverty, malnutrition, poor health, economic downturns and environmental change (Thaman, 1995).

Placing a monetary value on biodiversity and ecosystem services (see Chapter 1) would give a better idea of the immense value of the subregion's traditional agroforestry systems and the plants that were traditionally protected and planted within them and in surrounding protective coastal ecosystems. For example, about 75 percent of plants with known medicinal properties are found planted or protected in agroforestry areas (Thaman and Whistler, 1996; Thaman, 2002). The coconut palm has been documented to have 125 different uses (Thaman, 1994), and most of the other common Pacific Island agroforestry species all have many uses (Box 7), including products for both local sale and export, and are also culturally relevant as subjects of legends, mythology, songs, riddles and proverbs (Thaman, 2008b).

Photo 4. *Shifting multispecies agroforestry taro (*Colocasia esculenta*) garden with over 30 useful species managed by women on Koror Island, Palau, 2005*

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Box 7. **Most frequent uses of Pacific Island agroforestry species**

- Fuelwood
- Construction materials
- Cultivated or ornamental plants
- Food
- Domesticated and wild animal feed
- Food packaging or wrapping
- Medicine
- Fertilizer and mulching
- Toolmaking
- Woodcarving
- Cordage and fibre
- Adhesives and caulking
- Fishing equipment
- Boat or canoe making
- Cooking equipment
- Weapons or traps
- Fish poisons
- Handicrafts
- Games and toys
- Musical instruments
- Clothing
- Dyes and pigments
- Perfumes and scenting coconut oil
- Body ornamentation
- Magic and sorcery
- Ceremony and ritual

Ecosystem services from agroforestry

Being highly diversified by definition, agroforestry systems offer a broad range of ecosystem services and provide users with diverse social, economic and environmental benefits on and off farm, as testified by the numerous uses of tree products described above. Ecosystem services from agroforestry overlap to some extent with those offered by other types of diversified or integrated systems (e.g. multicropping, crop–livestock and aquaculture systems), but agroforestry also offers unique ecosystem benefits, summarized in this section according to the categorization of regulating, supporting, provisioning and cultural services outlined by the 2005 Millennium Ecosystem Assessment (MA, 2005) and followed throughout this book (Table 3).

Regulating services

Integrating and protecting trees in the on- and off-farm landscape strengthens the regulating processes of natural ecosystems in several ways. Trees influence climate and temperature regulation, e.g. by offering wind and ultraviolet protection and by supporting carbon sequestration. They help support watershed and coastal protection by controlling flood runoff and erosion and buffering waves. They help purify land, water and air resources by influencing moisture regulation and mitigating pollution through bioremediation.

Table 3. **Ecosystem services from agroforestry**

ECOSYSTEM SERVICE TYPE	ROLE OF AGROFORESTRY
Regulating	> Climate regulation > Protection from wind and ultraviolet rays > Control of floods, waves, erosion, runoff > Carbon sequestration > Purification of water and air > Moisture regulation
Supporting	> Pollination pathways > Soil formation and improvement > Soil nutrient absorption > Recycling of plant materials > Habitat for above- and below-ground biodiversity > Bioremediation > Control of weeds, pests and diseases
Provisioning	> Food products > Non-food products, e.g. timber, fuelwood, construction materials, handicrafts
Cultural	> Aesthetic and spiritual values > Tourism > Preservation of local habitats/traditions

Supporting services

Trees support and enhance the natural environment allowing agricultural crops to grow healthy. For example, they influence pollination and fertilization dispersal pathways. They support soil formation and help improve soil structure, for example by increasing soil nutrient absorption and through recycling of plant materials such as leaves and branches in the ground. They offer habitat, shelter and breeding grounds for both vertebrate and invertebrate species. They also support bioremediation processes and ecological regulation and control of weeds, pests and diseases.

Provisioning services

Agroforestry systems add to the provisioning services of agricultural crops by supplying food and non-food products from trees, plants and animals. They provide timber and wood for a wide range of uses, such as fuel, boatbuilding, woodcarving, torches, tools, toys and weapons, as well as non-wood products including a wide range of medicines, fertilizers, handicrafts, dyes, paints and tannins. Edible products include fruits and spices, beverages, fodder for livestock and, indirectly, food for and from wild animals that use these systems as habitat. Products from trees and tree-rich agro-ecosystems are also used in religious and traditional ceremonies.

Cultural services

Agroforestry landscapes are an important source of cultural services as they provide attractive sites for tourism, preserve local habitats and traditions and offer enriching spiritual and aesthetic values to all users. Commonly found within the matrix of agroforestry landscapes are sacred trees or tree groves and burial sites. Many of the trees and other plants and animals found in agroforestry systems serve as ancestral totems.

Challenges to the conservation of agroforestry systems in the Pacific Islands

Agrobiodiversity and ecosystem services are particularly threatened in PICTs, where traditional polycultural agroforestry systems (the dominant traditional system throughout the Pacific) have increasingly shifted to monoculture and associated high use of agrochemicals. Monoculture-based systems, offering lower agrobiodiversity and ecosystem services, are far more susceptible to invasive alien species, weeds and diseases, natural disasters and economic downturns, and in the long run are not socio-economically or environmentally sustainable.

As a result of this “agrodeforestation” – that is, the degradation of traditional agroforestry systems – hundreds of cultivated and wild multipurpose trees and other plants and animals that were traditionally deliberately planted or protected in rural and urban garden areas have now disappeared or are declining (Thaman and Whistler, 1996; Thaman *et al.*, 1995; Thaman, Elevitch and Wilkinson, 2000).

A 1996 study by the Secretariat of the Pacific Regional Environment Programme (SPREP) in the proposed South Pacific Biodiversity Conservation Programme Ha'apai Conservation Area in Tonga showed the diversity of native and cultivated multipurpose trees that are disappearing from agricultural areas (Thaman *et al.,* 1995). Local people considered 103 agroforestry trees and shrubs to be rare, endangered or in short supply. These include a wide range of cultivated and wild multipurpose trees and shrubs that are important sources of food, medicines, timber, handicrafts, dyes, tannins, perfumes, body ornamentation and many other useful products (Photo 5). Virtually all of these are important species in most other PICTs.

The major factors responsible for increasing agrodeforestation and loss of agrobiodiversity and ecosystem services in the Pacific Islands are summarized as follows:

» land degradation, decreasing fallow periods and loss of soil fertility, including increasing soil salinity (especially on atolls and other small low-lying islands and in coastal areas);
» indiscriminate burning, which destroys seedlings and saplings and favours the replacement of trees and forest remnants and their associated agrobiodiversity by degraded grasslands, scrublands and invasive alien species;

Photo 5. *A shifting sweet potato garden with protected but threatened Java cedar (or koka) (*Bischofia javanica*), a multipurpose tree known as a sign of fertile soils and a source of dye and tannin for tapa cloth, medicines and high-quality timber and fuelwood, Tongatapu Island, Tonga*

- overemphasis on monoculture of cash crops for export and local sale, which has included mechanization and the use of chemical fertilizers, herbicides and other pesticides, with the increasingly indiscriminate use of herbicides playing a particularly central role in the loss of trees and other useful plants in agro-ecosystems;
- increasing dependence on cash incomes and importation of foods, medicines, fuel and other products traditionally produced in agroforestry systems and surrounding wildlands;
- failure to replant trees, other plants and traditional cultivars after loss due to drought, pest and disease infestations, tropical cyclones, tsunamis and other natural factors;
- invasive alien species and diseases, including noxious weeds, mammals, insects and other pests and plant and animal pathogens in and around agricultural areas;
- overemphasis on modern urban education and loss of indigenous and local knowledge about agriculture (ethno-agrobiodiversity) (Lebot, 2013; Thaman, 2013b, 2013c; Ragone, 1997), including the loss of indigenous and local knowledge of the names, uses and management of both wild and cultivated plants and animals and of the biodiversity and ecosystem services in agroforestry systems;
- greater emphasis on conservation of wildland and marine biodiversity and ecosystem services and globally threatened (often endemic) red-listed species in biodiversity hotspots than on agrobiodiversity, even though for many PICTS, agrobiodiversity (rural and urban) represents the most useful, well-known and highly threatened type of biodiversity (Thaman, 2007/2008; JSSA, 2010).

Cultural practices that conserve biodiversity and ecosystem services in tree-based systems

Good cultural practices that have a direct or indirect impact on tree-based systems include:

- severe pruning, pollarding and coppicing as an alternative to ring-barking, burning or tree removal in clearing new garden areas for both commercial and subsistence crops or livestock production;
- bans on indiscriminate burning to protect trees and young plants, especially during drought periods when trees are most susceptible to uncontrolled burning, including bans on piling extra fuel and burning around the bases of trees in shifting agroforestry systems;
- the use of minimum or restricted tillage and the use of appropriate hand tools, which favour the survival of trees, as an alternative to complete tillage or ploughing;
- integration of livestock in agroforestry and cropping systems;
- improved fencing, penning and tethering of livestock to protect mature trees, saplings, seedlings and other endangered plants from damage by pigs, cattle, horses, goats and others;
- improved boundary plantings, windbreaks, live fencing, hedging and animal pens of useful species to increase the overall cover of useful arboreal species;
- crop breeding to increase the genetic base and to develop new cultivars that address climate change, increasingly destructive natural disasters, declining soil fertility, increasing salinity or invasive alien species problems, which is also a way of enriching existing agrobiodiversity (Lebot, 2013).

Suggested policy actions to protect agroforestry systems, for uptake in NBSAPs and agricultural sector policies

The following are some suggested key areas of intervention that could serve as policy entry points to encourage both direct and indirect actions to preserve agrobiodiversity and ecosystem services from agroforestry in NBSAPs, agricultural strategies and other relevant policies in place or under development in the Pacific Islands. Note that in addition to agricultural policies that directly target management of land and other natural resources within and around farming systems, the environment sector plays a key role in both direct and indirect conservation of agrobiodiversity and ecosystem services at the broader landscape level. Policy actions aimed at increasing sustainability in agroforestry by building on, restoring and/or enriching (with appropriate new species) local agrobiodiversity and ecosystem services must thus be cross-sectoral.

Forest protection

Policies should target protection of lowland, coastal and mangrove forest and uninhabited offshore islets from agricultural encroachment by encouraging or requiring all landholders or communities to conserve representative areas of primary and secondary forest, including remaining lowland, coastal and mangrove forest and other wildland vegetation associations, by considering them as ecologically important and culturally utilitarian components of their agroforestry systems. This would include:

» protection of existing tree groves or forest stands, including sacred forests or tree groves, in or bordering active agricultural areas, from agricultural encroachment as a basis for biodiversity conservation; watershed management, coastal protection and protection of agricultural areas from land degradation, accelerated erosion and increasing salinity; and as reserves for endangered plants, birds, reptiles, crabs, land snails and other threatened biodiversity;

» protection of uninhabited offshore resource islets (*motu*), which often have the best remaining stands of native coastal forest; are free of invasive alien species or offer the best opportunities for eradicating them; are commonly used as reserves for natural resources; and are the main nesting areas for sea birds, coconut crabs, hermit crabs, sea turtles and refuges for a range of threatened plants.

Agrobiodiversity reserves and/or buffer zones

The designation or establishment of community-based agrobiodiversity reserves, buffer zones and areas for forest restoration by rural landowners might follow several models.

» Small forest stands can be established in areas where no trees exist, following the Kayapo "islands of forest" (*apete*) model used in South America, where indigenous seedlings, compost, soil and other necessary inputs are transported to a carefully prepared planting site. The plantings are then carefully maintained, and additional trees and plants are added until natural succession takes over to establish a self-sustaining and expanding *apete* composed of tall, shade-producing, useful trees (Knudtson and Suzuki, 1992).

» Coastal and mangrove forests can be protected and restored as buffer zones to protect inland gardens and villages from inundation, wind and salt spray and as important animal habitat and sources of non-wood forest products, for example following a model used in Tonga in 1994 to address serious coastal deforestation (Box 8).
» Incentives can be provided to encourage adjacent landholders or communities to establish joint or communal inland and coastal reserves where their landholdings meet, to establish larger, more contiguous, complex and species-diverse reserve areas that preserve ecosystem connectivity.

Box 8. **Establishment of a protective "green wall" to prevent coastal degradation and salt spray damage in Tonga, 1994**

Starting in the late 1960s, Tonga started experiencing severe coastal degradation and salt spray damage to garden areas and houses as a result of the seaward expansion of monocultural plantations producing bananas for export and the indiscriminate burning and felling of coastal species for fuelwood and timber to make banana shipping crates. A restoration project along the southern coast of Tongatapu Island started in 1994 and involved the collection from the wild or propagation of about 25 000 seedlings and saplings of 30 indigenous coastal species. These species were then planted and maintained by a local community, with assistance from the Forestry Department nursery, along 2 km of coastline in a band 12 m wide. An inner double-rowed *Casuarina* windbreak was planted on the landward side. After two years, about 80 percent of the trees survived and the coastal "green wall" was successfully established (Thaman *et al.*, 1995; Thaman, Smith and Faka'osi, 2011) (Photo 6).

Photo 6. *Ten years after planting, a coastal "green wall" of planted trees with a landward* Casuarina *windbreak is established on Tongatapu Island, Tonga (shown in 2004)*

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Rural community-based planting and conservation

Community-based planting programmes (for trees, crop cultivars and other rare or culturally important plants) should be promoted in rural garden areas, in and around villages, on school grounds and in other appropriate areas. Such programmes might include the following.

- Coconut replanting and rehabilitation schemes are particularly important on small islands such as atolls and in coastal areas where coconut is a main staple food, livestock feed, export crop and source of water. Such schemes could include increased intercropping with ground crops and tree crops, the protection of indigenous and introduced utilitarian tree species within coconut plantations, and the planting of a range of traditional and improved coconut cultivars to maintain cultivar diversity as insurance against diseases, pests and adverse environmental or economic conditions.
- Deliberate planting, transplanting or protection of indigenous species, often from endangered coastal or inland vegetation associations, in rural and urban gardens (including institutional gardens) is a means of increasing public awareness of threatened indigenous tree species and building synergies among agriculture, species conservation and the conservation of the traditional names, knowledge and uses of native plants and arboreal biodiversity.

An almost endless list of staples, trees and other species can be designated for protection or planting in different PICTS, that when enriched with other local priority species could provide a basis for the development of community-based agrobiodiversity and ecosystem services initiatives; 100 such species of trees or tree-like shrubs or plants are listed in the Appendix.

Home gardens and urban agroforestry

Home gardens and urban agroforestry should be systematically promoted in villages, rural settlements and towns throughout PICTs as one of the most cost-effective means of agrobiodiversity and ecosystem services conservation and the preservation of associated knowledge (Box 9). These gardens could also be the foundation for recreation, education and food and health security. They represent one of the best ways of both addressing the epidemic increase in nutrition-related non-communicable diseases and protecting threatened cultural plants such as food, medicinal and handicraft plants. They can be established:

- in villages and house yards in both urban and rural areas;
- on undeveloped urban and peri-urban land;
- in specially designated garden areas or allotment systems where families are given small plots of land.

Conservation and enrichment of fuelwood resources

The conservation and enrichment of fuelwood resources, using both traditional and recently introduced species, should be made a priority in both rural and urban agroforestry systems to address serious deforestation and loss of agrobiodiversity and ecosystem services due to fuelwood gathering.

Box 9. Small-scale urban gardens and agroforestry in Honiara, Solomon Islands

The Ministry of Agriculture and Livestock (MAL) and the Ministry of Health of Solomon Islands, recognizing the beneficial effects of urban gardening and domestic food production in the capital city of Honiara, have promoted through the years the expansion of small-scale domestic gardens (*supsup* gardens, as they are known locally) to improve the health and well-being of the islanders and reduce the rates of non-communicable diseases across the country through increased access to nutritious food (MAL, 2013). As part of the initiative, through collaboration with the Taiwanese Technical Mission, urban dwellers receive training in the growing of crops that are easily adapted to the urban space and require little maintenance. These include, among others, Chinese cabbage (*Brassica rapa*), pakchoi (*Brassica rapa* subsp. *chinensis*) and peppers (varieties of the *Capsicum* genus). Trees, and in particular fruit-trees such as pawpaw (*Carica papaya*), guava (*Psidium guajava*) and carambola (*Averrhoa carambola*), are promoted as a key component of these domestic small-scale production systems. Youth have been a specific target for MAL's promotion of fruit-trees, in the attempt to encourage healthier eating behaviour (consumption of nutritious produce over unhealthy snacks) (MAL, 2013). Local initiatives and organizations such as Kastom Gaden Association (www.kastomgaden.org) support these efforts from the ground, for example by providing technical guidance materials (e.g. a manual on urban agroforestry for prospective gardeners, released in 2004) and inputs such as seed and rootstock varieties, and by focusing on vulnerable groups, particularly women (Lacey, 2012).

Actions could include:

- planting of single-species stands or intercropping of fuelwood species within polycultural agroforestry systems;
- planting of living fencing and the use of pruning and pollarding, coppice systems and selective weeding of fuelwood species;
- establishment of sustainable village or urban fuelwood reserves or plantings using fast-growing coppiceable species such as *Leucaena leucocephala*;
- more efficient use of deadwood, driftwood and coconut by-products;
- use of more efficient wood-burning stoves.

Invasive alien species management and biosecurity

Invasive alien species and diseases constitute one of the greatest threats to all biodiversity and related ecosystem services, including those associated with agroforestry systems. Concerted efforts must be made at the regional, national, island and community levels to strengthen biosecurity and ensure that invasive alien species are prevented from spreading, eradicated or managed. Specific suggestions for policy entry points for mainstreaming ecological management of invasive alien species are discussed in Chapter 8.

5

ECOSYSTEM SERVICES AND SOIL FERTILITY

Shane Tutua

Soils are the foundation of Pacific Island ecosystems, whether they be natural ecosystems such as rainforests or agro-ecosystems such as farms or food gardens. They perform important ecosystem functions and therefore provide services that are important to sustain life as well as to support the subregion's cultures and traditions (Leo, Wong and Tautai, 2014). Soil health or quality indicates the soil's capacity to perform its ecosystem functions. Soil health depends in large part on the activity of soil organisms, which regulate carbon transformations, nutrient cycles, soil structure and pests and diseases (Kimblewhite, Ritz and Swift, 2008). A healthy soil is a fertile soil. A holistic approach to soil management based on the use of soil quality indicators can ensure that the biological, chemical and physical properties of the soil are optimal to support productivity and provide environmental services (Doran and Parkin, 1996). This chapter highlights the key ecosystem services and functions that soils provide in agricultural landscapes and describes some means for enhancing ecosystem services to increase soil fertility and productivity while maintaining environmental quality and services.

Pacific Islands context

Soils in the Pacific Islands vary in their fertility or soil health status and constraints, as they are influenced by the tropical climate, topography and parent materials (Table 4). The coral sands that are common in low-lying countries produce soils that are inherently infertile, with low water-holding capacity, low nutrient content, high leaching potential and exposure to salt spray. In larger island countries where soils originate from volcanic parent materials soils are generally more fertile. However, soil erosion, soil acidity and nutrient leaching have contributed to declining soil fertility in these islands. Declining soil fertility is exacerbated by human interventions such as land clearing and subsistence farming. In particular, shifting cultivation

Table 4. **The state of soils in 14 Pacific Island countries**

COUNTRY	TOPOGRAPHY	SOIL PARENT MATERIAL	MAJOR SOIL CONSTRAINTS
Cook Islands	Low-lying atolls, including lowlands from volcanic islands as well as uplands	Coral, limestone and volcanic bedrock	Thin soil layer on some islands, high soil pH, low fertility in uplands
Federated States of Micronesia	Lowland swamps, hilly uplands, steep slopes	Inorganic materials, coral sands, basic igneous rocks	Poorly drained soils in lowlands, shallow soils on steep slopes
Fiji	Flat land, undulating, hilly lands, steep mountainous lands (>67%)	Beach sands, alluvia, limestone, volcanic and basic rocks	Poorly drained lowland soils, soil acidity, low nutrients, soil erosion from steep slopes
Kiribati	Low-lying islands (few metres above sea level)	Calcareous sand, consisting mostly of calcium and magnesium carbonates	N, P, K and micronutrients deficiency
Marshall Islands	Low-lying atolls (highest point 10 m above sea level)	Coral sands	Soil fertility very low in general, salt spray common
Nauru	Rim of raised coral with a central plateau, fringing sandy beaches	Coral limestone	N and K deficiency, soil erosion
Niue	Uplifted coral atoll plateau, slightly dish shaped, extinct submerged volcano	Volcanic ash	Nutrient deficiencies, low soil water retention, shallow soils
Palau	Volcanic origin with rolling hills, ridges, slopes and lowlands (some swampy) common	Volcanic, limestone, and coral limestone	Soil acidity, P, N and Ca deficiency, elevated K, Mn, Fe and Al, soil erosion on slopes
Papua New Guinea	Plains and valleys, low mountains and hills, high mountains	Volcanic	Salinity, inundation, shallow soils, extreme stoniness, anion fixation, low N, P, S and Cu, increased soil erosion on slopes
Samoa	Flat to undulating coastal plains, gentle to steeper slopes/ foothills, upland plateaus	Volcanic, olivine basalt	Declining soil fertility, high leaching of nutrients
Solomon Islands	Steep, rugged mountains, rolling hills and coastal lowlands, few flat lands, coral atolls and raised coral reefs	Volcanic, igneous and metamorphic rocks, alluvium, limestone, uplifted coral and marine sediments	Steep slopes (soil erosion), K deficiency in general, moderate P, declining soil fertility in populated areas
Tonga	Flat to small rolling hills, high hills in some islands, raised coral terraces	Volcanic ash and coral limestone	Salinity, coral outcrops, shallow soils, drought-prone sandy soils with low natural fertility in some areas
Tuvalu	Low-lying atolls (no more than 4.6 m above sea level)	Sand and coral limestone	Very poor quality soils
Vanuatu	Islands of low mountain ranges	Volcanic ash and rock, coral limestone, sedimentary deposition	Soil erosion, nutrient deficiencies in most islands (N, P, K and S)

Source: Derived from FAO, 2009b

with short rotations and little or no inputs, especially in populated areas, have contributed to the degradation of soil health and ecosystem functions in some regions of the Pacific. Intensive high external input farming, including monoculture and the use of agrochemicals to increase production, has also resulted in soil and environmental degradation. For instance, heavy use of agrochemicals has contributed to the declining soil health and pollution of the lagoons on Rarotonga, Cook Islands (RNZ, 2003). Soil erosion due to farming activities has also contributed to loss of soil fertility and siltation of coral reefs. Similar observations of agrochemical inputs on soil health have been observed in Fiji (Lal, 2013) and Niue (FAO, 2009b). In Taveuni, Fiji, in particular, the heavy use of agrochemicals has resulted in a decline in soil fertility and increase in soil-borne diseases, resulting in the decimation of Taveuni's taro export industry (Lal, 2013). Increasing forest cover, on the other hand, tends to slow these processes, by minimizing soil erosion, capturing nutrients in forest biomass and then slowly supplying the soil with nutrients and organic matter through litter fall.

Soil fertility is a major challenge to food security and sustainable economic development in the Pacific. Both subsistence farming and commercial, intensive cultivation, with increasing dependence on chemical fertilizers and pesticides, have largely ignored the ecosystem services offered by the soil and those required to sustain a productive soil.

Ecosystem services from soil fertility

Soils as a component of an ecosystem contribute to all the different types of ecosystem services, provisioning, supporting, regulating and cultural (Table 5). Central to the ability of soils to contribute to ecosystem services is soil organic matter (SOM), the biologically and chemically active substance which gives the soil its dark colour (Photo 7). Soil organic matter is the end product of decomposition and is a critical factor influencing the capacity of a soil to provide ecosystem services owing to its influence on the biological, chemical and physical properties of the soil. SOM positively influences all the dimensions of soil health by:

» providing habitat and a source of subsistence for soil-dwelling organisms that are central to regulating soil processes;
» regulating the ability of soils to store and release nutrients and water, with a 1 percent increase in SOM resulting in an 18 litre increase in water content per square metre of soil (20 000 gallons per acre [Bryant, 2015]);
» capturing noxious heavy metals and reducing their impact on the environment and human health;
» binding individual soil particles into aggregates, thus increasing soil porosity and properties that are key to provision of soil ecosystem services such as aeration, drainage, permeability and an active soil population (Oades, 1993; Beare *et al.*, 1995; Lavelle, 1996).

Management practices that enhance SOM are thus very important to maintain soil health and ecosystem services.

Table 5. **Ecosystem services of soils**

ECOSYSTEM SERVICE TYPE	ROLE OF SOILS
Regulating	> Renewal of ecosystems > Nutrient transformation > Filtering water > Buffering > Decomposing waste and dead organic matter > Climate regulation > Disease control > Detoxification > Erosion control
Supporting	> Habitat for soil biodiversity > Gene pools > Nutrient recycling > Substrate for growth of plant communities
Provisioning	> Provision of food, fuel, building materials > Freshwater
Cultural	> Heritage sites > Recreation > Preservation of archeological artefacts > Spiritual values, religious sites, burial grounds

Source: Adapted from Barrios, 2007

Photo 7. *Composted organic materials turning into humus or soil organic matter, which influences the soil's biological, chemical and physical properties*

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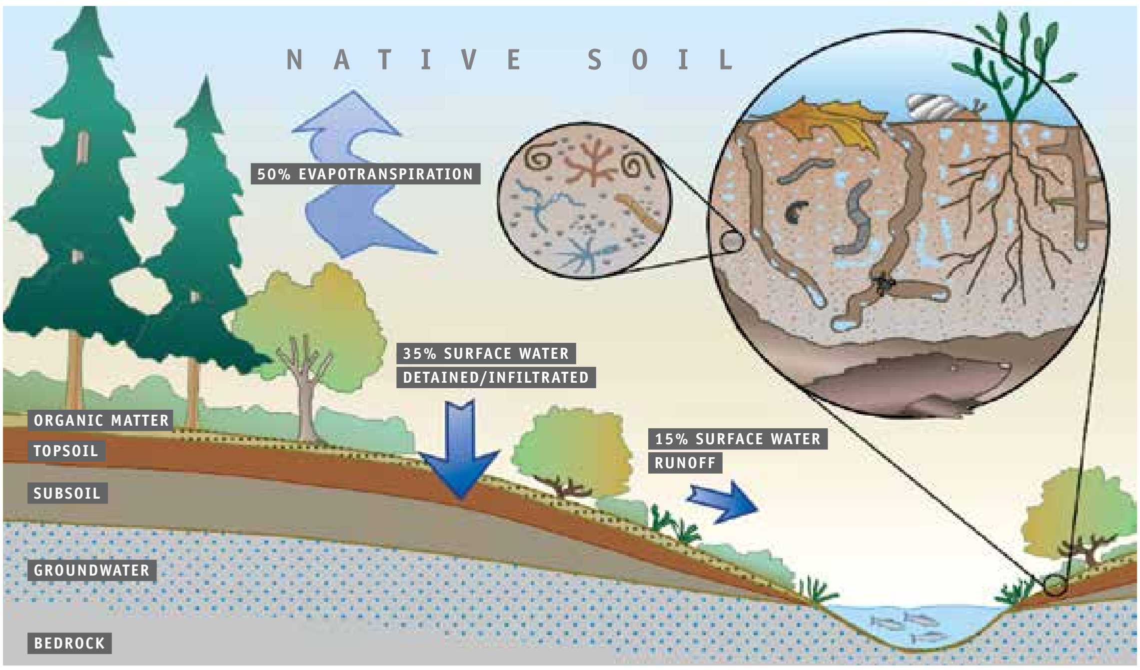
Regulating services

Soils have an important role in regulating energy, nutrients and other chemical substances, water and air flows through the ecosystem. Soil biodiversity, including fungi, bacteria and other organisms that can build or break down soil organic matter and transform carbon, is critical in the regulation of biogeochemical processes important to human survival (Barrios, 2007). A well-structured soil has air spaces or pores which allow air and water to move through it and thus assists in the percolation and filtration of water into streams. A stable soil structure also contributes to minimizing soil erosion. Thus, soil properties such as stable structures, porosity and burrowing of soil macro-fauna help to ensure provision of clean water to streams (Lavelle, 1996) (Figure 2).

Soil organisms, especially macro-fauna such as earthworms, also assist in the regulation of nutrient cycling through the provision of water and oxygen through the pores and channels or tunnels to decomposers (Figure 3). The processes of decomposition by micro-organisms and bioturbation by macro-fauna also help to regulate the carbon cycle by sequestering carbon dioxide in the soil as organic matter, giving soils a role in regulating climate change. Decomposition as a soil process also aids in the breakdown and assimilation of wastes and the detoxification of harmful compounds, helping to renew the environment or ecosystems.

Furthermore, a healthy soil with a diverse food web helps to regulate soil-borne pests and diseases, keeping them under control through interactions such as competition, predation and parasitism (Barrios, 2007). Studies have also shown a strong relationship between soil biology and fertility and plant health. Plants grown in poor soil conditions are weaker and more susceptible to pests and diseases (Altieri and Nichols, 2003). A healthy soil, with optimum chemical, physical and biological conditions, provides the nourishment necessary to boost the plants' immune system or to produce sufficient biochemical compounds to deter insects from attacking the plants (Zehnder *et al.*, 2007). There is also evidence that soil organic matter mediates various types of signalling between the soil and plant (Phelan, Norris and Mason, 1996; Stone, Scheuerell and Darby, 2004), which helps to maintain plant health.

Figure 2. **Linkage between soil ecosystem services (provision of nutrients and anchorage for plants; regulation of water infiltration, surface runoff and soil erosion) and the health of aquatic ecosystems**



Source: Washington Organic Recycling Council, 2016

Figure 3. **Some examples of soil organisms and their contribution to soil ecosystem services**

© OregonCavesNPS

MYCORRHIZAL FUNGI

Size: Fungal strands 1–10 µm across, covering roots to varying degrees

Job: Plant symbiont

Function: Entwining with plant roots, helping the plant to gain water and minerals and gaining carbohydrates in return

© Terraprina, WMC

NITROGEN-FIXING BACTERIA

Size: 1–2 mm

Job: Plant symbiont

Function: Forming nodules in the roots of legumes and turning atmospheric nitrogen into ammonia that the plants can use

© Agricultural Research Service

NEMATODE

Size: 150 µm – 10 mm

Job: Nutrient cycler

Function: Feeding on fungi and bacteria that feed on dead organic matter, and transferring nutrients to the soil through defecation

© Erbe, Pooley; USDA, ARS, EMU

MITES

Size: 1 mm

Job: Nutrient cycler

Function: Feeding on detritus, microbes and micro-fauna, and returning organic matter to the soil

Source: Adapted from Dance, 2008

Supporting services

Soils support life by providing a medium for growing plants – including food plants – as well as a basis for infrastructure such as buildings and roads. They also represent a habitat for many different kinds of living organisms; there are more living organisms below ground than above (Dance, 2008). For instance, 1 gram or a teaspoonful of soil could contain up to 1 billion bacteria, with a species diversity ranging from 2 000 to 50 000 species (Dance, 2008). Thus soil is a storehouse of biodiversity containing a large gene pool with complex food webs contributing to the resilience and stability of ecosystems.

Furthermore, soils house organisms which carry out specific ecological functions that provide ecosystem services through their feeding behaviour or activities (Beare *et al.*, 1995; Lavelle, 1996) (Figure 3). Soil microbes graze on other organisms such as fungi and bacteria and assist in decomposition of dead organic materials, recycling nutrients which support plant communities (Lavelle, 1996). Larger soil organisms such as earthworms also contribute to nutrient cycling through the shredding of larger debris into smaller pieces which increases the surface area for microbial attack and therefore the rate of nutrient release for living plants (Beare *et al.*, 1995). Some soil bacteria (e.g. *Azotobacter* and *Rhizobium* species) fix nitrogen from the air and convert it to forms that plants can use (Barrios, 2007). Others (mycorrhiza) contribute to the uptake of water and nutrients, especially phosphorus (Barrios, 2007), and increase the concentration of nutrients available for plant uptake. Phosphorus-solubilizing bacteria dissolve fixed phosphorus into the soil solution for root uptake (Rodriguez and Fraga, 1999; Chen *et al.*, 2006). The interactions of different soil organisms with various functional roles greatly enhance the recycling and transformation of elements necessary to support life (Beare *et al.*, 1995).

Provisioning services

Soils provide Pacific societies with food, animal feed, fuel, fibre, medicinal plants and clean water (Gachene, 2016). Most Pacific Islanders rely on the soil to provide their daily food supplies. Soils support the forests that provide building materials and the cotton plants and grass for grazing that provide the cotton and wool for clothing. As described above under regulating services, a healthy soil is critical for recharging streams and rivers. Soils also provide a growing medium for florists, home gardeners and horticulturists (Gachene, 2016).

Cultural services

Soils culturally enrich people's lives through landscapes and sense of place. Soils support diverse vegetation in different landscapes which have provided aesthetic stimulus for artists throughout the ages. They play a major part in religious beliefs and store cultural heritage, thereby giving insight into the societies, climate and environment of the past. Many Pacific cultures have a spiritual connection to the soil, and some cultures refer to the soil as "mother". Soils also provide a place to bury the dead, material for building houses and a place to store and cook food. Soils provide the platform for many recreational opportunities and are the foundation for various disciplines such as agriculture, environment and engineering (Dominati, Patterson and Mackay, 2010; Gachene, 2016).

Practices that maintain or enhance soil ecosystem services

Subsistence farming is the main form of farming practised by Pacific Island communities. Traditionally it is associated with shifting cultivation, and in many cases with slash and burn practices. Shifting cultivation, which involves fallow cycles, is a sustainable practice in that it regenerates SOM and therefore soil health in the Pacific Islands. Revegetation during the fallow period allows accumulation of SOM and nutrients through litterfall biomass. The deep and extensive root systems of trees capture the leached nutrients in deeper soil layers and bring them to the leaves. As the leaves senesce and drop as litter, the nutrients get returned to the topsoil. The accumulation of litter leads to the recolonization of the soil with organisms that work the soil. The duration of the fallow period, however, is critical for the sustainability of this system. Fallow periods of at least 8 to 15 years have been noted to improve the productivity of soil to pre-cultivation levels (Kabu, 2001). However, increasing population, land disputes and competing land use activities on some islands have diminished the available arable land per individual, forcing smallholder subsistence farmers to practise shorter rotations (e.g. two to five years in some parts of Solomon Islands), greatly reducing crop yield (Kabu, 2001). The cash economy also adds pressure to subsistence farming systems, as it leads to continuous cash cropping without a balanced input of nutrient sources, as well as neglect of sustainable traditional practices. These factors lead to loss of soil nutrients and SOM, poor soil fertility and therefore reduced productivity of the subsistence farming system. Furthermore, the depletion of SOM limits the ability of the soil to store water, making this largely rainfed farming system vulnerable to climate change related droughts. Thus maintaining soil health, and especially a climate change resilient soil system, is imperative for most smallholder farmers around the Pacific Islands.

Furthermore, the increasing market-driven semi-commercial and commercial farming in the Pacific Islands, with monocultures and heavy use of agrochemicals (see Chapter 1), is also a threat to soil health and its ability to provide ecosystem services. The continuous heavy use of agrochemicals, especially NPK fertilizers, has caused soil degradation and, ironically, low production – for example in the taro export industry in Fiji, which largely ignored the biology, ecology and ecosystem functions of soil. Intensive and continuous cultivation, which depletes SOM, and use of agrochemicals have had an impact on coastal marine ecosystems through soil and fertilizer runoff. Thus commercial farmers in the Pacific Islands need to minimize the use of agrochemicals while employing practices that increase SOM and nutrient use efficiency to maintain productivity and minimize environmental impacts.

Increasing SOM in degraded soils has been shown to increase agricultural production, sequester carbon dioxide, increase biological activity and enhance soils' water capture and retention (Gachene, 2016). However, few scientific studies have explored how farming practices influence the soil's ability to provide these ecosystem services in the subregion (Leo, Wang and Tautai, 2014). It is important to explore the traditional and introduced practices that some countries in the Pacific have used or currently use which are likely to conserve and/or enhance SOM, and therefore allow the soil to perform its ecosystem services.

Traditional practices

A number of traditional practices in the Pacific Islands have merit for enhancing or maintaining SOM levels. Unfortunately, most of these practices have been abandoned with the introduction of modern industrial farming technologies. They are highlighted here for potential integration with introduced technologies.

Single-stick cultivation (minimum tillage). The use of a single stick for cultivation has been a common practice for planting vegetables and root crops in the Pacific Islands (Tutua and Jansen, 1994). It is usually a 2.1-m stick sharpened into a wedge on one end and levered into the soil to make an opening for planting. The opening is usually filled with organic debris or mulch. On slopes the stick is levered at a slanting angle along the direction of the slope, so the opening traps soil or organic matter that is moving along the slope. The single-stick method is a form of minimum cultivation that minimizes soil disturbance and therefore soil and SOM loss through erosion. The stick also minimizes aeration and therefore oxidation of SOM. Thus the single stick is an important soil and SOM conservation practice. However, with the introduction of modern cultivation implements the use of this practice is diminishing.

Slash and mulch. The slash and mulch method of farming (Tutua and Jansen, 1994; Jansen and Maemouri, 2000) is practised along with single-stick cultivation, although less frequently now, in Papua New Guinea and Solomon Islands. In New Hanover, Papua New Guinea, farmers would clear the undergrowth of the forest and ringbark the stems of the standing trees before planting taro (*Colocasia esculenta*). The ringbarking caused the trees to lose their leaves or foliage, which dropped to the ground where the taro was planted. On Guadalcanal, Solomon Islands, instead of ringbarking, the farmers would cut trees to the ground where yams (*Dioscorea esculenta*) were planted, using the cut trees for mulching and trellising or staking for the emerging yam vines (Jansen and Maemouri, 2000). This practice contributes to the accumulation of SOM and nutrients in the soil. The mulch is also likely to minimize soil water loss and provides a favourably cool environment for soil biological activity, as evidenced by the high yields in this farming system.

Taro terracing method. Terracing of neatly packed stones was used in the past to plant taro on hillsides in the Pacific Islands. The remains of these terraces can be found in Cook Islands, Fiji, New Caledonia, Palau, Samoa, Solomon Islands and Tahiti (Allen, 1971; Ferentinos, 2000; Tutua and Jansen, 1994). Terraces help to build up soil fertility by trapping silt and debris on the hillsides, and they also minimize siltation of nearby coral reefs. This traditional method of farming was a type of permanent agriculture, allowing taro crops to be continuously cultivated on the hillsides without compromising yield. In many cases, the terraces were flooded through an elaborate irrigation system. Flooding was sometimes used to control taro beetles.

Composted sweet potato mounds. Perhaps the most well-assessed and documented traditional practice is the use of composted mounds for planting sweet potato, a method still in use in the highlands of Papua New Guinea. Harvest residues or other green biomass from a fallowed garden are piled into the centre or crater of a circular mound 2 to 4 m in diameter and covered with soil until the mound is 0.6 to 1.5 m high (Taraken and Ratsch, 2009). These mounds are then planted with sweet potato as the main crop, although mixed cropping has also been reported. The mounds are cropped with multiple harvests before they are destroyed and rebuilt as before or left to fallow. A number of studies in the region showed that composted mounds gave higher crop yield than those without compost (Bourke *et al.*, 1991; Preston, 1990). This practice improves soil structure and therefore aeration, infiltration, drainage and soil bulk density; maintains soil moisture and increases water-holding capacity; provides food and favourable conditions for soil organisms; and minimizes soil erosion by channelling water between the mounds (Taraken and Ratsch, 2009). In addition, trials in East New Britain Province, Papua New Guinea showed that composted mounds served to control major pest and disease infestations (Leng, 1982).

Introduced methods of enhancing SOM and soil ecosystem services

Many variations of traditional farming technologies that have been seen to enhance soil fertility and ecosystem services elsewhere have been introduced in the Pacific Islands, including conservation tillage, mulching, harvest residue retention, crop rotation, cover cropping with legume plants and use of animal manure and compost (Jansen, Tutua and Logan, 2011;

Tiemann *et al.*, 2015; Gachene, 2016) (Figure 4). In Guam and Kiribati, composting has been shown to improve soil bulk density, SOM, pH, nutrient distribution, water-holding capacity and other soil health parameters, and in turn to increase crop yield and quality (Figure 5) (Golabi, Iyekar and Denney, 2005; ACIAR, 2014). Cover cropping with mucuna or velvet bean (*Mucuna pruriens*) has also been studied as a method of soil improvement (Box 10).

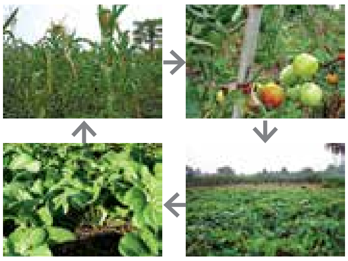
Jansen, Jasperse and Logan (2011) describe other practices integrating traditional and modern, introduced techniques in the Pacific Islands, such as incorporating nitrogen-fixing plants and elaborate multi-storey canopy systems into traditional agroforestry systems specifically to address the soil's role in climate regulation and adaptation to climate change. Integrating casuarina (*Casuarina oligodon*) in coffee plantings was shown to increase yields by about 400 kg green beans per hectare in Papua New Guinea (Kukhang, 2013). Casuarina–coffee systems increase biodiversity as well as fix atmospheric nitrogen through the symbiont *Frankia* sp.

Figure 4. **Farming practices that maintain or increase SOM and enhance soil ecosystem services**


MULCHING


COMPOST/MANURE


COVER CROPPING/FALLOWING


CROP ROTATION


RETAINING HARVEST RESIDUES

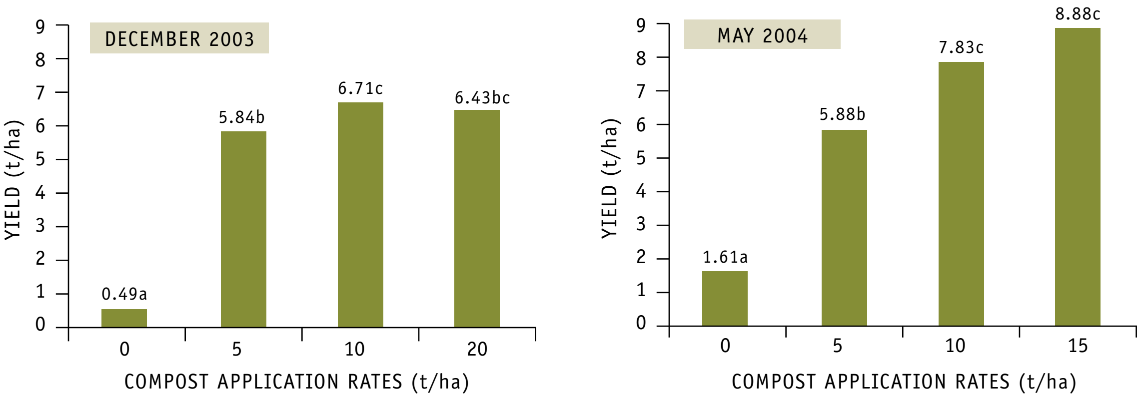

MINIMIZING CULTIVATION


TREE CROPS


INTERCROPPING


CONSERVATION OF TOPSOIL
e.g. using vetiver
(*Chrysopogon zizanioides*)

Figure 5. **Increase in yield of corn with increased compost application rates, Guam**



Source: Adapted from Golabi, Iyekar and Denney, 2005

Box 10. **Impact of mucuna cover cropping on soil properties and crop yield**

Mucuna pruriens is a legume plant that provides thick ground cover (Photo 8). It is usually grown for up to 6 to 12 months as a fallow crop before being slashed down for use as mulch on the soil surface or tilled into the soil. A number of studies in the Pacific Islands have shown that mucuna improves the nitrogen supply to the soil and to subsequent crops (DSAP, 2009; Lal, 2013; Anand, 2015). In Tonga, mucuna fallow was seen to improve soil's physical properties (DSAP, 2009). In Taveuni, Fiji, mucuna fallow also increased soil total organic carbon, phosphorus, potassium and earthworm count in comparison with a bare fallowed treatment (Lal, 2013). These observations were consistent with the increased biological activity attributed to mucuna in other parts of the world (Boateng, 2005). The increase in phosphorus is likely to be due to the activities of phosphate solubilizing bacteria (Rodriguez and Fraga, 1999; Chen *et al.*, 2006). A study in Samoa showed that mucuna fallow increased the population of free-living nematodes while suppressing the population of parasitic nematodes (Anand, 2015).

Photo 8. Mucuna pruriens *used as a cover crop and rotated around farm plots at Zai Na Tina Organic Farm, Solomon Islands*

© S. Tutua

Challenges in adopting ecosystem approaches to improving soil fertility

As indicated above, the Pacific Islands currently face two main soil fertility issues:

- declining soil fertility faced by subsistence farmers using little or no external inputs;
- soil and environmental degradation caused by overuse of agrochemicals to increase production by semi-commercial and commercial farmers.

Both of these situations require the same solution: an ecosystem services approach. However, although the benefits of ecosystem approaches to farming have been increasingly demonstrated in the Pacific Islands, the adoption of these practices has been slow for the following reasons:

- limited research on the benefits of ecosystem approaches to farming (in part because of inadequate data and information on the status of natural resources), resulting in limited understanding of the links among farming practices, ecosystem services and biodiversity conservation, in turn limiting the ability of stakeholders to resolve trade-offs and make evidence-based decisions on land-use planning;
- lack of government support or policies to encourage the adoption of ecological farming practices;
- agricultural extension officers' lack of knowledge and skills to demonstrate these technologies to farmers;
- aggressive promotion of synthetic pesticides and fertilizers by suppliers;
- the difficulty of reducing reliance on fertilizers, herbicides and pesticides in systems with longstanding use of such inputs;
- competing demands between economic gains and environmental quality.

Recommendations to capture soil ecosystem services in NBSAPs

While Pacific Island countries mention organic farming, agroforestry and sustainable land management in their NBSAPs, only five countries specifically mention soil fertility (Table 6). Attributes such as soil health, soil ecosystem services and their importance to biodiversity conservation are overlooked even in themes such as terrestrial ecosystem/biodiversity management, marine ecosystem management, aquatic/river system management and climate change adaptation, which are clearly influenced by soil ecosystem functions or services. Other potential themes that could capture soil ecosystem services are awareness and education and research and information management. Thus, it is recommended that each Pacific Island NBSAP include the following strategies for capturing soil ecosystem services.

- ecological farming or ecosystem services approaches, building on the integrated landscape-wide approach to land, water, forest, biodiversity and coastal management adopted in the Ridge to Reef Programme – a programme aimed at maintaining and enhancing ecosystem goods and services in PICTs to contribute to poverty reduction, sustainable livelihoods and climate resilience, supported by US$90 million from the Global Environment Facility (GEF) Trust Fund and US$300 million in co-financing (SPC, 2016d).

Table 6. **Mention of soil fertility and ecosystem services in Pacific Island NBSAPs**

COUNTRY	NBSAP BIODIVERSITY CONSERVATION THEMES			SOIL FERTILITY MENTIONED IN RELATION TO				SOIL FERTILITY IMPLEMENTATION IN RELATION TO TERRESTRIAL BIODIVERSITY CONSERVATION[a]	
	Total number	Number explicitly including soil fertility	Number that could include soil fertility	Sustainable economic development	Biodiversity	Ecosystem services	Agriculture	Current	Planned
Cook Islands	8	0	2	N	N	N	N	N	N
Fiji	7	0	3	N	N	N	N	N	N
Kiribati	8	0	1	N	N	N	N	N	N
Marshall Islands	5	0	2	N	N	N	N	N	N
Micronesia (Federated States of)	11	0	3	N	N	N	N	N	N
Nauru	8	2	3	Y	Y	Y	Y	Y	N
Niue	8	2	1	Y	Y	N	Y	N	Y
Palau	8	2	3	Y	Y	N	Y	N	Y
Papua New Guinea	9	0	3	N	N	N	N	N	N
Samoa	8	2	2	Y	Y	N	Y	N	Y
Solomon Islands	12	0	3	N	N	N	N	N	N
Tonga	8	1	2	N	Y	Y	N	N	Y
Tuvalu	8	0	3	Y	Y	N	N	N	Y
Vanuatu	6	0	3	N	N	N	N	N	N

[a] Based on NBSAP and latest national report to the CBD (fourth report for Cook Islands, Papua New Guinea and Tuvalu; second report for Marshall Islands; fifth report for all other PICTs)

» the use of ecological farming practices as climate change adaptation technologies, to address issues of soil and nutrient loss during heavy rainfall, nutrient pollution and siltation of coral reefs, which can affect biological diversity;
» agro-ecological practices such as no burning, harvest residue retention and compost application as climate change adaptation technologies for soil water retention during drought;
» the use of soil health or ecosystem services as the first line of defence for pest and disease control, as a means of reducing the use of harmful pesticides for biodiversity conservation;
» the use of cover cropping and crop rotation as methods to reduce weed pressure and therefore the use of herbicides;
» actions to promote and facilitate the importation of agro-ecological technologies and inputs, such as farmer-to-farmer knowledge exchange and South–South cooperation programmes, especially across the islands or among countries with similar tropical island contexts;

- support (financial or otherwise) for organic or ecological certification of agricultural products as incentive for enhancing soil ecosystem services and therefore conservation of natural ecosystems;
- integration of traditional practices, including agroforestry, in methods for enhancing soil health and biodiversity conservation;
- recycling and composting of household and municipal organic wastes to address issues of waste management, soil health, climate change adaptation and biodiversity conservation;
- support for research into soil management practices and ecosystem services in PICTs to fine-tune methods of promoting biodiversity conservation;
- incorporating ecosystem services approaches to farming in school and university curricula;
- mainstreaming ecosystem approaches to soil fertility management in all relevant government ministries (including, for example, agriculture, environment and natural resources and health) and promoting cross-sectoral and cross-ministerial collaboration;
- banning highly hazardous pesticides (HHPs), phasing-out noxious products and minimizing importation of synthetic fertilizers, while at the same time increasing farmers' capacity in the proper application of synthetic fertilizers;
- strengthening capacity in research, data collection and information systems management relating to soil fertility, ecosystem services and biodiversity conservation.

Soil fertility initiatives in the implementation of NBSAPs

A number of PICTs have undertaken initiatives on soil fertility and sustainable agriculture or land management to implement their plans in relation to biodiversity conservation and soil ecosystem services. The following are some examples.

The government-funded Grow and Green Project in Nauru (Government of the Republic of Nauru, 2014) has assisted households in planting local fruit-trees (lime, breadfruit, salsop) and coconuts to support food security and improve soil fertility while rehabilitating forest cover and its associated native flora and fauna. In collaboration with the Taiwan Technical Mission, the project has provided technical support to households and schools not only in tree propagation and care and nursery establishment, but also in composting, establishment of pits for compost production, and livestock production (piggery and poultry) as a source of manure for composting. Awareness raising activities and promotion of an enabling environment for supporting biodiversity conservation help support Nauru's programmes for rehabilitation of forest and vegetation cover.

In Tonga, the GEF-funded Integrated Land and Agro-ecosystem Management Systems project (GEF, 2016), approved in 2016 for implementation as a contribution to the Ridge to Reef Programme, aims to strengthen the resilience of communities by enhancing land tenure systems, improving forest management and piloting an integrated agro-ecosystem approach to rehabilitate degraded landscapes. The project seeks to maintain a sustainable balance among livestock production, crop production, forest ecosystem services and biodiversity conservation. Among other agro-ecosystem management activities, the project will provide organic fertilizer to increase crop production and improve soil fertility and will pilot an integrated piggery/biogas system to reduce the use of fuelwood, provide organic fertilizer and minimize pollution. The project will provide communities with knowledge, capacity and tools to plan and manage their broader environment.

On the island of Taveuni, Fiji, collaborative research among 300 farmers, relevant government ministries and SPC has led to the design of best practices for managing soils which integrate natural and synthetic interventions and allow intensification of taro farming (SPC, n.d.). Farmers have been taught about fertilizers, alternative nutrient sources, the use of mucuna as living fertilizer, crop rotation and alley cropping. They have also received hands-on training on soil sampling, reading soil tests and making compost. Scientific trials are ongoing to test various soil improvement methods such as fish manure, mucuna ground cover, rock phosphate and other chemicals and fertilizers as compared with current practices. During each harvest season in 2012 and 2013, data were collected from the soil to test the components and nutrients as well as the levels of insects and diseases. Initial results show that fish manure and rock phosphate worked well in promoting microbial activity, which has resulted in healthy soil and suppression of corm rot in taro.

6
EXPLOITING ECOSYSTEM SERVICES FOR BIOLOGICAL CONTROL OF PESTS AND DISEASES

Michael J. Furlong

Ecological pest management in agricultural crops seeks to suppress populations of noxious organisms below economically damaging levels by exploiting the services that agro-ecosystems can provide. Cultural practices designed to prevent or reduce the probability of infestation by these organisms have long been adopted in agriculture and include strategies such as crop isolation and rotation to reduce the spatial and temporal exposure of crops to pests. When pests do colonize crops, adoption of practices that promote healthy soils and the selection of crop varieties with at least partial resistance to key pests can reduce the susceptibility of plants to attack.

Biological control exploits the regulatory ecosystem services provided by the natural enemies of crop pests. It can involve:

- *in situ* conservation of natural enemies through crop and habitat management;
- mass production and release of existing natural enemies to augment their populations at strategic times;
- importation, mass production and release of exotic natural enemies to control exotic pests.

The use of broad-spectrum pesticides in agro-ecosystems can disproportionately favour pest populations in the long term. However, the crop habitat can be manipulated – for example through intercropping, planting of trap crops or management of resources for natural enemies in and around fields – to favour the natural enemies over the pests. Agronomic practices for growing a healthy crop can also contribute to its resilience to pests, even if the measures are not adopted with this objective in mind. Favourable practices include optimized planting time (early or synchronized planting), choice of cropping system (mixed cropping, intercropping and strip planting), crop rotation, use of plant genetic diversity, use of pest-resistant crop varieties, weed management, balanced fertilization and liming, and irrigation and drainage. Increasing the complexity in the crop environment and promoting healthy, biologically functioning soils is critical to sustainable pest management strategies that facilitate viable crop production and a healthy environment.

Habitat management (a form of conservation biological control) involves creating a suitable ecological infrastructure within the agricultural landscape to provide resources such as alternative prey or hosts for pests, and food and shelter from adverse conditions for natural enemies. Hedgerows, woodlots and other non-crop areas in agricultural landscapes are important sources of alternative prey for pest predators and hosts for parasitoids, as well as shelter from adverse conditions (including for hibernation).

Ecosystem services of ecological pest management

Regulating services

In the context of ecological approaches to agricultural production, the natural enemies (predators, parasites and pathogens) of crop pests and diseases provide valuable regulating ecosystem services that can be exploited to provide improved control of these noxious organisms. This suppression of pests by natural enemies is the fundamental regulating ecosystem service exploited in ecological pest management. Although it is difficult to measure the economic benefits of these services with precision, Pimentel *et al.* (1997) estimated that biological control of pests in crop and forest systems has a combined value of US$238 billion per year worldwide (2016 dollar value). In a more recent analysis, Naranjo, Ellsworth and Frisvold (2015) showed that classical biological control programmes typically have a cost:benefit ratio greater than 1 (ranging from 5:1 to >1000:1) but noted that their ongoing nature and the difficulty in accounting for all of the advantages that accrue from conservation biological control makes further economic analysis very difficult.

Supporting services

Certain practices can promote the regulating services provided by the natural enemies of pests through changes in the crop environment at the field, farm or landscape scale. Practices providing such supporting services include those that minimize harm to natural enemies and/or provide them with extra food sources and refugia – for example, management of non-crop vegetation to provide additional resources for natural enemies proximate to crops, or complementary crop management practices.

Practices for ecological management of insect pests and diseases

Most insecticides used in agriculture are synthetic nerve poisons that act on highly conserved components of animal nervous systems. As such, in addition to being toxic to the pest species that they target, their broad-spectrum activities render them extremely harmful to a wide range of organisms, including humans. Thus their use represents a direct threat to farm workers, and residues on crops are a danger to consumers. Because of their persistent nature, they can cause environmental contamination and pollution which may compromise ecosystem services even in spatially separated systems (Dadhich and Nadaoka, 2012).

Pesticides are often used inappropriately as prophylactic treatments with the aim of minimizing the risk of crop losses. Paradoxically, such indiscriminate use of insecticides increases the longer-term risk of crop losses because of their unintended effects on non-target components of agro-ecosystems. Arthropod predators and parasitoids (i.e. the natural enemies of pests) are typically more susceptible to synthetic insecticides than the pests on which they feed. When herbivores are freed from predation by natural enemies, pest populations are exacerbated, a phenomenon known as pest resurgence. In addition, the removal of natural enemies can create secondary pests, when herbivores that were previously maintained below economically damaging densities by natural control become a pest problem (Furlong *et al.*, 2004, 2008). Further, in some instances, repeated exposure of pests to insecticides can lead to the evolution of resistance, and in extreme cases to the presence of highly resistant pest populations that are devoid of natural enemies. This scenario effectively locks farmers onto the "pesticide treadmill", whereby the only apparent solution to pest problems is the application of more insecticide, which compounds the problems that their inappropriate use has created.

In certain crop systems, some pesticide use may be essential for commercially viable crop production to meet market demand (Devine and Furlong, 2007). However, biological control provided by natural enemies should be the cornerstone of pest management. When their use is essential, pesticides should be chosen judiciously. Modern selective products, which are less harmful to natural enemies and the wider environment than older broad-spectrum compounds, should be used, and they should be applied rationally in the light of pest and natural enemy abundance and the relationship between pests and crop damage.

Exploiting ecosystem services for improved insect pest management in *Brassica* crops in Fiji and Samoa

In Fiji and Samoa, the major *Brassica* crops are head cabbage (*Brassica oleracea* var. capitata) and Chinese cabbage (*Brassica rapa* var. pekinensis and *B. rapa* var. chinensis). A combined total of approximately 685 tonnes of these crops are grown in Fiji per annum (FAO, 2016b). In recent decades these leafy vegetables have become more important in local diets, and they represent attractive cash crops for smallholders and subsistence farmers. However, *Brassica* yields are typically low (8.5 tonnes per hectare in Fiji) compared with elsewhere (36.0, 31.6 and 21.4 tonnes per hectare in Australia, Malaysia and Indonesia, respectively) despite significant increases in the use of synthetic inputs in recent decades (FAO, 2016b).

In both countries the *Brassica* crops are attacked by a complex of lepidopteran pests that includes the diamondback moth (*Plutella xylostella*), the large cabbage moth (*Crocidolomia pavonana*), the cabbage centre grub (*Hellula undalis*), the cluster caterpillar (*Spodopotera litura*) and the semi-looper (*Chrysodeixis eriosoma*). *Plutella xylostella* and *C. pavonana* are ubiquitous pests of *Brassica* vegetable crops throughout tropical regions of Asia and the Pacific (Uelese *et al.*, 2014) and pose the major constraint to *Brassica* crop production in the Pacific Islands (Atumurirava, 2015; Tuivavalagi, 2016). The management of pest complexes in a crop presents a significant challenge, as different, and even conflicting, approaches may be needed to suppress different pests below economically damaging levels.

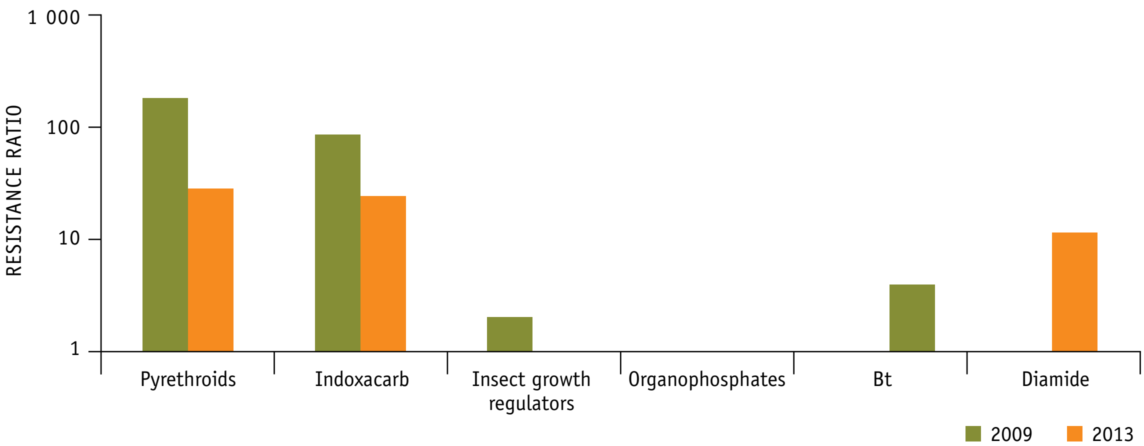
Broad-spectrum insecticides have historically constituted the single tactic for managing *Brassica* insect pests in both Fiji and Samoa. Most farmers typically apply insecticides to their *Brassica* crops every four days in Fiji (Atumurirava, 2015) and every eight to nine days in Samoa (Tuivavalagi, 2016). In Fiji the repeated and often exclusive use of one of the few broad-spectrum insecticides available to farmers has led to significant levels of insecticide resistance in *P. xylostella* (Figure 6).

In recent years a more holistic approach to insect pest management in *Brassica* crops based on improved farmer understanding of crop agronomy and of the significance of ecosystem services has been promoted in Fiji and Samoa. As part of this approach, farmer field school programmes have helped increase awareness of the importance of crop ecology, particularly the role of natural enemies in pest population suppression, and encouraged regular crop examination so that interventions to manage pests are rational, ecologically sound and sustainable.

An integrated strategy for the management of *Brassica* pests might include the following elements.

Natural enemies. The larval parasitoids *Cotesia vestalis* and *Oomyzus sokolowskii* have been established in Fiji as part of classical biological control programmes for *P. xylostella* (Waterhouse and Norris, 1987). For the other pests, parasitoids are either unknown or comprise incidental generalist species that do not provide significant levels of biological control. In Samoa the efficacy of parasitoids has not been investigated.

Figure 6. **Resistance to insecticides from different classes in Sigatoka Valley, Fiji, 2009 and 2013**

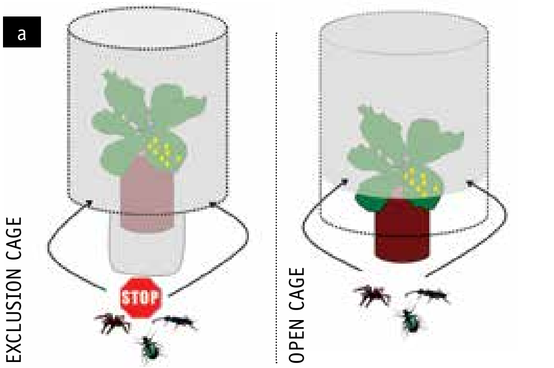


Note: Resistance ratio is the relative susceptibility of a given field population and a standard, laboratory population of the pest to a given insecticide

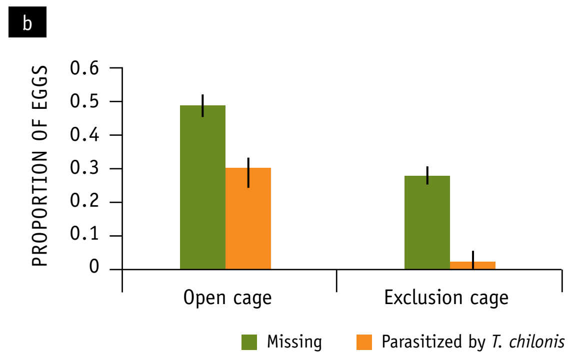
Source: Atumurirava, 2015

Habitat management. In crops where effective natural enemies of major pest species are established, management of adjacent non-crop habitat is an important practice to promote ecosystem services within the crop (Schellhorn, Bianchi and Hsu, 2014). Despite the paucity of effective natural enemies that attack *C. pavonana* throughout its range, mortality of *C. pavonana* eggs in *Brassica* crops in Samoa can be extremely high as a result of the combined action of predators and the parasitic wasp *Trichogramma chilonis* (which lays its eggs in the eggs of its hosts) (Figure 7) (Tuivavalagi, 2016). *Trichogramma chilonis* has a wide host range (Uelese *et al.*, 2014) and it attacks several species of Lepidoptera in Samoa. One of these, *Nyctemera baulus alba*, feeds on the common weed *Crassocephalum crepidioides* (known locally as "pualele"), which is associated with disturbed areas across the Pacific and which is

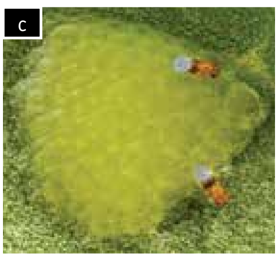
Figure 7. **Interactions among the cabbage pest *Crocidolomia pavonana*, its natural enemy *Trichogramma chilonis*, the lepidopteran *Nyctemera baulus alba*, the cabbage crop and the weed *Crassocephalum crepidioides* in Samoa**



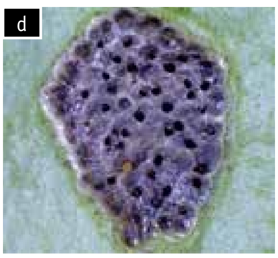
Cages used to compare the impact of natural enemies on *C. pavonana* egg masses in field experiments: Exclusion cages prevent access of natural enemies to eggs on plants, while open cages allow natural enemies to prey upon or parasitize eggs. Comparison of egg survivorship between the two treatments allowed the impact of natural enemies on the pest to be assessed.



In the absence of natural enemies (exclusion cages) fewer *C. pavonana* eggs went missing than in the presence of natural enemies (open cages) (P<0.001), and fewer eggs were parasitized by *T. chilonis* (P<0.0001), demonstrating the high impact that natural enemies can have on the pest in Samoa.



T. chilonis females parasitize a *C. pavonana* egg mass.



New *T. chilonis* adults exit a parasitized *C. pavonana* egg mass.

Healthy (white) and *T. chilonis*-parasitized (black) eggs of *N. baulus alba*. This alternative host for the parasitoid can supplement *T. chilonis* populations that parasitize *C. pavonana*.

Researchers monitor *C. pavonana* and *N. baulus alba* populations in an experimental cabbage crop seeded with *C. crepidioides*.

Source: Tuivavalagi, 2016

frequently found growing at the margins of, and sometimes within, *Brassica* fields in Samoa. Rates of *T. chilonis* parasitism in *N. baulus alba* eggs can be high, and the adult wasps that emerge from these eggs can move into *Brassica* crops to attack *C. pavonana* eggs. Thus weed populations in field margins can provide resources that can boost the populations of natural enemies of pests.

Minimizing pesticide applications. In an integrated pest management (IPM) strategy introduced in Fiji, data on natural enemy populations as well as on *P. xylostella* and *C. pavonana* abundance and distribution within the crop are used to inform strategic interventions with selective insecticides (M.J. Furlong, unpublished). Farmers can adopt high intervention thresholds at stages of the crop cycle when plants are least susceptible to pest damage and more conservative thresholds when the crop has lower pest tolerance. Broad-spectrum insecticides are removed from the production system, more environmentally friendly compounds such as *Bacillus thuringiensis* (Bt) (see Box 11) are introduced, and the total number of insecticide applications is reduced (Figure 8). In Fiji, adoption of this strategy by cooperating growers increased rates of *P. xylostella* larval parasitism to over 90 percent. The strategy has now been integrated into farmer field school programmes in Fiji, Samoa and Tonga, where it has led to significant increases in both the yield and quality of head cabbage crops (Figure 9).

Box 11. ***Bacillus thuringiensis* (Bt), a biological insecticide**

Commercial formulations of the biological insecticide *Bacillus thuringiensis* (Bt) contain insecticidal crystal proteins that are toxic to specific groups of insects. Bt products used in agriculture are highly selective for target pests but harmless to non-target natural enemies from different taxonomic groups (Shelton, Zhao and Roush, 2002). Consequently, Bt has been an important element of many IPM strategies for insect pests of *Brassica* crops, to substitute for broad-spectrum insecticides which destroy or disrupt arthropod natural enemies (Furlong, Wright and Dosdall, 2013). Collaboration among several regional and international agencies has facilitated the registration and importation of Bt in the Pacific Islands.

Bt has been integrated, for example, into an insecticide resistance management (IRM) strategy for *P. xylostella* that was launched in 2014 (Atumurirava, 2015). Selective insecticides with different modes of action are applied only when required and within clearly defined temporal windows to ensure that successive generations are not exposed to a given insecticide. Bt is now well established in the market in both Fiji and Tonga, and to date there is no evidence of *P. xylostella* resistance to it.

Figure 8. **Pest populations and insecticide use in typical farmer practice (commercial mixture of pirimiphos methyl and permethrin applied on a prophylactic weekly schedule) and under IPM (Bt applied rationally when the combined pest complex required suppression)**

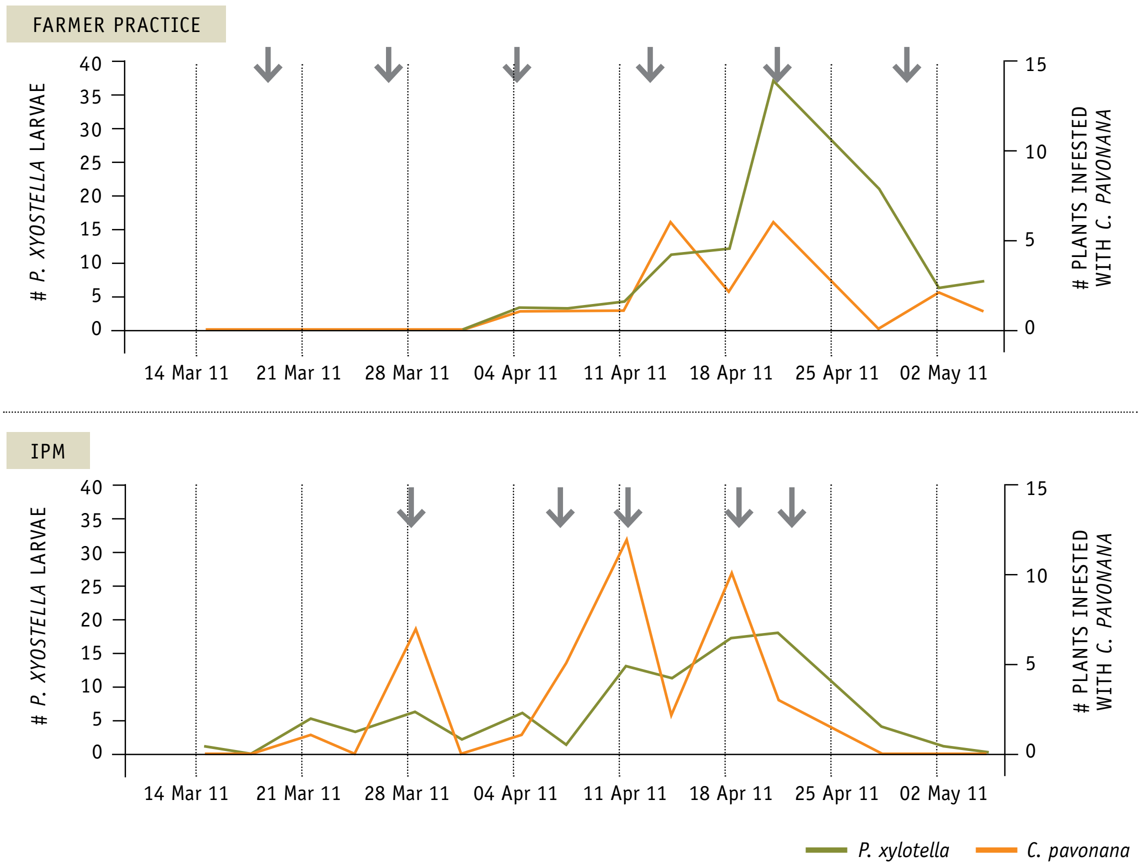
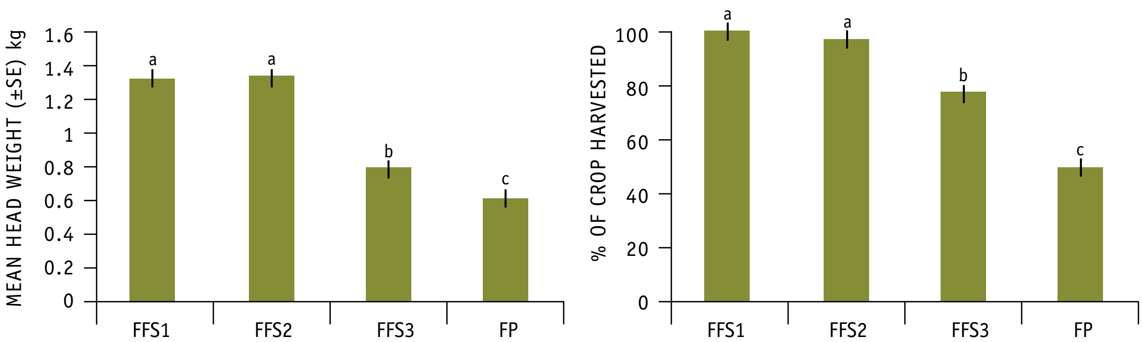


Figure 9. **Yields of head cabbage crops grown by groups of farmers adopting ecological practices in farmer field schools (FFS1–3) and a "control" group adopting usual farmer practice (FP)**



Note: A different letter above columns represents significant differences among columns (P <0.05).

Improved soil health for management of soil-borne pests and diseases of taro in Fiji

Across the Pacific Islands, recent intensification of production practices has neglected traditional fallowing practices. With the failure to replace nutrients and organic matter, soil health has declined (see Chapter 5). Many agricultural soils suffer from soil-borne pathogens that exacerbate problems associated with low fertility (Gunua, 2015).

In Fiji, taro (*Colocasia esculenta*) is an important crop for domestic and export markets and more than 67 000 tonnes are produced annually (FAO, 2016b), but in major production areas crop quality has declined in recent years due to increased incidences of corm diseases. Introduction of the legume *Mucuna pruriens* (mucuna) as a green manure to help rehabilitate soils used for taro production has resulted in reduced incidence of soil-borne diseases and increased taro yields. The improved soil structure and fertility promoted by *M. pruriens* changes the soil biotic community, leading to the suppression of pathogenic organisms (Gunua, 2015). Mucuna also has additional weed-suppression benefits (see Chapter 7).

Cultural control to replace pesticides in slipperi kabis in Solomon Islands

Abelmoschus manihot is an important traditional vegetable crop in the Pacific Islands, known as slipperi kabis in Solomon Islands, aibika in Papua New Guinea and bele in Fiji. In Solomon Islands, adults of the slipperi kabis flea beetle (*Nisotra basselae*) feed on the foliage, causing significant damage to the crop. Mated females crawl down the plant, enter the soil and lay their eggs close to the surface, in close proximity to the stem. Larvae feed on the roots and then pupate in the soil (Vaqalo, 2014).

In attempts to control the flea beetle, commercial producers often resort to foliar applications of hazardous broad-spectrum insecticides (Vaqalo, 2015). These interventions have little effect on the pest but cause environmental contamination, disrupt the agro-ecology of the system and leave toxic residues on the crop.

Blocking access to oviposition sites by covering them with coconut matting reduced egg densities by more than 50 percent and led to similar reductions in the adult population feeding on leaves (Vaqalo, 2014). Further development of this cultural control strategy based on physical barriers or disruption of oviposition sites has the potential to provide an ecological solution for the management of the flea beetle and reduction of pesticide inputs.

Challenges to the adoption of improved pest management strategies

Ecological methods of pest control are technically challenging to implement, and growers often associate them with economic risk. Thus, if farmers lack full knowledge of the benefits of these methods, there is a risk that they may regress to conventional pesticide-based pest control over time (Zalucki, Adamson and Furlong, 2009). Efforts are therefore required to promote longer-term adoption of the strategies, including:

- clear communication of the benefits of these practices, since in the vast majority of crop systems where natural enemies provide significant pest control services their economic value is not known (Naranjo, Ellsworth and Frisvold, 2015);
- explicit demonstration of the effectiveness of natural enemies in suppressing pest populations;
- improved scientific methodologies;
- farm-based research that involves farmers and investigates ecological interactions at the appropriate scale (see Furlong *et al.*, 2004, 2008).

Policy and institutional frameworks for adoption of ecological pest management in the Pacific Islands

In the Pacific Islands, National governments variously mention biodiversity and reducing the impact of agriculture on natural systems in policy documents and agricultural plans, but no country has a clear policy on the adoption of ecosystem services for improved pest and disease control. In order to promote the implementation of ecological pest management by exploiting ecosystem services to replace external inputs in Pacific Island agriculture, NBSAPs should:

- promote the importance of agro-ecology and the critical value of ecosystem services in the management of agricultural pests, stressing that the foundation of these management strategies should be the ecosystem services provided by the natural enemies of pests;
- ensure the availability to farmers of appropriate technologies and knowledge consistent with the promotion of ecosystem services for improved pest control through means such as regional information sharing and fostering collaboration between farmers and research and extension agencies;
- promote traditional farming methods to conserve biodiversity in agro-ecosystems;
- integrate strategies to promote the importance of ecosystem services for improved pest management in high school and regional and national university curricula;
- include strategies to replace hazardous pesticides with appropriate alternatives that are compatible with ecological approaches to pest management;
- build capacity in ecosystem services research in relevant national ministries, regional organizations and universities;
- functionally link research organizations with government and NGO extension agencies so that critical information on ecosystem services and how they can be exploited for sustainable pest management flows freely to farmers.

In recent years various agencies have cooperated to facilitate the creation of National IPM Coordinator positions in government ministries responsible for agriculture in Fiji, Samoa, Solomon Islands and Tonga. These officers provide a clear interface between research and farmers and have the opportunity to work closely with growers to advocate the benefits of natural enemies and the importance of the pragmatic use of pesticides. This is a critical step in developing farmer understanding of the utility and importance of natural enemies and a prerequisite for the integration of ecosystem services into mainstream pest management strategies.

Local farmers' knowledge and appropriate management of highly specific local resources are key for sustainable production. Strategies built on these principles can re-empower farmers as they regain control over the management of their land and crops and reduce their reliance on external inputs whose availability and quality is beyond their control.

7
ECOLOGICAL WEED MANAGEMENT[2]

Gualbert Gbehounou and Paolo Bàrberi

In the global quest for more sustainable cropping and farming systems, the emerging paradigm of ecological intensification exploits synergies between agriculture and biodiversity. Improved solutions stem from the use of (mainly) local resources including agrobiodiversity at gene, species and habitat/ecosystem level and improved knowledge of biological interactions in an agro-ecosystem. Within this framework, ecological weed management (EWM) is a set of practices using locally available resources (mainly at the gene or species level of agrobiodiversity) to attain long-term weed suppression without the use of synthetic herbicides. Although minimal and judicious use of synthetic herbicides may not necessarily jeopardize the overall efficacy of an EWM strategy, experience suggests that whenever herbicides are chosen as part of a weed management arsenal, overreliance on them and mismanagement are just around the corner. On the other hand, it is where herbicides are deliberately given up that EWM can deploy its full potential. This chapter focuses on weed management strategies and methods that do not imply the use of synthetic herbicides. Reference to them is only included where it is deemed helpful to provide an up-to-date picture on a given subject.

In the Pacific Islands, the most difficult-to-control weeds include *Chromolaena odorata, Commelina benghalensis, Cyperus* sp. and invasive alien plants such as *Mikania micrantha* (e.g. infesting taro, banana and sugar cane in Fiji) and *Parthenium hysterophorus*.

In the Pacific Islands, herbicide use by farmers to overcome weed problems has been increasing, exacerbated by labour scarcity in a context where manual and hoe weeding are the dominant practices. Of particular concern is the use of paraquat for weed control in taro and banana plantations. If ecological weed management is not promoted to counterbalance the increasing use of herbicides in the subregion, not only will environmental pollution increase, but herbicide resistance may become a major concern, as is already the case in other parts of the world.

[2] This chapter draws in large part from a chapter on the same topic in FAO's Technical Guidance Document *Mainstreaming ecosystem services and biodiversity into agricultural production and management in East Africa* (Gbehounou and Bàrberi, 2016).

Ecosystem services of ecological weed management

The most evident impacts of weeds are "disservices" more than services: decreased crop production, increased production costs (including seed cleaning costs) and increased resource consumption (e.g. of water and nutrients) without contribution to production. Yet in agro-ecosystems the weed community also provides a number of biodiversity-related services that can be enhanced through ecological management (Table 7).

Indeed "weed" is a relative term. In an EWM approach, it is important to distinguish between plant species that behave as weeds in a negative sense and those that can be beneficial, especially when their population does not significantly affect crop yield. This distinction can be made in any given agro-ecosystem context and in a participatory manner, i.e. with the active involvement of local farmers and other relevant stakeholders.

Table 7. **Ecosystem services of ecological weed management**

ECOSYSTEM SERVICE TYPE	ROLE OF ECOLOGICAL WEED MANAGEMENT
Regulating	> Reducing invasibility > Sustaining ecological trophic interactions > Natural weed seed predation > Allelopathic effects of crops on weeds
Supporting	> Providing habitat for biological pest control agents
Provisioning	> Allowing greater growing space for crops > Medicinal plants > Animal feed
Cultural	> Heritage weeds

Regulating services

Reducing invasibility. Proper weed management has been shown to discourage weed invasions. Weed species diversity can be an important defence against invading species.

Maximizing crop species diversity in time and space (e.g. co-presence and rotation of different crops in the same field) is considered the most effective management tool for maintaining crop health and weed community diversity and for limiting weed invasions.

Sustaining ecological trophic interactions. It is known that some so-called weeds may support organisms belonging to higher or lower trophic levels, e.g. natural enemies of crop pests delivering a biological control service. The following are the most important agro-ecosystem services that weeds can provide.

» **Increased soil fertility.** In this regard one plant species emerges above all the others: *Chromolaena odorata*, which is not perceived as a weed in some areas. For example, in West Africa it is valued as a useful fallow plant that can considerably increase soil fertility, even in a short time period, and therefore boost crop productivity.

- **Biological regulation of pests, diseases, nematodes and other weeds.** Aqueous extracts of many weed species have been discovered to interfere negatively with the establishment of important crop diseases and parasitic nematodes, and some may also be used to control other weeds through allelopathic mechanisms (Mahmood *et al.*, 2014; Yahya *et al.*, 2014).

Natural weed seed predation. Seed losses due to predation may be an important mechanism in ecological weed management. Depending on tillage practices, weed seed predators may have strong impact on the fate of weed seeds and of seedling establishment; less disruptive tillage favours greater seed predation. Soil treatments that lead to higher plant diversity and density also tend to favour weed seed predation by arthropods. In a vineyard in California, United States of America, seed predation rates were from 20 to 40 percent in soil under a cover crop, twice that observed in a herbicide-treated soil (Sanguankeo and León, 2011).

Conceptually similar to weed seed predation by insects is the use of grazing animals to consume weeds. One of the most popular systems of this kind is the rice–duck system, which is relatively common in East Asia, especially under organic production. A study of the long-term effect of rice–duck farming on weed seed banks showed that after nine years total weed seed bank numbers and density in the field decreased by more than 90 percent (Li *et al.*, 2012).

Allelopathic effects of crops on weeds. Crops may have inherent weed-suppressive properties through allelopathic traits; these can be enhanced through cultural practices. This feature has been particularly noted in rice, and the allelopathic traits are found even in high-yielding varieties (Kong *et al.*, 2008). Similarly, some cover crops may have allelopathic potential (Labrada, 2008).

Supporting services: providing habitat for natural pest control

A limited presence of weeds may benefit pest control, as diverse weed communities likely support a diverse herbivore community, providing alternative prey and therefore enhancing the effectiveness of biological pest control (Harker, Clayton and O'Donovan, 2005).

Provisioning services

Some weeds are useful for humans and animals, e.g. as a source of medicines, as feed for cattle, poultry or fish, as renewable biomass for on-farm use or for bioremediation of polluted soils (Stintzing *et al.*, 2004; Willcox *et al.*, 2007).

Weeds that have long coexisted in farming ecosystems are often appreciated for their medicinal attributes. Species-rich agricultural fields usually have subthreshold weed communities which may harbour species important in traditional medicine.

Cultural services

Heritage weeds. Somewhat unexpectedly, weeds may have strong cultural values. For example, in the United Kingdom, it is recognized that numerous weeds have evolved in continuously cultivated landscapes. Many of them were introduced with grain crops by the first farmers, thousands of years ago; thus they have become an integral part of countryside landscapes. With dramatic changes in agriculture over recent decades, including the move to autumn-sown cereal crops, the decrease of overwintered stubble and increased use of fertilizers and broad-spectrum herbicides, some "heritage weeds" such as violet horned poppy and corn woodruff are now extinct or threatened with extinction. The fact that communities and NGOs have mobilized to protect these species is an indication of the cultural value of heritage weeds.

Practices of ecological weed management

Weed management methods can be grouped in three categories:

» **Preventive methods** are applied before a crop is grown. Their main effect is to reduce weed emergence during the crop growing cycle.

» **Cultural methods** are applied during the crop growing cycle. Their main effect is to increase the competitive ability of the crop against weeds.

» **Direct methods** are those applied during the crop growing cycle with the specific aim of eliminating emerged weeds. These methods include the use of synthetic or natural herbicides (chemical methods); the use of harrows, hoes or other tools (mechanical methods); flame weeding (thermal methods); other minor physical methods (e.g. use of electromagnetic waves or cold temperatures); the release of insects or pathogens for selective control (biological methods); and hand weeding.

EWM – a concept still in its infancy – can be defined as a combination of methods aimed to achieve long-term weed suppression through the use of ecological interactions among crop, weeds, soil and/or other taxa, fostered by appropriate agro-ecosystem management with the least possible use of direct weed control methods. In this sense EWM is similar to the original concept of integrated weed management (IWM), first adopted in 1982 as an extension of the aims and concepts of IPM. In IWM, weed management, like pest management, was considered as one important component of overall agro-ecosystem management. IWM was conceived as an approach integrating all possible means of control (agronomic, genetic, biological, physical and chemical), but with a main emphasis on prevention. However, over 25 years of practice it was usually (erroneously) considered an approach combining the use of synthetic herbicides with other non-chemical direct weed control methods (mainly mechanical).

EWM stresses the importance of avoiding both chemical and mechanical inputs, the latter being increasingly recognized as an environmental problem because of fuel consumption, soil degradation and production of greenhouse gases (even in systems with no synthetic herbicide use, such as organic farming). It can be applied to any cropping, farming or management system anywhere.

Among 521 papers reviewed for this chapter, only 7 percent explicitly used the term "ecological weed management" in their title or abstract, but most dealt with EWM approaches and methods. The refinement of the EWM concept and clarification of its role in the context of IWM could be instrumental to increase its adoption rate.

Examples of success stories in EWM include:

» the use of trap crops to stimulate suicidal seed germination in parasitic weeds (*Orobanche* spp., *Phelipanche* spp., *Striga* spp.);
» the continuous development and use of resistant or tolerant crop cultivars to minimize damage from parasitic weeds;
» the introduction of legume-based intercrops or fallows to improve weed management and soil fertility and to reduce considerably (sometimes to nil) the use of herbicides and fertilizers.

Methods and tools for ecological weed management

Methods of EWM are based on three mechanisms: reducing weed emergence, improving crop competitiveness and reducing the size of the seed bank (Table 8). The following methods are all available for EWM in the Pacific Islands.

Table 8. **Methods of ecological weed management**

METHOD	MECHANISM	APPLICATION TIMING	CATEGORY	EXAMPLES
Mulching	Reduced weed emergence Increased crop competitiveness	Before/during crop cycle	Preventive Cultural	Dead mulching Plastic mulching
Sowing/planting pattern	Increased crop competitiveness	During crop cycle	Cultural	Increased seeding rate Reduced distance between rows
Transplanting	Increased crop competitiveness	During crop cycle	Cultural	Use of transplants instead of seeds
Fertilization (localized)	Increased crop competitiveness	During crop cycle	Cultural	Banded fertilization Seed dressing
Irrigation (localized)	Increased crop competitiveness	During crop cycle	Cultural	Drip row irrigation
Competitive/ resistant genotypes	Increased crop competitiveness	During crop cycle	Cultural	Use of cultivars with higher tillering ratio and/or allelopathic potential, or resistance to parasitic weeds (e.g. *Striga* spp.)
Polycultures	Increased crop competitiveness	During crop cycle	Cultural	Intercropping Living mulches Agroforestry
Seed predation	Reduced weed emergence	Before crop cycle	Preventive	Untilled field margin strips to attract seed predators
Seed decay	Reduced weed emergence	Before crop cycle	Preventive	Incorporation of residues Green manures or composts
Increased germination	Reduced weed emergence	Before crop cycle	Preventive	False or stale seedbed technique Use of germination stimulants
Prevention of seed shedding	Reduced weed emergence	Before crop cycle	Preventive	Stubble cultivation or spraying
Direct weed control methods	Elimination of emerged weeds	During crop cycle	Direct	Chemical applications Physical (e.g. mechanical, thermal) Biological

Reduction in weed seedling emergence. Seedling emergence can be reduced, for example, by covering the soil surface using either natural or artificial mulches. Mulches make the environment at the soil surface unsuitable for weed emergence by acting as a physical barrier, altering radiation or releasing allelopathic compounds (Davis, 2010).

Improved crop competitiveness. Solutions based on this mechanism include any management practice that shifts the temporal and/or spatial access to resources by crop and weeds in a direction favourable to the former and unfavourable to the latter. The following are some examples.

- **Altering the sowing or planting pattern.** Increasing the seeding rate of crops can make them more competitive against weeds by creating a denser crop canopy (O'Donovan *et al.*, 2013). However, there is an upper limit of canopy density (varying by crop) beyond which the competition among crop plants becomes too strong, making increased seeding rate of no further practical use.
- **Transplanting.** Along the same line, the use of transplanting instead of sowing can make the crop more competitive than weeds by shifting the temporal access to resources between the larger plants (the crop) and smaller ones (the weeds) (Bàrberi, 2002).
- **Proper management of fertilization and irrigation.** Specifically, localizing the application of fertilizers and water along the crop rows can alter competitive relationships between crops and weeds by facilitating capture of these resources by the nearest and strongest neighbour, which is usually the crop (Petersen, 2005). This can be seen as a way to shift the spatial access to resources between closer – and usually larger – plants (the crop) and more distant and smaller ones (the weeds).
- **Use of competitive genotypes.** Competitive relationships between crops and weeds can be altered by selecting cultivars that possess competitive traits within the available gene pool of a crop. In general, such traits include higher seed vigour, quicker emergence, greater height, greater tillering or branching tendency and a more developed root system (Andrew, Storkey and Sparkes, 2015). In addition, some crop cultivars can produce a relatively high amount of secondary metabolites with allelopathic potential, as has been shown in wheat, sorghum and rice (Sangeetha and Baskar, 2015). Using cultivars with increased competitive ability against weeds is an important tool in EWM because it can reduce the need to apply direct weed control measures (including herbicides) during the crop growing cycle.
- **Application of polycultural systems.** Cropping and farming systems in which two or more plant species occur together in the same area (e.g. field) provide more productive and non-productive agro-ecosystem services than systems in which each species is grown alone. Polycultural systems are common in many tropical and subtropical areas of the world and yield clear potential for improved weed suppression anywhere (Picasso *et al.*, 2008). In annual systems, polycultures take the form of either intercrops (where all plant species, usually two, are cash crops) or living mulches (where a cash crop is grown side by side with a companion plant whose biomass is not taken out of the system because it is recycled to improve the system itself, including the performance of the cash crop). In some agricultural systems it is not easy to distinguish between an intercrop and a living mulch because the companion plant may at times be used as fodder or for other on-farm purposes. Different types of polycultures

include relay cropping (where a second species is interseeded within an already existing crop and concludes its life cycle after the crop has been harvested) and agroforestry systems (where annual and perennial plants – shrubs and/or trees – occur together. Mixed farming systems that include animals are properly called agrosilvipastoral systems.

Reduced seed bank size. Most weeds on agricultural land reproduce and survive as seeds. Thus the soil weed seed bank represents the main source of future weed infestations. The weed seed bank can be depleted by increasing seed losses and/or reducing seed inputs, in the following ways.

- **Attracting seed predators.** Weed seed predation, especially after seeds have been shed on soil, may be an important determinant of seed bank losses (Davis *et al.*, 2013). Insects and small rodents are the main contributors to weed seed predation. Thus manipulation of agricultural habitats to attract them (e.g. through no tillage, delayed stubble cultivation, introduction of uncultivated strips within fields or as field margins) is expected to decrease the weed seed bank (Landis *et al.*, 2005).
- **Promoting weed seed decay.** The mechanism of weed seed decay is so far poorly understood and consequently poorly exploited. It refers to the creation of soil conditions that are conducive to increased seed mortality, for example through fungal attack. Some interesting results have recently been noted; however, differences in weed species susceptibility to decay indicate a need to develop species- and cropping system-specific management solutions (Gómez, Liebman and Munkvold, 2014).
- **Increasing weed seed germination.** Methods for increasing seed germination include the false and stale seedbed techniques, i.e. early soil seedbed preparation to stimulate germination and emergence of weed seedlings that are subsequently destroyed before the actual crop seeding or crop emergence takes place (Cloutier *et al.*, 2007). In the false seedbed technique, weed seedlings are usually destroyed by harrowing or using similar mechanical tools, whereas in the stale seedbed technique chemical herbicides or thermal methods (flame weeding or soil steaming) are used to avoid any further soil disturbance.
- **Fatal germination.** Weed seed losses can also occur when seed germination is not followed by seedling emergence, usually because the seed is placed too deep in the soil (when deep ploughing is practised) and has not enough reserves in its endosperm to sustain seedling growth until it reaches the soil surface and becomes autotrophic.
- **Preventing production and shedding of new seeds to avoid replenishing the seed bank.** Seed production and shedding can be prevented as an outcome of increased competition or as an effect of a well-planned crop rotation (Légère, Stevenson and Benoit, 2011). It is also important to prevent seed shedding from late-emerging weeds which, although usually unable to diminish crop yield in the same growing season, could create weed problems in subsequent crops or growing seasons through their seed inputs. Similarly, it is important to avoid weed seed shedding (e.g. by stubble cultivation or mowing) in the period between two crop growing cycles, which many farmers tend to disregard.

Possibilities for using biodiversity to address weed management in agro-ecosystems

Biodiversity-based approaches and tools offer ample potential for improving weed management in agro-ecosystems. However, this potential is not yet fully visible because the concept itself is blurred. Talking about "biodiversity" in general does not help in understanding how it can contribute to EWM. A much better term would be "functional biodiversity", defined as "that part of the total biodiversity composed of clusters of elements (at the gene, species or habitat level) providing the same (agro)ecosystem service, that is driven by within-cluster diversity" (Moonen and Bàrberi, 2008). Applied to EWM, this definition highlights the importance of selecting clusters of elements (e.g. cultivars, companion species, management or habitat types) possessing traits that confer better weed suppression ability (i.e. the agro-ecosystem service).

Depending on the context, the weed suppression service can be provided by:

» the traits possessed by a single element, e.g. the use of a *Striga*-resistant cultivar or the use of *Desmodium* sp. as companion crop to maize or sorghum ("functional identity");
» the complementarity of traits between or among elements, e.g. the use of a *Striga*-resistant maize or sorghum cultivar intercropped with *Desmodium* sp.;
» the diversity of traits within an element, e.g. the use of a New Rice for Africa (NERICA) rice cultivar with broad-spectrum resistance against several *Striga* ecotypes ("functional diversity").

Costanzo and Bàrberi (2014) presented these functional categories in detail.

The use of sound functional agrobiodiversity approaches and methods in EWM will rely on the improvement of basic knowledge on the autoecology and sinecology of target weed species and communities in target environments and cropping systems, and on a better understanding of soil–climate–crop–weed interactions as shaped by novel management practices. Important progress has been made in understanding the physical, chemical and biological interactions occurring when selected cover or trap crops, soil amendments or crop genotypes are included in cropping systems, unravelling a complex world with huge potential for improved weed management. For example, weeds can be managed by the production of chemicals and semiochemicals or the stimulation of (micro)organisms interfering with key life history traits of weeds such as germination, emergence, vegetative growth, reproduction and propagule survival.

Examples of ecological weed management in the Pacific Islands

Biological control of *Chromolaena odorata* in Papua New Guinea

Chromolaena odorata is a shrubby shade-tolerant weed which efficiently displaces other vegetation. Its distribution (which includes many PICTs) is typically so extensive that mechanical or chemical control is impractical or compromising (e.g. extensive use of herbicides would create environmental risks). The weed significantly reduces the area of land available for agriculture. Given the limited options available for controlling *C. odorata* in Papua New Guinea, where its impact is substantial, a stem-galling fly (*Cecidochares connexa*) was introduced as a classical biological control measure. The gall fly readily spread and established in 13 provinces – some populations reaching as far 100 km from their release sites – causing a decrease in the cover, height and density of *C. odorata* (Day, Bofeng and Nabo, 2011). *C. odorata* is now considered under control in nine provinces, and its management has allowed the re-establishment of food gardens and the regeneration of natural vegetation. Socio-economic surveys have revealed that with the reduction of *C. odorata*, there has been a significant reduction in the time spent on weeding and an increase in the size of food gardens, representing an increase in productivity and income for landowners. Indirect benefits reported included reduced habitat for snakes and wild pigs, a reduced need to erect fences around food gardens to exclude pigs, and fewer injuries from clearing *C. odorata*. It is anticipated that the gall fly will continue to spread and reduce the impact of *C. odorata* in Papua New Guinea.

Biological control of water hyacinth

Water hyacinth (*Eichhornia crassipes*) is an invasive weed species, native to the Amazon region of South America, which has spread widely and is regarded as the world's worst water weed. In the Pacific Islands it is reported from American Samoa, Cook Islands, Federated States of Micronesia, Fiji, French Polynesia, Guam, Marshall Islands, New Caledonia, Northern Mariana Islands, Papua New Guinea, Samoa, Solomon Islands and Vanuatu (SPC, 2010). Water hyacinth spreads rapidly, doubling in numbers approximately every five days and forming dense layers over the water surface (NSW Department of Primary Industries, 2015), causing a wide range of problems. It disrupts water transportation, which affects among others access to food gardens, fishing areas and local markets, as well as access of livestock to water bodies. It decreases the availability of oxygen in water, preventing sunlight from reaching beyond the surface and increasing evapotranspiration, resulting in depletion of stocks of fish and other aquatic organisms. It can hamper irrigation or water harvesting in drier areas. It may also damage infrastructure such as dams and drainage systems and create favourable conditions for water-borne disease by impeding the flow of water. Starting from the late 1970s, a number of natural enemies of the weed have been released and are now widely available in PICTs, contributing to successful control of its spread (SPC, 2010). While it may take some time for the biological control agents to act (reportedly two to six years), once they are established the ecosystem self-regulates; with the weed and the biological control agent living in equilibrium, little to no control efforts are needed in the long run. The savings in terms of economic, health and environmental impacts can be substantial.

Planting of mucuna for weed suppression

Mucuna (*Mucuna pruriens*), a ground cover planted as a soil improvement measure (see Chapter 5) and used in controlling soil pathogens (see Chapter 6), has also been explored for weed control (Photo 9). In Fiji, a study was conducted to investigate the impact of mucuna on the density and composition of weeds on fallow land at Koronivia Research Station (Macanawai *et al.*, 2013). Results showed that the density of jungle rice (*Echinochloa colona*), the most prominent grass weed species, was substantially lower in plots with mucuna than in plots without it.

Photo 9. *Mucuna (*Mucuna pruriens*), seen here planted in Niue as a soil improvement measure, may also help control weeds*

Trade-offs and synergies of ecological weed management

Several studies have shown that, besides enhanced weed suppression, EWM approaches and methods can simultaneously provide other agro-ecosystem services. However, other studies have shown the existence of trade-offs in which higher weed suppression reduced provision of other agro-ecosystem services (Table 9). Promotion of other agro-ecosystem services can also sometimes have a negative impact on weed management. For example, a *Tithonia diversifolia* living mulch can be beneficial to soil fertility and crop yield but may increase the risk of *Striga hermonthica* infestation (Smestad, Tiessen and Buresh, 2002). Such results are normal in functional agrobiodiversity studies. If acceptable compromises are not possible, conflicts among services can only be resolved by prioritizing one at the expense of the others.

Some studies have addressed the selection of cover crops based on multiple traits that can provide several services, such as weed suppression, soil erosion control, soil water and nutrient provision and biological pest control. This interesting approach should be fostered in future participatory studies carried out in the Pacific Islands.

Table 9. **Trade-offs of EWM: cases in which methods for enhanced weed suppression may reduce other agro-ecosystem services**

EWM METHOD	AGRO-ECOSYSTEM SERVICE PENALIZED
Reduced row spacing	Crop yield
Grass mulch	Crop yield
Cover crops (e.g. mucuna)	Pest control (increased pest presence observed in some studies)

Challenges to adoption of ecological weed management and how to foster it

A number of factors have been identified that may hinder adoption of EWM, related to its applicability, efficacy, reliability and compatibility with curative weed control measures (Bastiaans, Paolini and Baumann, 2008) as well as the trade-offs between weed suppression and farmers' other objectives mentioned above.

Cultural weed control (or EWM) is more crop specific than the use of chemical herbicides and difficult to standardize. Farmers wary of innovation will have more difficulties in embracing EWM approaches and methods. On the other hand, it should not be forgotten that where herbicides are concerned, the standardization of weed management practices is the primary cause of exacerbation of weed problems, specifically the development of herbicide-resistant weed biotypes. Consequently, weed management (as well as cropping system management in general) should be diversified and adapted to local conditions. Successful application of EWM is region specific and depends on local socio-economic conditions. However, lack of uptake is often not a question of the appropriateness of the EWM approach and methods as such, but rather the lack of a participatory approach to weed management and the limited knowledge exchange between scientists and practitioners. If participatory actions can be strengthened, EWM will have a much broader application than it presently has, with more locally appropriate "tailor-made" weed management.

EWM methods have highly variable effects, which may limit their overall efficacy and reliability. However, the greatest strength of EWM may lie in the integration of methods and their interaction effects, the so-called "many little hammers" approach (Liebman and Gallandt, 1997), which usually shows results in the long-term. A diversified weed management system calls for more complex overall cropping system management, which some farmers may find too complicated to apply. Nevertheless, when serious trouble arises (e.g. herbicide-resistant weeds), the only option is to rely on a plethora of tactics integrated within a sound and targeted overall weed management strategy.

EWM places a strong emphasis on prevention of weed problems, which implies a necessary shift in farmers' attitude to weed management, i.e. from the application of curative (direct) measures to that of preventive measures. Beyond weed management, such a paradigm shift – the basis of the agro-ecological approach – is of paramount importance for the uptake of real sustainable/ecological intensification in future farming anywhere.

A participatory approach to the design, development and testing of EWM innovations has been recognized as a key factor by many authors. Farmers are often averse to innovation, especially when it is most needed. In the United States of America, a participatory "mental models" approach has been developed to identify the main obstacles to adoption of EWM (Box 12); it would be interesting to apply such an approach to EWM adoption in the socio-economic contexts of the Pacific Islands. This example illustrates how the long-standing wall dividing experimental and social sciences is slowly breaking down. Transdisciplinary collaboration and scientists' engagement in participatory research and action will be of fundamental importance to speed up and broaden the adoption of EWM approaches and methods.

Although, overall, research on EWM has been directed more towards occasional funding opportunities than towards coherent regional or transregional long-term funding and policy programmes, it can be expected that once EWM is more clearly defined, it will be fostered as a key component of sustainable/ecological intensification within the context of new policies and programmes established to promote it.

Box 12. **A "mental models" approach to identify obstacles to adoption of ecological weed management**

In the United States of America, a novel participatory approach has been proposed to investigate the adoption of EWM in organic production, where communication and collaboration among the scientific community, extension services and the organic farming community is considered weak. Zwickle, Wilson and Doohan (2014) developed a "mental models" approach to unveil the major obstacles against adoption of EWM. In the first step, they generated an expert model based on interviews with weed scientists and extension personnel and theories from behavioural sciences. This expert model highlighted two main issues:

» EWM is a complex strategy that may encourage farmers to solve their weed problems through an experimental, trial-and-error, heuristic approach;
» communication and outreach activities targeting organic farmers should emphasize the long-term benefits rather than the risks of EWM.

This first step should be followed by farmer interviews and development of a farmer decision model.

8
ECOLOGICAL MANAGEMENT OF INVASIVE ALIEN SPECIES

Greg Sherley

An invasive alien species is one that compromises or threatens to compromise a natural or human asset or human welfare (e.g. health). Invasive alien species are typically resilient to a wide range of climatic and physical variables (temperature, salinity, humidity) and are hence highly competitive with native species and resistant to many control practices.

Impacts and threats of invasive alien species have been well described in the literature (e.g. Reaser *et al.*, 2007 for island countries). They are usually broken down into three general categories:

» human health;
» native biodiversity (including terrestrial, freshwater and marine ecosystems);
» agriculture (including horticulture and aquaculture, with the main threat coming from invertebrates and weeds) (e.g. Photo 10).

Many individual invasive alien species threaten assets across more than one of these categories. For example, many weed species compromise both agricultural and biodiversity assets. Annual damage due to invasive alien species in all sectors has been estimated at more than US$1.4 trillion, or 5 percent of the world economy (Pimentel *et al.*, 2001).

Prevention

Prevention-based strategies, aiming to prevent the movement of species across borders, represent the most cost-effective means of reducing threats from invasive species (SPREP, 2009). An effective biosecurity system must work at four levels:

» pre-export control, to ban the export of known invasive alien species from locations where they are already established to others where they are not;
» pre-border control, to regulate the import of species to one island or country;
» at-border control, to prevent the arrival of species in one island or country;
» post-border rapid response or early intervention procedures, to eliminate immediately any potentially threatening species that has made its way into an island or country. This will be more effective (and less costly) the sooner the introduction is identified.

Photo 10. Merremia peltata*, a perennial invasive vine widespread in Pacific Islands, is well known for smothering all foliage, especially in disturbed habitats such as forest plantations*

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Strategies for preventing the introduction of invasive alien species must also include complementary and supportive instruments such as cost-benefit analyses; comprehensive statutes, policy and regulations; and education and awareness aimed at targeted sectors such as importers and travellers (Wittenberg and Cock, 2001). The unusual situation in the Pacific Islands is that since SIDS are often made up of archipelagos with islands that have different invasive species, there is a risk of incursions among islands in the same country. Samoa, for example, failed to restrict giant African land snail to Upolu and prevent its spread to Savaii. Hence many of the necessary prevention measures for national borders apply in-country to prevent the spread of invasive alien species in the Pacific Islands (Box 13).

Box 13. **Preventing introduction of alien pests: some successful cases**

Small Indian mongoose intervention in Samoa. The small Indian mongoose, which was introduced to many Pacific Islands in a naïve attempt to control rats, causes immense damage to native species, especially vertebrates. An incursion of a solitary mongoose (*Herpestes auropunctatus*) was discovered on the south coast of the main populated island of Upolu, Samoa in 2010. Following emergency response protocols, a successful delimitation survey and trapping programme was instigated around the discovery site (following expert advice from overseas), and the single animal was caught, avoiding a potential disaster for

CONTINUES →

Samoa's native vertebrate fauna. The captured mongoose's DNA was used to investigate its probable origin. It turned out that the animal was probably a "stowaway" on a timber shipment from Fiji (where the mongoose had been introduced to control rats in the sugar-cane industry). This example demonstrates the importance of rigorous border quarantine procedures as a preventive measure against invasive alien species.

Red imported fire ant. The red imported fire ant (*Solenopsis invicta*), originally from South America, has spread throughout the world and represents a major problem in some countries, for example the United States of America, where its damage – to native species and landscapes, but also to human health – is estimated in the order of billions of dollars. In agriculture, these ants may collect and eat seeds as well as attack new roots and shoots of plants, reducing crop yields (PIAT, 2016). The Pacific Islands may be particularly vulnerable owing to lack of native ant species. While other invasive ants have made their way into some Pacific Islands, so far the red imported fire ant has successfully been kept at a distance. The Pacific Ant Prevention Programme, led by SPC in partnership with other organizations such as the Pacific Invasive Initiative (PII) and The Nature Conservancy, has been instrumental in successfully applying a preventive strategy. When red imported fire ants were found on a yacht arriving in New Zealand, the programme alerted all islands in the region that the yacht had previously visited to make sure that the species had not been introduced. This example reinforces the idea that successful preventive strategies must be developed and applied at the regional level; it can offer an example for other island ecosystems, for example in the Caribbean, which may face similar threats from invasive alien species.

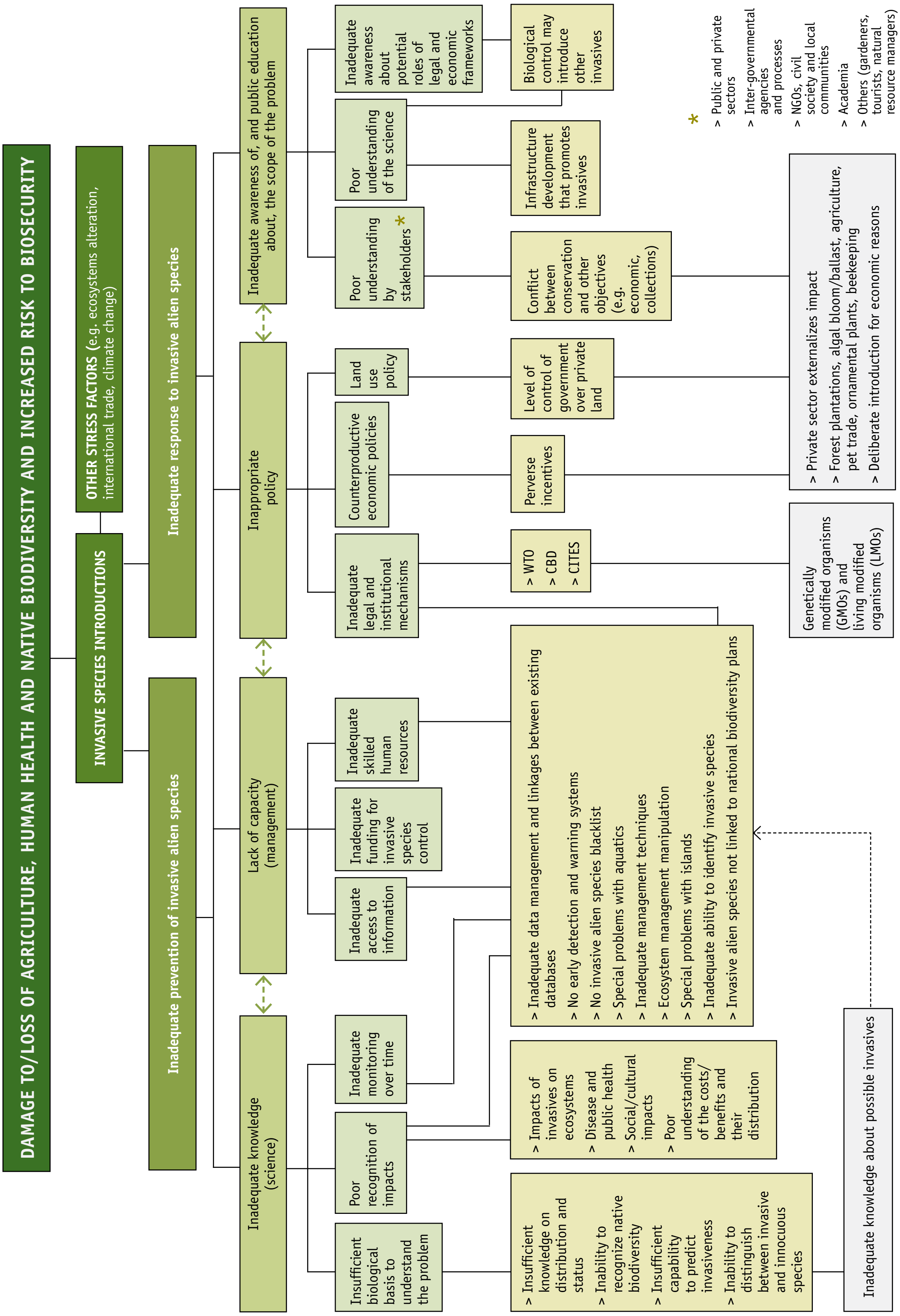
Management

Different approaches to managing invasive alien species target the problem at different levels:

- "Control" of invasive alien species, including containment and exclusion, refers to those practices used to reduce abundance and distribution in order to achieve economically sustainable agricultural production; recover natural assets, e.g. local biodiversity; or protect human health – depending on which asset is under threat.
- "Eradication" of invasive alien species refers to the complete removal of all individuals of a species from within a given area, which usually coincides with the spatial scale at which further invasions can be prevented, e.g. the national borders.

Figure 10 summarizes the elements that should be considered in defining the components of an invasive alien species threat. The diagram is a hierarchical map of most of the attributes that may be responsible for an invasive alien species problem and the relationships among them. It signals the depth and breadth of the questions that need to be asked in any project aiming to mitigate an invasive alien species threat.

Figure 10. **Invasive alien species problem tree**



Source: Summary of brainstorming by specialists on invasive alien species at an International Union for Conservation of Nature (IUCN) workshop, 1998

Challenges of managing invasive alien species in the Pacific Islands

Invasive alien species are a particular problem in the Pacific Islands, with introductions mounting as trade volume and routes increase. Climate change may increase the suitability of island environments for new pest species and may allow existing non-invasive exotic species to become invasive. Some existing threats, such as taro leaf blight, are likely to increase in some PICTs under projected climate change scenarios (Taylor and Iosefa, 2013).

Conventional management of invasive alien species in the Pacific Islands – that is, management largely based on the use of agrochemicals – is not working, as testified by the continued loss of productivity due to pest insect and mammal species (Photo 11) in recent decades despite increased pesticide use and the availability of more types of pesticides. New pests continue to be introduced, and insects and pathogens are developing resistance to toxins. The following are the main constraints to effective management of invasive alien species in the subregion.

Absence of natural enemies

In comparison with the continents where many pest species originate, the relatively depauperate fauna of PICTs does not offer the same options for natural enemies to control introduced species. Conversely, introducing natural enemies of invasive alien species (classical biological control or integrated pest management) raises island-specific issues. For example, it may be difficult to find optimal ecological conditions (e.g. patchy distributions of the target species in sufficient densities) for natural enemies to become established well enough to have a significant impact on the target species.

Photo 11. *Palm nuts eaten by rats, Malinoa Island, Tonga*

© David Moverley, SPREP

Lack of relevant knowledge

Traditional pest control methods based on local knowledge and millennia of experimentation will generally have low impact and be cheap and context specific. However, while traditional knowledge offers capacity for managing long-established pests, it may have limitations in coping with new incursions. IPM techniques customized for the Pacific Island context could offer a good entry point for combining reduced and proper application of selected non-harmful chemicals with a stronger focus on alternative options such as biocontrol, mixed cropping, retention of remnant or modified native vegetation and adjustment to timing of cropping.

Most of the literature relating to innovative control of invasive alien species in Pacific Islands farming systems is "grey literature" (institutional reports, records and documents) searchable on the Internet. Caution is needed in applying this information, however. The field of invasive alien species and biosecurity is highly technical, and related actions and recommendations should be based on best-practice, peer-reviewed science. Reliance on poor (unpublished) science could result in introduction of species liable to cause serious environmental harm. For example, agriculturists introduced the invasive flatworm *Platydemus monokwari* into Samoa hoping to control the invasive giant African land snail *Achitina fulica* based on informal reports of its success in Micronesia (author's personal observation). Unfortunately, there is no solid scientific evidence proving the effectiveness of the flatworm as a biological control agent, but it does present a threat to native land snail fauna (e.g. Iwai, Shinji and Chiba, 2010).

In addition, the challenges of managing invasive alien species in PICTs are aggravated by difficulties in communicating innovative best practices among scattered islands.

Relevant practices for an ecosystem approach to management of invasive alien species in the Pacific Islands

Population regulation is an old science with a huge literature for both wild and agricultural scenarios. However, while its principles are well understood, their application to local circumstances (especially on small islands) requires specific targeted scientific research. Interventions should be based on threshold levels of pest abundance and/or impact which need to be set *a priori* – implying a need for comprehensive monitoring programmes, which may be impractical or difficult to afford in many PICT situations. However, small PICTs have at least one advantage: their relatively depauperate fauna, which results in fewer ecological variables that might complicate predator–prey, host–parasite or host–pathogen interactions.

Ecosystem approaches to managing invasive alien species, that is approaches using fewer pesticides and intended to add value to existing ecosystem services (such as soil quality), are essentially the same as those used for managing native pests and weeds (see Chapters 6 and 7). They mainly involve:

- "classical" biological control, i.e. using a known species-specific enemy species to attack a pest species;
- biological control in combination with other methods such as pesticides and crop management – usually termed "integrated pest management";

» relying only on habitat management practices that have been seen to result in lower impact of pest species.

The following are some examples of how these approaches have been successfully used to manage invasive alien species in PICTs.

Taro blight in Samoa

Taro is typically produced from plantations. It is important for food security in many PICTs (including Cook Islands, Fiji, Palau, Papua New Guinea, Samoa and Tonga) and is also cultivated for export (e.g. in Fiji and Samoa).

Taro leaf blight is a major disease of taro, caused by the fungus *Phytophthora colocasiae* (Photo 12). The centre of origin of *P. colocasiae* is believed to be Asia. It is also present in Africa and the Caribbean, and was probably introduced to the Pacific Islands from the Philippines early in the twentieth century. The disease has been recorded in American Samoa, Federated States of Micronesia, Guam, Hawaii, Northern Mariana Islands, Palau, Papua New Guinea and Samoa). Cultural control (removing affected leaves) was found to be ineffective (at least in Samoa), and fungicides, while effective against *Phytophthera colocasiae*, are expensive and environmentally undesirable (Taylor and Iosefa, 2013).

Resistant taro varieties have been developed using genetic material from around Asia and the Pacific, and the new resistant genotypes have been distributed throughout the region for potential recombination with local varieties (Taylor and Iosefa, 2013). In Samoa, a proven process and facilities were developed for capturing genetically based improvements in taro, including a gene bank, clonal propagation, participation of local farmers in improvement breeding programmes and a variety distribution network. Today, Samoa's taro production for the domestic and export markets depends on leaf blight resistant taro. The new taro varieties have the same or improved productivity and palatability, and economic costs and dependency on fungicides have been reduced.

These benefits have also been made available globally and may have value in West African countries such as Cameroon, Ghana and Nigeria where taro leaf blight is an issue. Upscaling would be possible within the Pacific Islands, as Fiji (for which taro is a significant export commodity) may still have taro leaf blight susceptible varieties (Taylor and Iosefa, 2013).

Taro beetle management

Taro beetles (*Papuana and Eucopidocaulus* spp. [Coleoptera: Scarabaeidae]) are important pests in the Pacific Islands. At least 19 species are known. These beetles are native to some areas of the subregion, including Papua New Guinea, Solomon Islands and Vanuatu, but are alien to other islands such as Fiji. In all the countries where they are found, they are a serious threat to taro production and are the main constraint to improving its yield and quality (Lal, 2008).

In countries where they have been introduced, taro beetles have behaved like many adventive, r-selected species in new habitats without the usual constraints of co-evolved predators and other enemies. An EU–SPC project on taro beetle management studied the biology and ecology of taro beetles and explored control methods involving pathogens, chemicals and cultural means

Photo 12. *Taro leaf blight (*Phytophthora colocasia*) showing typical symptoms of advanced infection*

© P. Donohoe

in Papua New Guinea, where the species is considered native, and in Fiji, where the beetle was introduced in 1984 (Lal, 2008; ACIAR, 2013). The project also evaluated potentially resistant or tolerant taro cultivars, but no suitable varieties were identified.

The taro beetle project investigated the relative efficacy of classical biological control and chemical options for controlling taro beetles. Insecticides proved significantly more effective than the fungus *Metarhizium anisopliae* in reducing the impact of the beetles, probably because the fungus did not kill beetles immediately, allowing them to continue damaging corms, while the insecticides were acutely toxic. However, biological control options did demonstrate benefits in specific instances, particularly when *Metarhizium anisopliae* was applied in combination with a low dosage of one of the insecticides tested (Lal, 2008).

Cultural techniques used by farmers vary among countries and include manipulating planting time, flooding gardens, keeping taro gardens free of weeds, manipulating planting depth, mixed cropping, planting new gardens farther away from old gardens, applying wood ash, crop rotation, planting repellent plants, hand collecting adult beetles, and slashing and burning vegetation. However, the only method found to give good control of the beetle was planting taro away from old gardens in bush locations. The cultural methods were accompanied by some environmental costs – mostly clearing new forest for more plantations.

Cultural practices have yet to be combined with modern pest control approaches to create a holistic approach to pest management. However, the combination of biological control with insecticides was found effective in some tests in Papua New Guinea and may represent a way forward in controlling taro beetles (e.g. the safe use of insecticides in combination with *Metarhizium anisopliae*), probably eventually in tandem with cultural and pheromone-based methods. The use of plant-derived insecticides could also be explored, since plant extracts are thought to have been used historically by taro farmers to control beetles in their plantations before the advent of pesticides. Clearly, local combinations of methods need to be further developed.

However, beetle control still relies on insecticides, and capacity development (e.g. through farmer field schools) is needed to prevent, for example, inappropriate use of insecticides and the development of resistance. In addition, the use of chemicals – even synthetic pyrethroids, generally considered safe for humans – needs to be moderated in fragile environments with high water tables, such as Kiribati.

Feral pig control in Niue

Feral pigs (*Sus scrofa*) (Photo 13) can cause extensive damage to natural habitats and agriculture and are present as pests in most PICTs. In a pilot pig management programme in Niue (Craw, 2016), this damage was seen to affect seedling coconuts, coconut crab populations, soil invertebrates, soil structure and fertility transfer. Pig hunting has been a popular pastime for years and could remain so because the feral population is continuously being restocked with domestic escapes. Craw (2016) therefore advises against developing an eradication programme until housing, watering and feeding of domestic pigs can be brought up to standard. Instead, he recommends management to permanent low densities through scientific hunting with specially bred and trained dogs and sodium nitrite toxin delivered with a specially designed bait or lure (coconut oil carrier with split coconut lure). Incorporating a poisoning programme into the management activities will deter pig owners from allowing their animals to escape. Human behavioural strategies are also planned, including tagging all domestic pigs, neutering all non-breeding boars and registering piggeries. Single-catch cage traps were also recommended as a potential future method if other methods are not affordable. Bounty systems, in contrast, were found to be ineffective and prone to abuse. The Niue experience should provide priceless lessons for other PICTs.

Photo 13. *Feral pigs (*Sus scrofa*) may permanently damage the environment through their feeding habits*

© Department of Environment, Government of Niue

Tools and frameworks for management of invasive alien species in the Pacific Islands

International policy frameworks supporting management of invasive alien species and biosecurity in the Pacific Islands include:

- the International Plant Protection Convention;
- the World Trade Organization (WTO) Agreement on the Application of Sanitary and Phytosanitary Measures;
- CBD-related technical advice (since invasive alien species is a cross-cutting theme for the CBD);
- International Convention on the Simplification and Harmonization of Customs procedures (revised Kyoto Convention of 2006).

In addition a number of regional agencies and conventions are relevant, including:

- SPC and SPREP;
- the Convention on Conservation of Nature in the South Pacific (Apia Convention);
- the Waigani Convention to Ban the Importation into Forum Island Countries of Hazardous and Radioactive Wastes and to Control the Trans-boundary Movement and Management of Hazardous Wastes within the South Pacific Region.

In practice, SPC and SPREP are the main agencies providing immediate practical support to PICTs for biosecurity and management of invasive alien species, through specialized bilaterally funded projects and programmes (see examples in Box 14). SPC and SPREP also provide services including training and the use of tools such as pathway risk analysis, border control, quarantine and testing of biological control agents.

At the national level, the National Invasive Species Strategy and Action Plan (NISSAP) is probably the key mechanism for future national and interagency coordination and in-country resourcing of invasive alien species and biosecurity work. All PICTs have NISSAPs, all operationalized through projects supported by SPREP and SPC. The NISSAPs are exactly aligned with the countries' NBSAPs. Countries can commission UN Trust Fund projects (e.g. via the Global Environment Facility [GEF] System for Transparent Allocation of Resources [STAR] allocations to countries) to create the capacity for national-level implementation of NISSAPs and NBSAPs; such projects benefit agriculture and biodiversity conservation and hence are evidence of tangible progress in meeting the country's obligations and national priorities. In the near future, a number of regional GEF Trust Fund financed projects will facilitate monitoring and evaluation of progress on these and other environmental management activities in the Pacific Islands subregion – especially Pacific Regional Environmental Monitoring Capacity Development (GEF-5) and Pacific Invasive Alien Species (GEF-6) projects. In tandem with related ongoing programmes of other agencies such as SPREP and SPC, these projects should start to significantly improve the subregion's capacity to meet the challenges that invasive alien species present to both agriculture and biodiversity conservation, which are inextricably intertwined in the Pacific.

Box 15 provides links to some resources and tools available to practitioners operating in the Pacific Islands for management of invasive alien species.

Box 14. Selected SPC agricultural projects relating to invasive alien species

- Integrated control of powdery mildew and other disease, weed and insect problems in the squash industry of Tonga and Australia
- Biological control of mile-a-minute (*Mikania micrantha*) using a rust fungus (Photo 14)
- Management of taro beetle – insecticide evaluation
- Integrated weed management in PICTs, including Jerusalem thorn (Fiji) and parthenium weed (Papua New Guinea)
- Weed eradication: Tuvalu from soil imports; *Miconia calvescens* in New Caledonia; about 10 species in Solomon Islands; *Mimosa pigra* in Madang, Papua New Guinea; mile-a-minute in Pohnpei, Yap and Palau; African tulip in Chuuk, Federated States of Micronesia; chain of love and ivy gourd in Palau and Yap, Federated States of Micronesia; *Chromolaena odorata* in Marshall Islands
- Biological control of glassy winged sharp shooter in French Polynesia using the bioagent *Cryptolaemus montrouzieri*
- Biological control of spiralling white fly using bioagents and natural enemies including *Encarsia* sp.
- Biological control of the weeds *Sida acuta*, *Sida rhombifolia*, *Sida retusa* and water hyacinth (*Eichhornia crassipes*) in Vanuatu and Samoa
- Biological control of Siam weed (*Chromolaena odorata*) using natural enemies *Pareuchaetes pseudoinsulata* and *Cecidochares connexa*

Source: SPC, 2006

Photo 14. *The rapid spread of* Mikania micrantha *(commonly known as mile-a-minute), a vine native to tropical America, is a threat to both natural and agricultural environments, severely affecting biodiversity and production*

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Box 15. Some tools and resources for management of invasive alien species in the Pacific Islands

- Pacific Ant Toolkit (http://piat.org.nz)
- Global Invasive Species Database (www.issg.org/database/welcome)
- CABI Invasive Species Compendium (www.cabi.org/isc)
- Pacific Island Ecosystems at Risk (PIER) database on plant threats to Pacific Ecosystems (including risk assessments for invasive and potentially invasive species) (www.hear.org/pier)
- Cook Islands Biodiversity and Natural Heritage Database (http://cookislands.bishopmuseum.org/)
- Multilateral environmental agreements database for the Pacific Islands (www.sprep.org/attachments/MEA_database.pdf)
- Millennium Ecosystem Assessment (www.millenniumassessment.org)

Recommendations for consideration of invasive alien species in NBSAPs

It is important for countries to recognize the importance of the invasive alien species threat to biosecurity and the need for safe environmental management. Invasive alien species and biosecurity need to be tackled in an integrated manner, taking ecosystem services into account and capitalizing on the best technology available.

The following recommendations should be considered for inclusion in NBSAPs for environmentally safe and effective management of invasive alien species.

- **Prevention.** As mentioned at the outset, prevention is critical, as the cheapest and most effective strategy for managing the impact of invasive alien species.
- **Enhanced technical knowledge** is clearly required to tackle invasive alien species. Ecological management of invasive alien species – using natural methods such as biological control and habitat management to harbour natural pest enemies – requires further research across countries. Existing options should be applied based on feedback from ongoing research. However, the greatest cost associated with using biological control agents is the research and testing required by standard biosecurity protocols.
- **Knowledge and technology transfer.** Effective biological control interventions such as the control of *Chromolaena odorata* in Papua New Guinea (see Chapter 7), may have potential to succeed in other locations with similar ecological conditions. The introduction of new pests often necessitates the introduction of new practices. Farmers in PICTs face a number of challenges in adopting alternative management practices for invasive alien species. Social barriers and physical isolation greatly influence the dissemination and adoption of new

practices. Best practices for introduced pests can be transferred through outreach techniques such as the use of local farmer extension groups. In Taveuni, Fiji, for example, farmer support groups have been created modelled on "farmer teaching farmer" (or "islanders teaching islanders") methods. This has the dual advantage of providing incentives to farmers to adopt improvements and helping to bridge social barriers.

» **Strengthening capacity.** Technical capacity needs to be in place to handle the monitoring and evaluation requirements of biological control and to follow quarantine protocols necessary in the introduction of biological control agents. In addition, specialized facilities are required for the research needed to determine host/target species specificity and for breeding disease- or parasite-free inoculum material.

» **The role of rural women** in managing, *ipso facto*, invasive alien species in the subregion has been well documented (Balakrishnan, 1998) and should be recognized and enhanced. In Samoa, the organization Women in Business Development Inc. (WIBDI) plays a pivotal role in commercializing food production, organizing cooperative-style businesses and working at village level with all the organizations implicated in these activities (marketing, capacity building, transport, etc.). Such a local village-based model can be extended or copied to implement invasive alien species control, obviating the need to create new models or infrastructure.

» **Cross-sectoral collaboration.** The natural biodiversity aspects of invasive alien species (native habitat and natural ecosystems) and the human health and welfare and agricultural aspects (biosecurity) are typically handled by different government ministries with inadequate coordination. Efforts should be made to harmonize and link the two aspects, as the GEF-6 Pacific Invasive Alien Species programme is attempting to do. The support of SPC, SPREP and targeted bilateral aid should also emphasize such a joint focus.

9
ECOSYSTEM SERVICES OF ECOTOURISM IN AGRICULTURAL ZONES

Clare Morrison

The tourism industry has become one the fastest growing global industries and contributes approximately 5 percent to global gross domestic product (GDP) and more than 10 percent to GDP in developing regions (UNWTO, 2015). Increasing tourism pressure around the world, if not managed sustainably, poses socio-economic and environmental challenges, including possible negative consequences for biodiversity and ecosystem services (Box 16).

Ecotourism is a form of tourism that involves responsible travel to natural areas and helps conserve the environment; sustain the well-being of local communities socially, culturally and economically; and create knowledge and understanding through education (in staff, visitors and community members). In short, ecotourism is non-consumptive or non-extractive (i.e. it excludes hunting), creates an ecological conscience and promotes ecocentric values and ethics in relation to nature and its sustainable use.

The nature-based tourism sector (e.g. wildlife viewing, outdoor recreation such as hiking, agritourism), which is dependent on natural settings and environments, is a key ecotourism sector experiencing significant growth (Kuenzi and McNeely, 2008; Balmford *et al.*, 2009). It is widely recognized that these types of tourism are an important ecosystem service (MA, 2005) and are able to generate significant financial resources for local economic development and conservation management.

Box 16. Challenges of unsustainable tourism for biodiversity and ecosystem services

While ecotourism can promote biodiversity conservation, conversely, unsustainable tourism can have negative environmental, economic and social impacts through overuse and mismanagement. Tourism threatens 15 percent of all IUCN Red List species in the subregion; its impacts are more apparent in countries with relatively large tourism industries (Morrison, 2012). Only one current Pacific NBSAP (Palau) recognizes tourism as a threat to biodiversity. Thus most governments, tourism agencies, conservation agencies and other stakeholders in the region will be unprepared to manage its impacts in the short to medium term. The following are the main mechanisms for minimizing, avoiding and/or managing these impacts:

» **Development of sustainable tourism practices for each country, including environmental, socio-cultural and economic factors.** Such practices are already implemented at a local scale in a number of conservation areas (Morrison and Buckley, 2010). The challenge is to develop national-scale plans. To achieve this, conservation agencies and NGOs in the region will have to recognize the potential threat posed by tourism and work in conjunction with tourism agencies, local communities, regional development agencies and national governments.

» **Education and awareness on the potential negative impacts of tourism and the benefits of sustainable tourism.** Successful and sustainable nature-based tourism ventures generally involve extensive local community awareness and education, but most tourism agencies in the subregion fail to acknowledge the importance of maintaining the natural base on which the industry is dependent (Morrison and Buckley, 2010).

Ecosystem services of ecotourism

Many ecosystems are publicly manifest as important social or cultural places where people can come for rest, relaxation, refreshment, recreation and exercise (Simmons, 2013). While nature-based tourism directly draws on the environment and ecosystem services, this form of tourism can also directly provide or enable the provision of ecosystem services for other users. The most obvious and direct benefits of ecotourism for the conservation of biodiversity and ecosystem services are the protection of species, habitats and ecosystems for conservation purposes and sustainable livelihoods; and the generation of financial resources that can be used for conservation and/or local community economic development.

Ecotourism has a direct or indirect role in all four main ecosystem service categories (Table 10).

Table 10. **Ecosystem services of ecotourism**

ECOSYSTEM SERVICE TYPE	ROLE OF ECOTOURISM
Regulating	> Reducing land clearing > Promoting habitat regeneration > Reducing soil erosion > Decreasing water sedimentation
Supporting	> Providing species habitat > Protecting biodiversity > Protecting natural ecosystem processes, e.g. carbon sequestration
Provisioning	> Subsistence harvesting > Resources for cultural activities (e.g. traditional medicine, handicrafts)
Cultural	> Protection of cultural areas (e.g. old village sites) > Protection of cultural practices and traditional knowledge (e.g. traditional medicine collection, handicraft making, traditional harvesting practices) > Protection of heirloom seed varieties and endemic crops > Recreation > Education

Regulating services

Terrestrial nature-based tourism relies heavily on intact ecosystems and habitat for a range of activities including hiking, birdwatching, camping, rock-climbing and photo safaris (Gossling, 1999; Buckley, 2003). The presence of businesses or organizations offering activities of these types encourages a range of environmental protection strategies to enhance visitor satisfaction and conserve the natural base of the operations. These protective strategies can include bans on habitat clearing for other purposes (e.g. agriculture, logging), rehabilitation of land previously used for or degraded by other purposes, and restrictions on species harvesting (Eagles, McCool and Haynes, 2002; Morrison *et al.*, 2012). These actions can lead to the continued existence and integrity of natural ecosystems and their associated ecosystem services.

The maintenance of natural vegetation for ecotourism purposes (e.g. aesthetic value or provision of species habitat) helps regulate watershed flows under normal conditions, for example through maintenance of natural drainage and buffering of excessive waterway discharges in extreme conditions, such as floods or storms. The maintenance of natural vegetation also provides habitat for species at various trophic levels and with a range of trophic roles. Pollination is essential for most plants for reproduction, including crop species, and this function is provided by many wild species, including insects, birds and bats, that are dependent on natural vegetation for habitat. Increasing natural vegetation for ecotourism purposes can provide additional habitat for populations of pollinators and pest predators which can lead to increased agricultural production in nearby areas (Klein, Steffan-Dewenter and Tscharntke, 2003).

Supporting services

The relationship between biodiversity and supporting ecosystem services depends on the composition, relative abundance, functional diversity and taxonomic diversity present (MA, 2005). Nature-based tourism can contribute to community composition, species abundance and diversity through a range of conservation strategies. In addition to habitat restoration and rehabilitation, mentioned above, nature-based tourism can also promote species and community diversity directly through funding for introduction of key species, anti-poaching or land-clearing patrols, habitat protection and removal of invasive species, and indirectly through supplementary feeding (including introduction of prey species), community education and local community conservation-incentive and compensation programmes (Morrison *et al.*, 2012; Buckley, Morrison and Castley, 2016).

Provisioning services

While cultivated lands provide many provisioning services (such as grains, fruits and meat), habitat conversion to agriculture typically leads to reduction in local native biodiversity (MA, 2005). In the Pacific Islands and many other developing regions, a substantial part of the local diet still comes from wild plants and animals, and loss of this diversity can have significant impacts on human health and well-being. The protection of habitats and ecosystems for ecotourism purposes indirectly leads to the protection of species important to local communities for food, medicinal and ornamental purposes (Pegas, Grignon and Morrison, 2015). Sustainable ecotourism or nature-based tourism often permits small-scale subsistence harvesting in areas of tourism significance as long as the harvesting does not have significant impacts on the natural base of the tourism activity or visitor satisfaction (Pegas, Grignon and Morrison, 2015). In many community-based conservation areas, one of the conditions for local landowning communities' permission and participation in the tourism enterprise is that they can continue their limited subsistence harvesting of species that are not targets of the tourism – whether directly within areas protected for ecotourism, e.g. community ecotourism conservation areas, or in surrounding "buffer" areas which may be more accessible for local communities and where species diversity and abundance is often relatively high (akin to spillover effects in Marine Protected Areas) (Palomo *et al.*, 2013).

Cultural services

Many culturally important species and places are also important for nature-based tourism (Pegas, Grignon and Morrison, 2015). Conservation strategies funded by tourism to protect species, habitats or ecosystems can also have direct and indirect positive impacts on cultural services, for example through the protection of culturally important areas (e.g. old village sites, sacred groves), traditional practices and knowledge (e.g. handicraft making skills, traditional harvesting, agricultural practices) and education, both traditional and scientific. Natural ecosystems are also important for recreation, fostering and/or reinforcing humans' attachment to nature, artistic inspiration and spiritual connections (de Groot, Wilson and Boumans, 2002; Tengberg *et al.*, 2012). Nature-based tourism not only plays a role in protecting ecosystems for these purposes, but in many cases provides the services directly.

Ecotourism in relation to agriculture and conservation of ecosystem services

Tourism and agriculture can be linked in three main ways in relation to biodiversity and ecosystem services:

» agriculture as a tourism attraction, i.e. agritourism;
» agriculture as part of the tourism value supply chain;
» tourism as an alternative land-use to intensive or non-sustainable agriculture.

Agritourism is a form of tourism that involves tourist activities at a working farm, ranch or agricultural plant which generate supplemental income for the owner. Agritourism involves a wide range of activities including educational experiences (e.g. farm tours, wine tasting, exposure to traditional farming practices), hospitality services (e.g. farm stays, guided nursery tours), on-farm direct sales (e.g. roadside stands, farmers' markets) and outdoor recreation (e.g. horseback riding, fishing) (Sznajder, Przezbórska and Scrimgeour, 2009). Tourism mainly adds value to agricultural production (when agriculture is the main land use), and occasionally agriculture can add value to tourism (by providing additional attractions or activities in an area). Agritourism is popular in Europe (mainly France, Italy and Spain) and North America (Canada and the United States of America) and is becoming increasingly popular in Asia (e.g. the Philippines), Australia and South America (e.g. Brazil).

The promotion of linkages between tourism and agriculture helps create economic opportunities, build resilience in rural communities and enhance sustainable development in both the tourism and agriculture sectors (FAO, 2014b). More local produce on plates and more local agrifood products on offer for visitors, tourists and the hotel industry mean higher income and more employment opportunities for farmers, suppliers and the private sector and greater overall interest in the agricultural sector. Many ecoresorts offer menus based on sustainable and/or organically harvested produce, in keeping with their policies on "green" tourism. Demand for organic produce in the tourism sector can therefore encourage environmentally friendly agricultural practices and justify the higher production costs involved.

Tourism in the Pacific Islands

Tourism is of increasing importance in the Pacific Islands subregion, accounting for more than 60 percent of GDP in some countries (Morrison and Buckley, 2010). Tourism in Pacific Island countries grew about 3.5 percent per year between 2008 and 2012, and the total value of Pacific tourism is forecast to reach US$4 billion by 2019 (UNWTO, 2015). Historically, most tourism in the region was in heavily developed coastal areas – "sun and surf tourism" based on beaches, diving, fishing, sailing and local cultures (Morrison and Buckley, 2010). Alternative activities focusing on inland areas, such as birdwatching, hiking, old village site tours, traditional medicine walks and white-water rafting, are increasingly being promoted and form the basis of a small but popular ecotourism industry. It is difficult to determine what proportion of visitors to each country participates in ecotourism activities. However, research elsewhere has shown that a large portion of visitors to developing countries engages in ecotourism (MA, 2005).

Agriculture currently has a limited role in ecotourism and ecosystem conservation in PICTs, but as the following cases demonstrate, there is great potential for increasing this role and creating demand for the products of sustainable agriculture as a niche market opportunity (agritourism) or as part of existing tourism value and supply chains.

Agritourism

Agritourism occurs on a small scale in some countries, e.g. Fiji and Samoa, promoted or marketed by a few operators but not yet recognized for its value-adding capacity by tourism marketing bodies, relevant government departments or the agriculture and tourism industries.

Example of agritourism: Aviva Farms, Fiji. Aviva Farms is a 22-ha former sugar-cane plantation now generating income through agritourism. When changes in weather patterns started to result in irregular revenue from sugar cane, the owner and director, Livai Tora, diversified the farm for additional income. He planted 20 indigenous species, 4 000 organic papaya trees (Photo 15) and a tobacco field, and added horseback riding to provide an additional sustainable income stream. More than 60 young men and women from rural and remote communities work and learn on this farm (Aviva Farms, 2016).

The farm's tourist activities primarily centre on promoting sustainable agriculture and its benefits for local communities, traditional knowledge and practices, healthy lifestyles and carbon-neutral activities. Touring the different parts of the farm, visitors observe the benefits of diversification and learn about:

- the certification of organic papaya and its relation to sustainable farming practices;
- how tobacco, a lucrative short-term crop grown four months in the year, cushioned the economic shock of the transition away from sugar-cane farming;
- the domestication of breadfruit, a traditional staple crop, and its benefits for food security, carbon sequestration, gluten-free diets and resilience.

Other activities include tours of the farm's ethnobotanical garden, which connects people and plants; cross-country tours on horseback, which minimize carbon footprints; and visits to neighbouring vegetable farms to observe their different production systems. The farm also hosts events such as weddings and other celebrations, for which it provides local produce.

The farm has approximately 40 to 50 visitors monthly, and the agritourism component of the farm is financially sustainable given the low overhead costs (L. Tora, personal communication). Visitor numbers are expected to rise, but marketing (through Facebook, word-of-mouth and a website) is currently kept low to avoid impacts associated with excessive visitor numbers.

Photo 15. *Organic papaya at Aviva Farms, Fiji*

© Oliver Flemming

Aviva Farms collaborates with many organizations (e.g. in certification, watershed management, landscaping with indigenous plants) and is also involved in local community training and development in areas such as alternative production systems (e.g. introduction of new varieties of fruit-trees to supplement current seasonal fruit supply); riverbed stabilization using local indigenous trees; and climate change mitigation strategies using traditional knowledge.

Joining the tourism supply-chain

In some Pacific Island countries up to 80 percent of the food in the tourism industry is imported, partly because hotels, resorts, restaurants and airlines need reliable supplies of good-quality products that are unavailable through local suppliers and producers. Attempts have recently been made to link the tourism and agriculture value chains in the region, for example in Fiji, Samoa, Tonga and Vanuatu, mainly through the supply of fresh produce to resorts and airlines (FAO, 2012b, 2014b). Several initiatives have been established in PICTs to enable local producers to link into the existing value and supply chains (Box 17). In 2015, the first Pacific Community Agritourism Week brought together tourism agencies, chefs and producers (SPC, 2015).

Box 17. **Farm to Table, Samoa**

In Samoa, Women in Business Development Inc. (WIBDI), in partnership with UNDP, established the Farm to Table programme in 2013 to create a sustainable source of income for farmers and raise the profile and quality of Samoa's cuisine (WIBDI, 2016). WIBDI provides training, seeds and support to farmers and takes on the ordering, grading and delivery roles. Local restaurant and hotel chefs are trained and supported by a chef associated with the programme. More than 20 farmers (with farm size from 1 to 100 ha), all organic certified, supply two hotels and ten restaurants in Samoa with organic fresh produce (WIBDI, 2016).

Joining the supply chain: Tetapare Island, Solomon Islands. Tetepare Island is a 120 km^2 forested island in the Western Province of the Solomon Islands and is the largest uninhabited tropical island in the Southern Hemisphere. When Tetepare was threatened by logging in 2001, Tetepare islanders and their descendants established the Tetepare Descendants Association (TDA) to convert the entire island, including marine and terrestrial ecosystems, to a community conservation area. The entire island is protected from commercial use, e.g. logging, intensive agriculture and plantations, but low levels of subsistence resource use by local landowners are permitted in some areas. Today it is home to one of the Solomon Islands' leading and most successful conservation projects and a unique, locally owned and managed ecolodge (Photo 16). The ecolodge employs local people as guides, cooks and hospitality workers and is also a source of pride for the TDA communities. Local communities on neighbouring islands provide all the fresh organic produce for visitor and staff meals and handicrafts sold in the small ecolodge market. Visitor numbers are growing each year, providing more job opportunities for local people.

TDA has developed a sustainable livelihoods strategy and is working to create more livelihood opportunities through provision of training and equipment for alternative income generating activities, financial literacy programmes, marketing assistance for local agricultural producers and artisans, distribution of high-quality vegetable seeds to local market gardeners and promotion of sustainable, organic agriculture (Tetepare, 2016). By partnering with local and international NGOs, development organizations, researchers and government departments, TDA has successfully incorporated conservation, tourism and sustainable community development to protect Tetepare Island biodiversity and the ecosystem services provided.

Photo 16. *Tetepare Ecolodge, Solomon Islands*

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Ecotourism as an alternative to agriculture

Although links between tourism and ecosystem services are rarely articulated in the region, income from tourism is often the only means and justification for protecting the environment through establishment of protected areas, legislation to protect threatened species and ecosystems and promotion of the sustainable use of natural resources (Buckley, 2004; Puppim de Olivera, 2008; Morrison and Buckley, 2010).

Linking tourism to environmental protection: Talanoa Treks, Fiji. Talanoa Treks was established in 2013 and is one of the only dedicated hiking tour companies in Fiji. It works in partnership with local communities to offer guided day and multi-day group walks through Viti Levu's rural areas (Photo 17). The company is committed to environmental and cultural sustainability and recognizes its dependence on Fiji's biodiversity and cultural heritage (Talanoa Treks, 2013). Its target markets are increasingly socially conscious travellers and adventure tourists.

The diversity of the natural landscapes (agricultural lands, cloud forest, talasiga grasslands, and freshwater rivers, streams and waterfalls) and the opportunity to visit remote areas are major drawing cards. Several tours explore medicinal plants, old village sites, food gardens, fishing grounds and battlefields. Village visits and stays allow tourists to experience local and traditional ways of life in Fiji.

Photo 17. *Hike through interior of Viti Levu organized by Talanoa Treks, Fiji*

© Matt Capper

Talanoa Treks works in partnership with four communities and two locally owned lodges. The company is responsible for overall trip management, logistics, marketing, quality monitoring (through visitor feedback) and training. The villages allow access to land; provide experienced guides, locally grown food, accommodation and other services; and maintain tracks and infrastructure. The revenue generated provides a valuable source of income for the remote communities. In 2014, the first full year of operation, the communities and lodges received more than 40 000 Fiji dollars (FJD) (more than US$20 000) as payment for food, accommodation and guiding.

In terms of biodiversity conservation, Talanoa Treks is currently focused on community and visitor education through training programmes funded by the Darwin Initiative and local conservation NGO NatureFiji-MareqetiViti. Many visitors on the treks are conservation oriented and help increase awareness among local communities and guides, promoting cross-cultural exchange of ideas and knowledge. While the company has yet to demonstrate tangible effects on conservation of biodiversity and ecosystem services because of its short time in operation, it has potential to encourage environmental and cultural heritage protection at both the landscape (habitat) scale (through links between villages, particularly in partnership with conservation NGOs) and the local (village) scale.

Recommendations for sustaining the ecosystem benefits of ecotourism in agricultural zones in the Pacific Islands

Strong involvement of local communities and support for alternative income-generating activities

As highlighted in the above cases, successful ecotourism enterprises in the Pacific Islands involve the participation of local landowning communities at all stages, from the initial concept to project planning and implementation, day-to-day operations and fair distribution of the economic benefits (Morrison and Buckley, 2010; Hunnam, 2002; Keppel *et al.*, 2012). This requires intensive and continuing dialogue and education between landowners and operators (if not from the community) at all stages. Such dialogue cements commitment to sustainable use of resources; permits increased ownership of the project; helps to manage community and operator expectations; and improves long-term support by local communities (essential because ecotourism enterprises, including agritourism, are generally small in scale and require time to generate tangible benefits).

Supporting diversification of local communities' roles in ecotourism also improves its success. Community members can be active within the tourism operation (e.g. as managers, guides, hospitality staff) or support the tourism value supply chain (e.g. by providing local produce, handicrafts, transport). Funds derived from ecotourism can also be used to support alternative livelihoods such as community bakeries or plant nurseries, which may or may not feed back into the tourism sector.

Government support for biodiversity conservation through tourism revenue

Tourism profits, along with specific taxes and levies, can be used to pay for the conservation of the natural resources that provide the core of the sustainable tourism industry, as recommended by Cook Islands, Fiji, Niue, Palau and Tonga in their NBSAPs. In Cook Islands and Palau this is already occurring: "Green fees" paid with departure taxes are used for protected area conservation and management. Samoa has established 20 protected sites based on their tourism significance. Governments could increase their investment in biodiversity conservation by reinvesting tourism revenue into enterprises or operations that promote conservation and/or sustainable use of natural resources, including those involved in agritourism or sustainable agriculture.

Education of all stakeholders on biodiversity and ecosystem services protection beyond provisioning services

While some ecosystem services are well-known, such as freshwater, food and wood, others are less obvious but no less important, including climate regulation, protection from soil erosion, pollination and biological control. Education of all stakeholders potentially involved in ecotourism (e.g. local communities, local authorities, the private sector and national governments) on the importance of all types of ecosystem services and the link among them is critical for improving attitudes towards and support for ecosystem protection. Most successful ecotourism enterprises conserve the natural base of their operations (e.g. individual species, habitats) but also recognize the importance of conservation of all biodiversity, incorporating wider-ranging conservation practices with larger-scale benefits. Traditional knowledge of biodiversity and sustainable use of natural resources, including traditional agricultural practices, should also be promoted and utilized in relation to protection of ecosystem services.

Strong links between ecotourism operators, markets and other industries

Most ecotourism enterprises in developing countries are small to medium-sized businesses and are often community based. These types of enterprises and products often struggle to reach markets, as their isolation, small size and lack of resources and skills make cost-effective promotion a challenge. Successful ecotourism enterprises involve local communities, private-sector enterprises, NGOs, local authorities and protected areas, national governments and international agencies in ecotourism development and marketing. Priorities for improved links can include infrastructure improvement, e.g. more reliable transport, and featuring ecotourism more strongly in destination and thematic promotional campaigns, including the promotion of niche markets, such as agritourism, and the role of local agricultural producers in sustainable tourism enterprises. International and domestic tour operators not only promote ecotourism but can advise on product development and quality based on knowledge of visitor requirements and market trends. Small, individual ecotourism enterprises can work together to strengthen their marketing outreach and avoid duplication of products in the same locality.

Incentives for conservation of biodiversity and ecosystem services at different scales

The highest levels of biodiversity in managed landscapes are more likely to be conserved for intrinsic (traditional value/social customs) or utilitarian (direct use) reasons than for functional or ecosystem services (Swift, Izac and van Noordwijk, 2004). As a result, most incentives for biodiversity conservation relate to protection of provisioning and cultural ecosystem services rather than regulating or supporting services. In the Pacific, most ecotourism conservation activities focus on species, habitats and ecosystems that will provide economic, subsistence livelihood and cultural use benefits for local landowning communities and tourism operators. As concepts such as carbon sequestration, nutrient cycling and climate regulation are less tangible and more difficult to explain, biodiversity conservation for these purposes is generally less well supported by all stakeholders.

Many Pacific ecotourism operations and the ecosystem services they provide and/or depend on are context-specific and small in scale. Most operations can conserve species or habitats at the local scale, but many important functional and supporting ecosystem services occur at a larger (e.g. catchment) scale. A coordinated strategy is therefore needed to conserve these ecosystem services at appropriate scales and over various land uses. Although some public policies exist to create incentives for individual operators (e.g. ecoresorts) or industries (e.g. tourism, transport, agriculture) to act on behalf of the common good, current policies are not designed to encourage coordinated behaviour within or among these groups (Zhang *et al.*, 2007).

Strong cross-sectoral linkages

Strengthening linkages between the tourism and agriculture sectors can increase the value of both sectors for national economies and benefit rural populations, which are largely responsible for ecosystem service protection. Demand for healthy or organic products for tourists promotes more sustainable agricultural methods and biodiversity protection. To meet the requirements for supplying fresh produce to the tourist market, local producers will need to find profitable and feasible ways to increase volume, quality and regularity. Meeting new market requirements will require significant investment in productivity, marketing, transport and methods to ensure that local products meet international food safety and quality standards (FAO, 2014b) (Box 18). Such links are currently absent or poor in most Pacific Island countries.

The ability to meet these requirements also depends on the government's ability to lower the costs of doing business for local, rural producers (e.g. through tax incentives for sustainable agriculture and investment in transport infrastructure). Many Pacific Island countries rank low in World Bank evaluations of ease of doing business, number of days to start up a new business and number of start-up procedures involved (World Bank, 2016). The difficulties associated with starting up new businesses and the lack of government incentives (e.g. tax concessions) for the establishment of operations that support conservation of biodiversity and ecosystem services and/or sustainable community development are also a challenge for the development of a sustainable agriculture-related ecotourism industry.

Box 18. **Pacific Organic Tourism and Hospitality Standard**

The Pacific Organic and Ethical Trade Community (POETCom) is developing the Pacific Organic Tourism and Hospitality Standard with the following objectives:

» to help protect the character and reputation of the Pacific tourism and hospitality sector and the core values that have made destinations in the Pacific Islands so desirable;

» to develop markets for locally produced organic food, to enhance the livelihoods of the small farmers who grow much of this produce;

» to meet the Global Sustainable Tourism Council's Criteria for Hotel and Tour Operators.

POETcom is currently developing mechanisms for inspection and certification to the tourism standard. The standard will be piloted in Fiji, Samoa and Vanuatu through the Farm to Table programme (see Box 17) beginning in late 2016.

The links between ecotourism operators and national or regional tourism bodies are also generally poor. Most ecotourism operations in PICTs rely on self-promotion through their own websites, brochures and other digital media (e.g. Facebook) to communicate their ecocentric ethos and the benefits of their organizations for the triple bottom line, including direct or indirect protection of ecosystem services. National and regional tourism agencies promote ecotourism activities (generally much less extensively than traditional sun and surf tourism) with no recognition of the contribution of ecotourism to the ecosystem services on which the whole industry relies. There is also no national or international promotion of niche markets relating to agriculture and conservation of ecosystem services, e.g. agritourism.

Land tenure, community participation, equitability and benefit distribution

Local community landowners are of central importance for conservation in PICTs because they own more than 80 percent of the land (Ward, 2000), have broad and unique knowledge of their biodiversity and depend on the environment for their survival (Keppel *et al.*, 2012). Decisions on the use of community-owned land therefore must involve all local community landowners. Conservation and sustainable development activities, including ecotourism and sustainable agriculture, generally cannot be implemented by the government or other organizations without support and approval by landowning communities (Hunnam, 2002).

Differences of opinion among multiple landowners can complicate decision-making on the best use of community-owned land. In terms of biodiversity conservation, this can lead to delays in the implementation of conservation activities (e.g. reforestation), bans on environmentally detrimental activities (e.g. intensive agriculture) and the introduction of sustainable land-use measures (e.g. ecotourism or ecologically intensive agriculture), leading to a patchwork of different land uses across the landscape and subsequent negative impacts on ecosystem services.

These differences of opinion are often based on inequalities in participation and distribution of benefits from different land uses. Most Pacific societies are patriarchal, and input from women and young people in decision-making is particularly limited. Hierarchical social structures are also present in many PICTs, allowing chiefs or community leaders more prominence in decision-making and a larger share of the community benefits.

Recognition of the challenges

Ecotourism has been promoted as a sustainable alternative income generating activity in the subregion for decades. Unfortunately, the difficulties associated with producing a viable product are rarely acknowledged. There are many instances of the "build it and they will come" approach, which usually results in poor success rates. Many tourism operations in the region have failed because of inadequate competitiveness in the established market (too many similar products on offer, e.g. village stays), marketing and links to national tourism promotions, financial and business management capacity and product quality. Other obstacles include unrealistic expectations and time frames, unequal distribution of benefits and limited or unreliable transport access, among others. Lack of economic success and/or long delays in receiving benefits often leads these enterprises to resume or begin activities that are not environmentally sustainable (e.g. logging, intensive agriculture) to generate income in the short term.

Factors that could contribute to a more successful product in the long term include better management of community and operational expectations (time-frames, profits, revenue-sharing), education on product development and management (operations, business plans, marketing, diversity) and better links with other sectors, as mentioned above.

Recommendations for capturing ecotourism in NBSAPs and other policies

Of the 14 Pacific Island NBSAPs, ecotourism is mentioned in relation to sustainable economic development in ten, biodiversity in nine, ecosystem services in two and agriculture in only one (Table 11). Ecotourism is explicitly mentioned in 18 percent of the conservation themes and can potentially be included in an additional 34 percent, primarily in relation to sustainable natural resource use, financial mechanisms for biodiversity conservation and mainstreaming biodiversity. Countries with large tourism sectors already include ecotourism in many of their conservation themes, while those with small tourism industries rarely include ecotourism (e.g. Marshall Islands, Nauru, Solomon Islands). Eleven countries are currently using ecotourism to promote and encourage terrestrial biodiversity conservation (based on NBSAPs and latest national reports to CBD), and all except two (Marshall Islands, Nauru) are planning to do so in the future.

Tonga's NBSAP provides an example of how the links between ecotourism, agriculture and conservation can be promoted or mainstreamed in an NBSAP. Continuing expansion of large-scale commercial agriculture constitutes the most significant cause of forest ecosystem degradation and habitat loss in Tonga and the biggest threat to the conservation of biodiversity. The priority placed on agriculture for food security and for export dictates that in terms of land use, agriculture will continue to dominate. Tonga's NBSAP contains five thematic areas that are relevant to this issue:

» Theme 1 (Forest Ecosystems) focuses on arresting agrodeforestation, integrated land-use planning and conservation areas.
» Theme 3 (Species Conservation) focuses on protecting priority species (which can include agricultural species) and their sustainable use and management.
» Theme 4 (Agrobiodiversity) is concerned with the conservation and sustainable use of threatened agrobiodiversity.
» Theme 7 (Mainstreaming Biodiversity Conservation) involves legislation, policy and plans.
» Theme 8 (Financial Resources) includes economic tools and instruments for conservation funding, e.g. ecotourism fees to fund biodiversity conservation.

Table 11. **Mention of terrestrial ecotourism in Pacific Island NBSAPs**

COUNTRY	NBSAP BIODIVERSITY CONSERVATION THEMES			ECOTOURISM MENTIONED IN RELATION TO				ECOTOURISM IMPLEMENTATION IN RELATION TO TERRESTRIAL BIODIVERSITY CONSERVATION[a]	
	Total number	Number explicitly including ecotourism[b]	Potential additional themes to include ecotourism[b]	Sustainable economic development	Biodiversity	Ecosystem services	Agriculture	Current	Planned
Cook Islands	8	2	3	Y	Y	Y	N	Y	Y
Fiji	6	3	1	Y	Y	N	N	Y	Y
Federated States of Micronesia	11	4	3	Y	Y	N	N	Y	Y
Kiribati	8	2	1	Y	N	N	N	N	Y
Marshall Islands	5	0	1	N	N	N	N	N	N
Nauru	8	0	2	N	N	N	N	N	N
Niue	8	1	2	Y	Y	N	N	Y	Y
Palau	8	2	3	Y	Y	N	N	Y	Y
Papua New Guinea	9	0	4	N	N	N	N	Y	Y
Samoa	8	2	4	Y	Y	Y	Y	Y	Y
Solomon Islands	12	0	5	N	Y	N	N	Y	Y
Tonga	8	2	3	Y	Y	N	N	Y	Y
Tuvalu	8	1	3	Y	N	N	N	Y	Y
Vanuatu	6	1	3	Y	Y	N	N	Y	Y

[a] Based on NBSAP and latest national report to the CBD (fourth report for Cook Islands, Papua New Guinea and Tuvalu; second report for Marshall Islands; fifth report for all other PICTs)
[b] Includes themes implicitly including tourism as well as new themes.

The different themes and their implementation involve a number of different stakeholders, but the overall link between themes and stakeholders is explicit throughout the document.

Less commonly, some countries promote links between the different sectors involved in biodiversity conservation, ecotourism and agriculture in their NBSAPs. Fiji promotes links between the tourism industry and organizations involved in establishing protected areas. The Federated States of Micronesia promotes links between government and ecologically friendly industries (e.g. ecotourism, sustainable agriculture) through the provision of economic incentives. Palau promotes links among all sectors involved in economic development and biodiversity conservation. Several countries also focus specifically on the conservation and sustainable use of agrobiodiversity. For example, the Federated States of Micronesia and Samoa highlight the importance of identifying, developing and establishing botanic gardens featuring locally endemic, endangered and threatened species; Tuvalu highlights the importance of the production and consumption of local food; and Solomon Islands wants to strengthen the conservation, management and use of agrobiodiversity, including traditional knowledge.

Several other national policies could capture ecotourism and its contribution to biodiversity, particularly those dealing with tourism development, sustainable or strategic development, agriculture and protected area management (Table 12), usually through stronger links among the different stakeholder groups involved in natural resource use and management. For example, the Federated States of Micronesia Agriculture Policy (2010) explicitly states the importance of increasing the links between the agriculture and tourism sectors and identifies several strategies for doing so, all involving collaboration with the tourism industry:

» market studies to identify the demand profile of the tourism market segment (seasonal trends or patterns in demand and current market share of local produce by product, volume and value);
» strategic reorientation of small-scale farmers' production operations (including transport and storage) to meet the needs of the hotel and restaurant sector;
» exploration of opportunities for promoting local foods in restaurant and hotel menus;
» exploration of opportunities for agriculture tours and farm stays.

Similar strategies could be carried out in any of the countries in the subregion.

Table 12. **Sectoral policies, legislation or plans that can or do associate ecotourism with ecosystem services protection**[a]

COUNTRY	POLICY	ECOTOURISM AND ECOSYSTEM SERVICES		ECOTOURISM AND/OR ECOSYSTEM SERVICES IN RELATION TO AGRICULTURE		CURRENT OR POTENTIAL PARTNERS/ STAKEHOLDERS[b]
		Current	Potential	Current	Potential	
Cook Islands	International Department Tax Amendment Act 1984	Y	Y	N	N	Cook Islands Tourism Corporation
	National Sustainable Development Plan	Y	Y	N	Y	
	Draft Tourism Master Plan	Y	Y	N	Y	
Fiji	National Tourism Development Plan	N	Y	N	Y	Tourism Fiji Ministry for Industry, Trade and Tourism iTaukei Land Tenure Board
	Rural Land Use Policy 2006	N	Y	N	Y	
	National Environment Strategy	Y	Y	N	Y	
	Integrated Coastal Management Framework	Y	Y	N	Y	
FSM	FSM Agriculture Policy	N	Y	Y	Y	FSM Visitors Board
	National Strategic Development Plan	N	Y	N	Y	
	State Strategic Development Plans	N	Y	N	Y	
Kiribati	Kiribati Integrated Environment Policy	N	Y	N	Y	Ministry of Communications, Transport and Tourism Development Kiribati National Tourism Office
	Kiribati National Tourism Action Plan	N	Y	N	Y	
	Kiribati Development Plan	Y	Y	N	Y	
Nauru	–	–	–	–	–	Ministry for Commerce, Industry and Environment
Niue	National Capacity Development Strategy and Action Plan	N	Y	N	Y	Niue Tourism Niue Government Commercial and Trading Arm – Tourism
	Niue Sustainable Coastal Development Policy	N	Y	N	Y	
	Village Development Plans for Hakupu and Tuapa villages (ecotourism sites)	Y	Y	N	Y	

[a] The list is not exhaustive.

[b] In all countries, partners/stakeholders will need to include local communities and tourism operators, government ministries in charge of the environment and/or natural resources, and the regional South Pacific Tourism Organisation.

CONTINUES →

COUNTRY	POLICY	ECOTOURISM AND ECOSYSTEM SERVICES		ECOTOURISM AND/OR ECOSYSTEM SERVICES IN RELATION TO AGRICULTURE		CURRENT OR POTENTIAL PARTNERS/ STAKEHOLDERS[b]
		Current	Potential	Current	Potential	
Palau	Palau Megapode Conservation Action Plan	Y	Y	N	N	Palau Visitors Authority Ministry of Natural Resources – Tourism Bureau
	State-level Master and Land Use Plans	N	Y	N	Y	
	State-level and protected area-specific management plans	N	Y	N	Y	
	State-level Conservation Action Plans	N	Y	N	Y	
Papua New Guinea	Papua New Guinea Development Strategic Plan, 2010–2030	Y	Y	Y	Y	Papua New Guinea Tourism Promotions Authority Department of Culture and Tourism
	Environment Act 2000	N	Y	N	Y	
Samoa	Samoa Tourism Development Plan	N	Y	N	Y	Samoa Tourism Authority Ministry for Natural Resources and Environment
	Environment Management and Conservation Bill 2013	N	Y	N	Y	
	National Environmental Sector Plan 2013–2016	N	Y	N	Y	
	Strategy for the Development of Samoa 2012–2016	Y	Y	N	Y	
Solomon Islands	Protected Areas Act	N	Y	N	Y	Solomon Islands Visitors Bureau Ministry of Culture and Tourism
	Solomon Islands Government Policy on Organic Agriculture Systems (2010)	N	Y	N	Y	
	Solomon Islands National Development Strategy 2011–2020	N	Y	N	Y	
Tonga	National Strategic Planning Framework – 2010	N	Y	Y	Y	Tonga Tourism Authority Ministry of Tourism
	Agriculture and Tourism Linkages in Pacific Island Countries – 2012 Tonga Tourism Sector Roadmap 2014–2018	N	Y	Y	Y	

CONTINUES →

COUNTRY	POLICY	ECOTOURISM AND ECOSYSTEM SERVICES		ECOTOURISM AND/OR ECOSYSTEM SERVICES IN RELATION TO AGRICULTURE		CURRENT OR POTENTIAL PARTNERS/ STAKEHOLDERS[b]
		Current	Potential	Current	Potential	
Tuvalu	National Strategies for Sustainable Development 2005–2015	N	Y	N	Y	Ministry of Foreign Affairs, Trade, Tourism, Environment and Labour
Vanuatu	National Conservation Strategy (1993)	N	Y	N	Y	Vanuatu Tourism Office National Tourism Development Office Ministry for Trade, Tourism, Commerce and Industry
	Vanuatu Forest Policy (2013–2023)	N	Y	N	N	
	Overarching Productive Sector Policy (2012–2017)	N	Y	N	Y	
	Vanuatu Strategic Tourism Action Plan 2014–2018	N	Y	Y	Y	
	Provincial tourism plans	N	Y	N	Y	

Part III

Policy measures for mainstreaming ecosystem services and biodiversity in agricultural production and management

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10 REGIONAL AND NATIONAL POLICY FRAMEWORKS SUPPORTING BIODIVERSITY AND ECOSYSTEM SERVICES IN AND FOR AGRICULTURE IN THE PACIFIC ISLANDS

Keneti Faulalo

Regional framework

The Pacific Islands currently have no regional strategy that is specifically focused on addressing biodiversity and ecosystem services in and for agriculture. Some key regional strategies, however, include a strong recognition of the need to integrate biodiversity and ecosystems services with agriculture.

Framework for Nature Conservation and Protected Areas in the Pacific Islands Region (2014–2020)

The Framework for Nature Conservation and Protected Areas in the Pacific Islands Region (SPREP, 2014) provides guidance on key priorities for conservation and ecosystem management, with clear linkages to the Aichi Targets and NBSAPs. The key agriculture-related Aichi Targets, including Targets 7, 8, 13 and 14, are addressed under several of this framework's objectives. Indeed the close alignment of the framework with both the global targets and the NBSAPs uniquely positions it as a regional bridge between global commitments and national-level policy formulation related to conservation of biodversity and ecosystems.

SPC Land Resources Division Strategic Plan 2013–2017

The SPC (2013) Land Resources Division Strategic Plan 2013–2017 articulates the division's focus areas and support to Pacific Island countries in the land, agriculture and forestry sectors. The strategy emphasizes the alignment of the division's work with national priorities. The strategy promotes the development of organic farming, which is gaining momentum across the subregion; it recognizes the potential benefits of organic agriculture for health, the environment, economies and income generation and its important role in strengthening food security, accessing niche markets, mitigating climate change and protecting fragile ecosystems.

FAO Pacific Multi-Country Programming Framework 2013–2017

The FAO (2012a) Pacific Country Programming Framework 2013–2017 is a multi-country document that defines the medium-term priorities for FAO's technical cooperation in support of Pacific Island countries and provides a regional framework within which country-specific priorities and expected outcomes are defined.

Through consultations and analysis of the national agricultural situation undertaken across Pacific Island countries, four priority areas have been identified for FAO partnership and assistance during the 2013–2017 cycle:

» evidence-based policy and strategic planning;
» food and nutrition security resilient to the impacts of disasters and climate change;
» value/supply chain efficiency and market linkages;
» environmental management and resilience.

An overriding aim of FAO assistance is to help countries in the region build policy and institutional frameworks that provide the right incentives for environmentally sound and resilient development of agriculture. FAO will focus assistance on outcome areas that are closely aligned to national development priorities as articulated in national sustainable development plans.

National policy framework

National-level planning processes and policies that influence the mainstreaming of ecosystem services and biodiversity within agriculture and across sectors are elaborated within the international framework described in Chapter 2. They include NBSAPs, National Agriculture Sector Plans (NASPs) and National Sustainable Development Strategies developed within the framework of Agenda 21 and the SDGs, as well as country processes for implementing MEAs.

Implementation of international instruments at national level

Since the first United Nations Conference on Environment and Development (UNCED) in 1992, Pacific Island countries have consistently relied on non-binding high-level political commitments, MEAs and other international instruments to guide and support their policy formulation and national development processes. The countries of the subregion have ratified most MEAs and international treaties. All are Parties to the CBD, and most have ratified the MEAs dealing with aspects of pesticides and the sound management of chemicals (the Basel, Stockholm and Rotterdam Conventions) (see Chapter 2) (Table 13). In addition, almost all have ratified the subregion-specific Waigani Convention to Ban the Importation into Forum Island Countries of Hazardous and Radioactive Wastes and to Control the Trans-boundary Movement and Management of Hazardous Wastes within the South Pacific Region.

However, the countries' National Capacity Self Assessments (NCSAs) have highlighted certain challenges constraining implementation of international environmental agreements and treaties, mostly underpinned by limited financial, human and institutional capacity (Mitchell, 2012):

» lack of historical and current evidence of the status of various environmental resources and the trends and drivers of change in that status;
» information management issues, including lack of standardized procedures for collecting and aggregating relevant environmental data;
» inadequate dissemination of information to local scientists, government officials or citizens.

Table 13. **Pacific Island countries' ratification of international instruments relevant to sound management of chemicals, biodiversity and ecosystem services and agriculture**

COUNTRY	ROTTERDAM CONVENTION	STOCKHOLM CONVENTION	BASEL CONVENTION	WAIGANI CONVENTION	CBD	ITPGRFA	IPPC
Cook Islands	✓	✓	✓	✓	✓	✓	✓
Fiji	–	✓	✓	✓	✓	✓	✓
Federated States of Micronesia	–	✓	–	✓	✓	–	✓
Kiribati	–	✓	✓	✓	✓	✓	–
Marshall Islands	✓	✓	✓	–	✓	✓	–
Nauru	–	✓	✓	✓	✓	–	–
Niue	–	✓	–	✓	✓	–	✓
Palau	–	✓	–	✓	✓	✓	✓
Papua New Guinea	–	✓	✓	✓	✓	✓	✓
Samoa	✓	✓	✓	✓	✓	✓	✓
Solomon Islands	–	✓	✓	✓	✓	–	✓
Tonga	✓	✓	–	✓	✓	✓	✓
Tuvalu	–	✓	–	✓	✓	✓	✓
Vanuatu	–	✓	–	✓	✓	–	✓

National development planning

Chapter 8 of Agenda 21 (the UNCED outcome) called on countries to adopt National Strategies for Sustainable Development that should build upon and harmonize the various sectoral economic, social and environmental policies and plans operating in the country. The 2030 Agenda for Sustainable Development reaffirms countries' commitment to achieve sustainable development for all, taking into account their different capacities and levels of development and respecting national policy space.

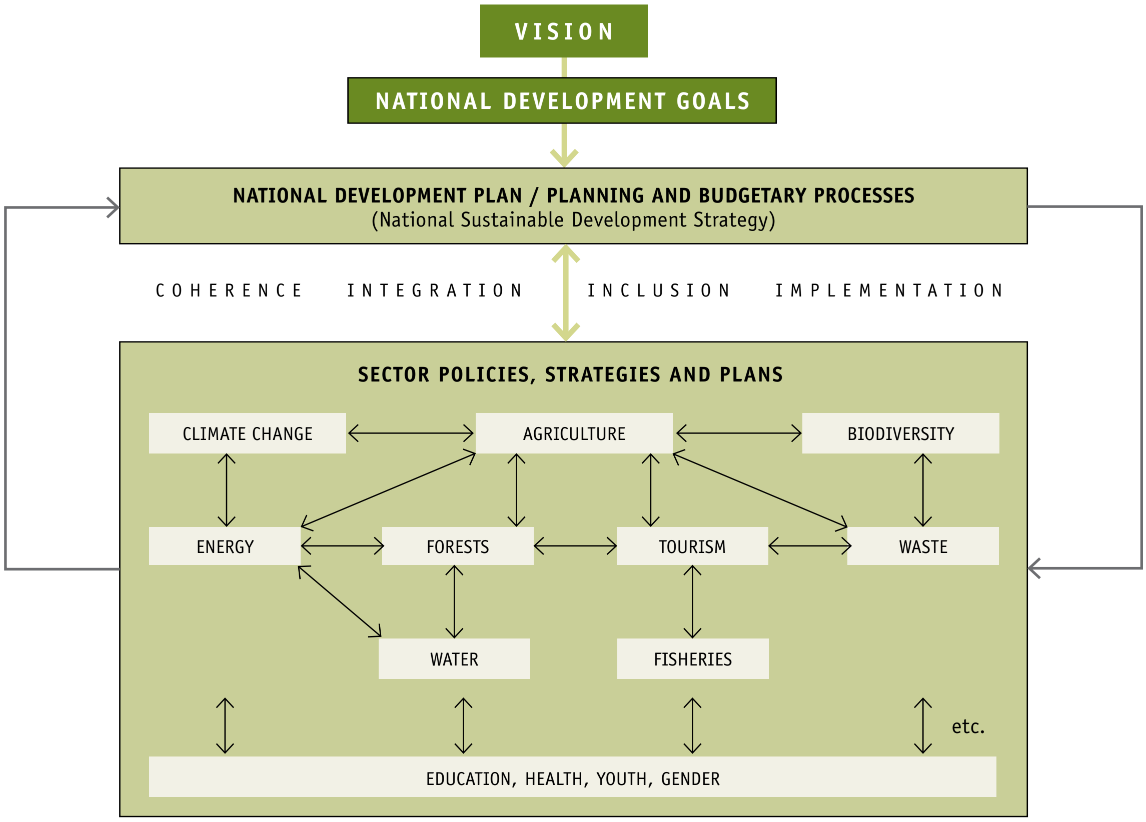
Guided by Agenda 21, the Pacific Island countries have been strengthening their national sustainable development planning over the past two decades, adopting a process that links sectoral plans, decision-making and budgeting (Figure 11). Remaining consistent with this overall planning process, the countries have taken a wide range of different approaches reflecting their national priorities and political and economic situations. In line with national visions, some have developed long-term national development strategies covering 10 to 30 years (Papua New Guinea, Solomon Islands, Tuvalu, Vanuatu), while others have shorter rolling plans in the form of medium-term development plans (Papua New Guinea, Solomon Islands). Some have developed a series of four- to five-year strategies, with each subsequent strategy building on reviews and lessons from the previous one and responding to changing national development priorities (Cook Islands, Kiribati, Niue, Samoa, Tonga). The Federated States of Micronesia developed a 20-year strategy comprising a set of sector chapters to guide national sector policies.

The National Sustainable Development Strategies provide the strategic direction and coordination framework for prioritizing, formulating and implementing national sectoral and cross-sectoral policies, strategies and plans. In some Pacific Island countries, agriculture is placed at the core of the national development strategy, either as a medium-term focus or as part of an overall long-term vision (Box 19).

The conceptualization of the national development planning process in Figure 11 applies also for national policy formulation aimed at promoting ecosystem-based approaches to agricultural production and management to minimize dependency on agrochemicals. It illustrates that the implementation of MEAs at the national level requires a high level of coherence and integration of policies across sectors and well-functioning coordination mechanisms among national entities. It also points to the value of implementing national obligations under MEAs in a synergistic manner at the national level in support of national development goals.

It should be noted, however, that Pacific Island countries face the same challenges as other developing countries in their national development planning – in coordinating across thematic sectors, integrating environmental issues into economic and other sector plans, making processes inclusive and bridging gaps between commitments and implementation (UN, 2012).

Figure 11. **National development planning process conceptualized as context for policy formulation**



Box 19. **Examples of National Strategies for Sustainable Development with an agriculture sector focus**

Samoa

To achieve the long term vision of "Improved Quality of Life for All", the 2012–2016 Strategy for the Development of Samoa includes a focus on strengthening economic resilience through increased investment in the productive sectors of the economy, with dedicated interventions in the agricultural sector to raise domestic production to meet food security needs and boost export capacity.

Papua New Guinea

To achieve the long-term vision that "Papua New Guinea will be a Smart, Fair and Happy Country by 2050", the National Strategic Plan: 2010–2050 (with medium-term reviews) places focus on shifting the economy, currently dominated by the mining and energy sectors, to an economy dominated by agriculture, forestry, fisheries and ecotourism by 2050.

Mainstreaming biodiversity conservation in national development strategies and national agriculture sector plans

Mainstreaming biodiversity conservation means integrating or including actions related to conservation and sustainable use of biodiversity in strategies relating to production sectors such as agriculture, fisheries, forestry, tourism and mining (CBD, 2007). The term can be used synonymously with "inclusion". Consistent with the national development planning process illustrated in Figure 11, Pacific Island countries have called for the mainstreaming of biodiversity in other national sector plans in their NBSAPs (Table 14), primarily as a result of efforts by GEF to promote this objective in capacity building for implementation of the CBD in the subregion. Implementation of actions and specific activities related to mainstreaming biodiversity on the ground, however, remains weak across the subregion.

The few Pacific Island countries that have shown some success in mainstreaming biodiversity in agriculture or other sectors appear to be those with more effective national development planning, in line with the process shown in Figure 11. In general, these countries have clear environmental sustainability goals and objectives and have demonstrated some kind of functional coordination mechanism in place for implementation of their national development strategies.

The immediate challenge for mainstreaming biodiversity is to further reinforce it within the environmental sustainability goals of the national development planning process, as a means of integrating it into other sectoral plans and national budgetary decisions. In their recent national reports on implementation of the CBD (all submitted in 2014–2015), nearly all Pacific Island countries (Cook Islands, Federated States of Micronesia, Kiribati, Niue, Samoa, Papua New Guinea, Tonga, Tuvalu, Vanuatu) linked the effectiveness of biodiversity mainstreaming into relevant sectoral and cross-sectoral strategies, plans and programmes to the macro-level environmental sustainability goals of their national development strategies. Regarding the processes and tools they intend to or have put in place as coordination mechanisms for supporting the mainstreaming of biodiversity, some referred to overarching environment sector plans tied to the environmental goals of the national development strategy (Cook Islands, Federated States of Micronesia, Kiribati) or to a sector-wide approach on environment (Samoa).

Some Pacific Island countries reported on how biodiversity has been mainstreamed into state development plans (Federated States of Micronesia), village development plans (Niue) and community and government projects and programmes (Tonga, Palau). Most of these achievements, however, are based on projects with funding support from development partners and are not fully integrated in national budgetary considerations.

The following are some examples of successful mainstreaming of biodiversity in agriculture:

- Vanuatu reported in its fifth national report to the CBD how biodiversity had been mainstreamed it its NASP (2015–2030) under Goal 8, Environmental Protection and Sustainable Farming, which has as specific objectives "Environmentally friendly agriculture" and "Agriculture soils improved and conserved". The policy directives under this goal are:
  - Mainstream environmental considerations into agricultural practices.

- › Incorporate sustainable farming practices such as agroforestry and soil improvement technologies in all agricultural practices.
- › Practice organic farming.

» In Samoa, mainstreaming of biodiversity in the NASP (2016–2020) is achieved under the Sector Policy Objective 4: "To ensure sustainable adaptation and management of agriculture resources". To strengthen the integration and link the NASP to the achievement of the Aichi Targets, the Ministry of Natural Resources and Environment chairs the working group for this component of the NASP, underlining Samoa's sector-wide approach for biodiversity and ecosystem services in agriculture.

Table 14. **NBSAP references to mainstreaming biodiversity in other national sector plans**

COUNTRY	REFERENCE TO MAINSTREAMING BIODIVERSITY
Cook Islands	Integrate biodiversity into national and sectoral legislation, policies, plans and programmes
Fiji	… [to] ensure mainstreaming of biodiversity across sectors of government, society and the economy and to find synergies with national implementation of multilateral environment agreements
Federated States of Micronesia	Integrate concepts of conservation and sustainable use of biodiversity into all relevant sectoral policies, programs and plans
Kiribati	Mainstream the protection and management of island biodiversity into different sectors of government, private sector and civil society
Niue	… mainstreaming biodiversity and environmental concerns into plans and actions
Palau	… integrate biodiversity conservation strategies and policies into all government planning and operations
Papua New Guinea	… mainstreaming of biodiversity conservation into all the main sectors is envisaged to be a gradual process
Samoa	Address the underlying causes and drivers of biodiversity loss by consolidating the mainstreaming of biodiversity conservation across government and society
Solomon Islands	Ensure the commitment of Solomon Islands government and stakeholders to conserving and managing biodiversity is integrated into national legislation, sectoral plans, policies and programs
Tonga	Biodiversity is recognized, respected and integrated into all social and economic sectors strategies and plans
Tuvalu	Mainstreaming of biodiversity into the national policy framework and sector plans
Vanuatu	Incorporate the Aichi Targets which will also be mainstreamed into other sectoral policies and legislations

Coherence in addressing ecosystem services and biodiversity in and for agriculture in NBSAPs and NASPs in Pacific Island countries

For national development planning processes to link biodiversity and ecosystem services effectively with agricultural production and reduced dependency on agrochemicals, a country's NBSAP, NASP and other related sectoral plans and strategies must be coherent and must be tied to both the production and environmental goals of the national development strategy. The term "coherent" in this regard means aligned, interconnected, logical and consistent. Coherence between key sectoral plans is an important basis for well-functioning coordination mechanisms and for the realization of synergies.

Analysis of keywords in NBSAPs and NASPs

To analyse the coherence between Pacific Island countries' NBSAPs and NASPs (Table 15) in terms of their inclusion of policy measures that promote ecosystem-based approaches to agriculture, a basic assessment was carried out by searching for keywords selected on the basis of their relevance to ecosystem services and biodiversity in and for agriculture. The keywords also include terms of relevance to issues of importance for sustainable agriculture such as climate change adaptation and resilience, revival of traditional farming systems and use of agrochemicals.

Broadly speaking, the findings of the keyword analysis (Figures 12 and 13) provide a general overview of how the various elements of agricultural biodiversity and issues relating to sustainable agriculture are reflected in NBSAPs and, conversely, how the various elements of biodiversity and ecosystem services are integrated in the NASPs.

In general, there is little coherence between the NBSAPs and NASPs as national instruments for promoting ecosystem-based approaches to agriculture across the region. The NASPs, for example, frequently use the term "environment" (including "environmental protection", "environmental sustainability") instead of "biodiversity" or "ecosystem services". While most Pacific Island countries identified agriculture as a threat to biodiversity conservation in their NBSAPs, the term "sustainable agriculture" is mentioned in only three NBSAPs, and only two Pacific Island countries (Fiji, Federated States of Micronesia) mention "sustainable agriculture" in both their NBSAP and NASP.

The low level of coherence may be attributed partly to the fact that NASPs have been developed primarily in response to, and in the context of, national development strategies, while the development of NBSAPs has been driven mostly through GEF capacity building projects for implementation of the CBD.

While the term "ecosystem" is used quite extensively in the NBSAPs and less frequently in NASPs, in both types of document it is mostly mentioned alone rather than as part of broader concepts such as "ecosystem services" (including "ecosystem functions"), "valuation of ecosystem services" and "ecosystem-based approaches" (including "ecosystem-based management").

Terms related specifically to agricultural components of conservation and biodiversity tend to be used with a narrow view of the concepts. For example, the term "agrobiodiversity" (defined by the CBD as "all the components of biodiversity that have relevance to agriculture and food, and all the components of biodiversity that constitute the agro-ecosystems: the variety and variability of animals, plants, and microorganisms, at the genetic, species and ecosystem levels, necessary for sustaining key functions of the agro-ecosystems, their structures, and their processes" [CBD, 2000]) is mostly used to refer to the diversity of food plants and animals, without reference to other components such as "pollinators" and "soil biodiversity".

Some general conclusions can be drawn from the findings of the keyword search:

» The development of well-functioning coordination mechanisms to support the integration of biodiversity and agriculture has reached different stages and levels in different Pacific Island countries. However, the observed lack of harmonization in terminology between NBSAPs and NASPs overall might indicate insufficient consultation across relevant sectors.

» The broader concepts of ecosystem services need to be introduced and supported in the environmental goals of national development strategies, in order to support ecosystem-based approaches in NASPs and plans in other sectors such as water, forests and fisheries.

» Organic farming and traditional farming practices based on traditional knowledge of local biodiversity should be given more attention in future reviews of NBSAPs to strengthen alignment with NASPs in promoting low-input farming practices that are less reliant on agrochemicals.

» The findings reflect the importance of climate change to Pacific Island countries but highlight a need for stronger coherence between the NBSAPs and NASPs as national instruments for promoting ecosystem-based approaches to building the resilience of the agriculture sector to the impacts of climate change.

» More effort is required in mainstreaming of gender issues within sectoral plans. This will remain a constraint without stronger support for inclusiveness as a core guiding principle in the overarching National Sustainable Development Strategy process.

Table 15. **Latest Pacific Island NBSAPs and NASPs**

COUNTRY	NBSAP PUBLICATION YEAR	NASP TITLE (YEAR PUBLISHED OR IMPLEMENTATION PERIOD)
Cook Islands	2002	Agriculture and Food Sector (2015)
Fiji	2007	Fiji 2020 Agriculture Sector Policy Agenda (2014)
Federated States of Micronesia	2002	Agriculture Policy (2012–2016)
Kiribati	2005	Agriculture Strategic Plan (2013–2016)
Marshall Islands	2000	–
Nauru	–	–
Niue	2015	Food and Nutrition Security Policy (2015–2019)
Palau	2004	–
Papua New Guinea	2007	National Agriculture Development Plan (2007–2016)
Samoa	2015	Agriculture Sector Plan (2016–2020)
Solomon Islands	2009	Agriculture and Livestock Sector Policy (2015–2019)
Tonga	2006	Agriculture Sector Plan (2016–2020)
Tuvalu	2012	–
Vanuatu	1999	Agriculture Sector Policy (2015–2030)

Figure 12. **Overview of occurrences of keywords in the NBSAPs and NASPs listed in Table 15**

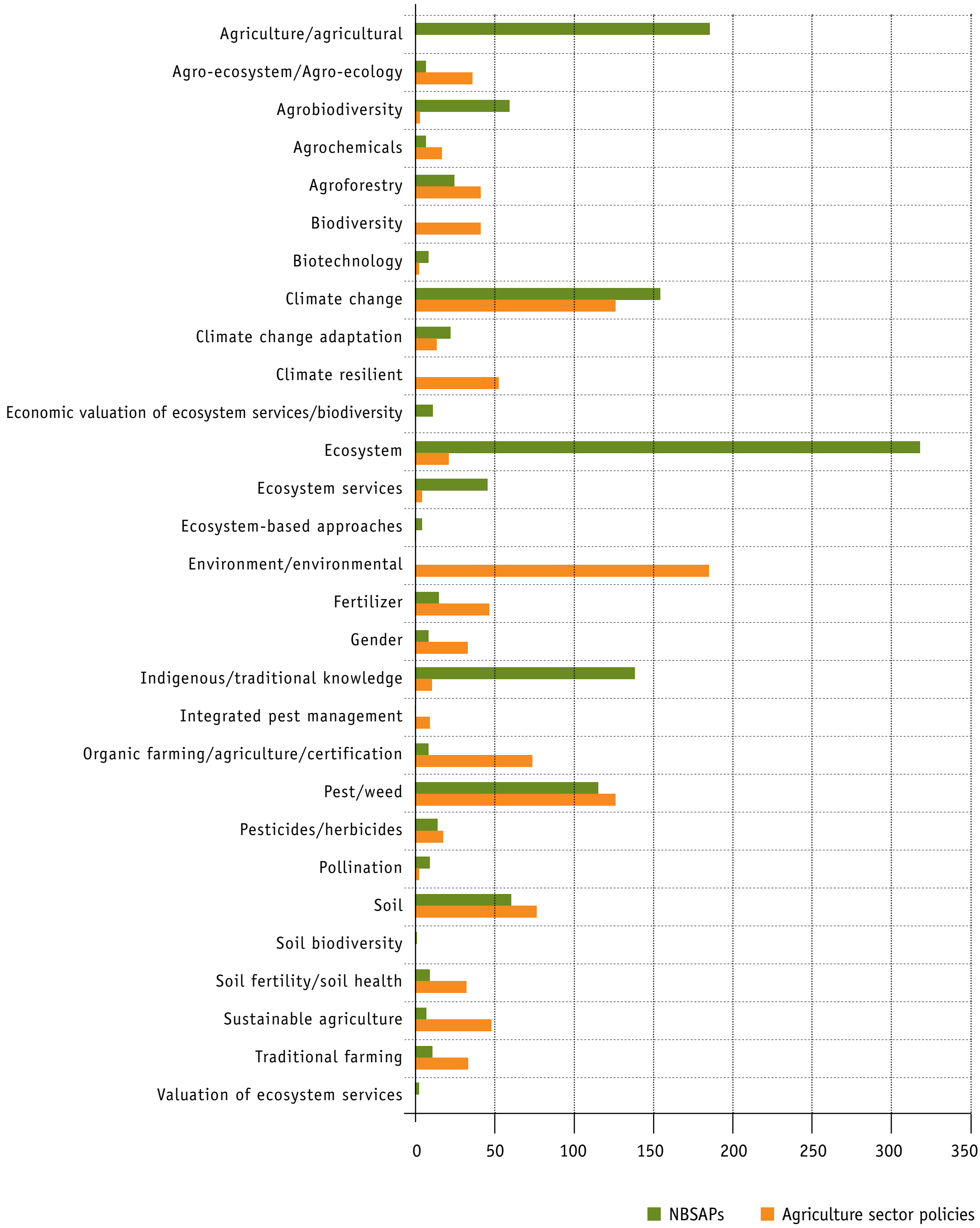
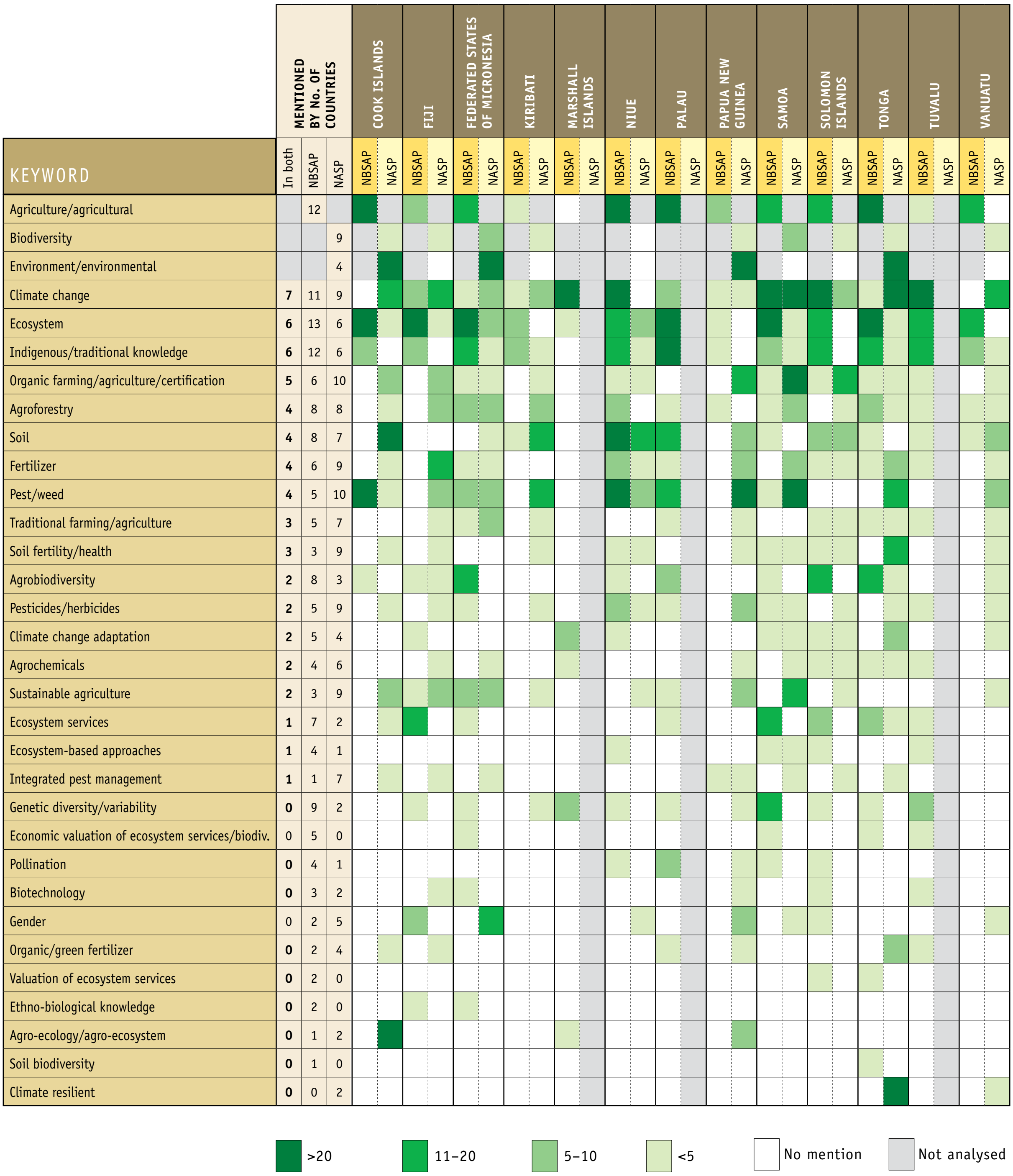


Figure 13. **Keyword appearance in Pacific Island NBSAPs and NASPs**



11 COORDINATED INCENTIVES TO SUPPORT ECOSYSTEM SERVICES THROUGH SUSTAINABLE PRODUCTION

Lucy Garrett and Bernardete Neves

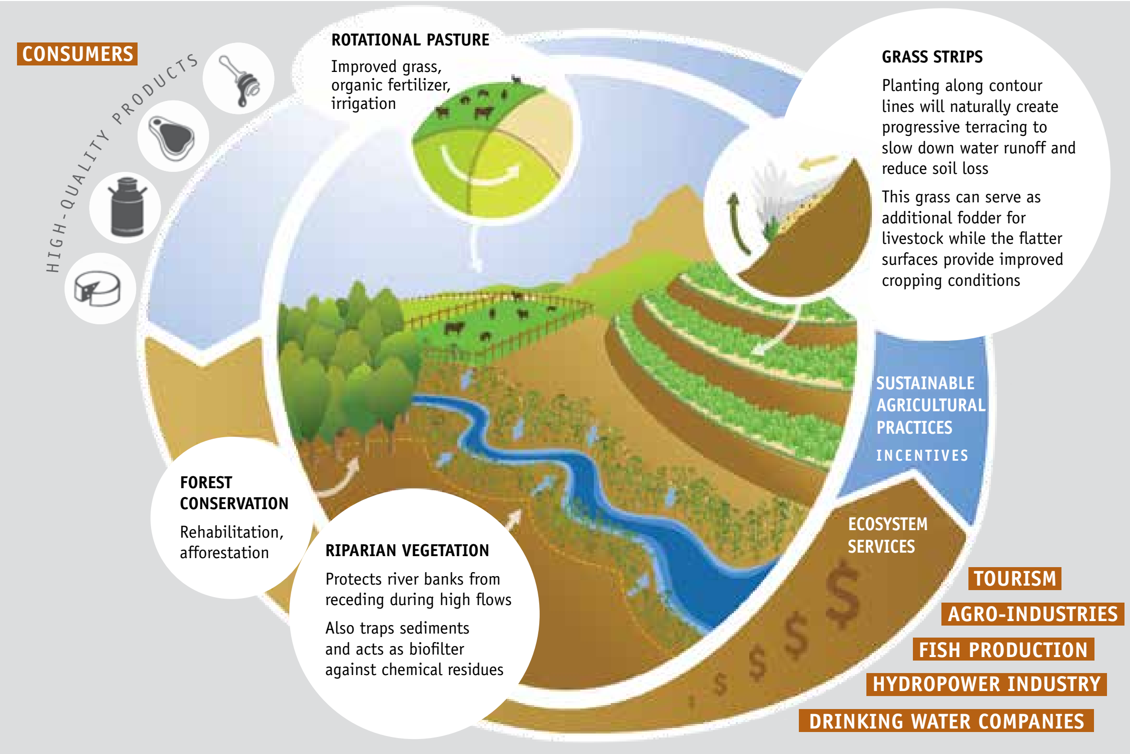
To reduce and reverse ecosystem degradation, the value of ecosystem services and the economic, social, cultural and well-being benefits they provide must be incorporated into subnational, national, regional and international policies. These policies must promote conservation and enhancement of agriculture-related ecosystem services in the planning and management of landscapes and must include incentives to support the transition of smallholder farmers to more sustainable practices (TEEB, 2013). Economic valuation of ecosystem services in and from agriculture in PICTs can guide the development of policies and initiatives to support investment in the landscape by both public and private stakeholders.

Incentives for ecosystem services

The CBD has encouraged Parties to create enabling conditions and provide incentives for the adoption of sustainable management practices in agriculture, forestry, fisheries, aquaculture and other sectors. Incentives for ecosystem services (IES) can provide an enabling policy framework for supporting sustainable agriculture and the protection of biodiversity and ecosystem services. Improved coordination of policy instruments through such a framework can enable strategic planning and investment in agricultural and environmental measures that are co-financed from multiple public and private users of ecosystem services (Figure 14).

The CBD (2002) noted “that a single measure will often not suffice to address the complexities involved in decisions on biodiversity conservation or sustainable use, and that a mix of measures may be needed”. Decision X/6 (CBD, 2008) and the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) (CBD, 2016b) emphasized that to enable harmonization across agricultural and environmental sectors, the design of an appropriate incentives package is vital (Lambin and Meyfroidt, 2011).

Figure 14. **Different users of ecosystem services provided by agriculture which could potentially co-finance investment in conservation-related measures**



Source: FAO, 2016d

Financial and non-financial incentives can support restoration, rehabilitation and conservation of ecosystems to protect biodiversity; improve productivity in a more sustainable manner; and improve livelihood outcomes through better access to markets, added-value products and diversified income development. Without incentives to address short- and long-term challenges, farmers, fishers and foresters are limited in their ability to invest time and capital to overcome barriers to sustainable production and conservation of biodiversity and to adopt sustainable practices (FAO, 2007b).

The IES approach can provide a package of actions for farmers that promotes increased productivity while also enhancing ecosystem functions. Conditionality is key to this development, linking conservation activities with improved productivity (Phalan *et al.*, 2016; Lipper and Neves, 2011). Conditional provision of incentives, when embedded into an IES framework and made explicit for stakeholders, can support positive changes in land use behaviours and practices. Where conditionality is absent, leakage of non-sustainable behaviours may continue in other locations. IES design should therefore link improved and sustainable production, such as agroforestry and reduced use of agrochemical inputs, with activities that benefit conservation and landscape restoration, such as reforestation and riparian habitat protection. When conditionality is combined with adequate monitoring and enforcement, this IES approach can provide motivation for positive land-use change and reduce the opportunity costs of conservation.

Sources of incentives

Incentives can be sourced from multiple public policies, private-sector investment and civil-society initiatives (Figure 15) (FAO, 2016d). A combination of different types of policy-driven and voluntary incentives, such as rural development, taxes, offsets, corporate social responsibility, payment for ecosystem services (PES) and cultural norms, is a more holistic approach for encouraging farmers and landowners to integrate conservation of biodiversity with sustainable production. This can reduce the cost of implementing conservation while assisting farmers and fishers in a more holistic way to improve agro-ecosystem management. For example, public policies to improve productivity combined with rewards for conservation practices can act as an incentive to comply with environmental regulation (Brewer and Goodell, 2012). Implementing incentives in a more cohesive framework can also reduce the social cost of conservation initiatives, helping farmers to overcome cultural, technical and financial barriers to their adoption.

Private-sector investment can contribute in diverse ways across the incentives spectrum and can be incorporated throughout the IES process. Since private enterprises are ecosystem service users, their investment in these services can be good for business. It can reduce their environmental and social impacts and risk, enable sustainability for commodity value chains, ensure compliance with environmental and health and safety regulations, and maintain a good corporate reputation. When private-sector investment is combined with public policies and civil-society initiatives, the burden of risk for private investors is dispersed across the IES package.

Figure 15. **Sources of incentives to support sustainable agriculture and conservation of ecosystem services and biodiversity**

Source: FAO, 2016d

A cross-sectoral IES approach

A number of measures, including policies and civil-society driven initiatives, are already in action in Pacific Island countries to support best practices and the mainstreaming of biodiversity and ecosystem services in sustainable agriculture and across other sectors. For example, the Federated States of Micronesia Agricultural Policy recognizes the importance of linking agriculture and tourism and identifies strategies for doing so, and the Vanuatu Strategic Tourism Action Plan seeks to improve local food supplies to the tourism sector (see Chapter 9). Organic practices in agriculture are promoted and supported through many mechanisms across the subregion, for example the promotion of organic farming and certification of organic products through the Pacific Organic and Ethical Community (POETCom) (see Chapter 3) and the Solomon Islands Government Policy of Organic Systems, which supports cross-sectoral partnership to develop national organic agriculture policies. Sustainable soil management practices have been promoted (see Chapter 5), for example in Samoa, Kiribati and Fiji through projects of the Australian Centre for International Agricultural Research (ACIAR, n.d.) and Development of Sustainable Agriculture in the Pacific (DSAP) (ALM, 2014–2016), implemented by SPC. These initiatives, however, have often been implemented in isolation. To improve the mainstreaming of biodiversity across sectors, a more integrated approach could support farmers and communities in implementing a broader range of sustainable activities.

Conclusions

IES can provide a supportive framework within an enabling environment to improve the coordination and implementation of policies, institutions and investments in the landscape. Co-financing from multiple public and private ecosystem service users can be supported through better planning of policies for agricultural and environmental management, which can also enable better targeting of incentives to farmers and fishers in priority areas (Mutoko, Rioux and Kirui, 2015).

To enable the scaling up and mainstreaming of ecosystem services and biodiversity into agriculture, fisheries and land planning, greater intersectoral and regional dialogue, coordination and integration are required. Enhanced dialogue can enable the design and implementation of initiatives that are context and resource specific (FAO, 2015) and can facilitate farmer participation, private-sector engagement and cross-sectoral planning in policy processes (FAO, 2016d). Better alignment and incorporation of existing initiatives and polices can promote assimilation of more integrated approaches into existing local land-use planning frameworks.

12
SUPPORTIVE POLICIES AND ENABLING ACTIONS FOR ECOSYSTEM-BASED AGRICULTURE IN THE PACIFIC ISLANDS

Randy Thaman and Keneti Faulalo

Holistic management has been practised throughout the Pacific islands for hundreds to thousands of years. Today, it represents a comprehensive approach to managing all activities from the catchment or watershed out to the sea to ensure natural resource sustainability and biodiversity – a ridge to reef approach. It recognizes the importance of managing the nature and functioning of whole ecosystems together, rather than focusing on one aspect or sector such as forestry, agriculture or fisheries. The high investments of Pacific Island governments in the regional Ridge to Reef programme – which is supported by US$90 million from the GEF Trust Fund with US$300 million in co-financing, including from the governments in the subregion (SPC, 2016d) – demonstrates their support for holistic approaches to the management of natural resources. This concept can help promote the uptake of ecosystem approaches in agriculture and strengthen farmers' consideration of biodiversity and ecosystem services in their farming practices.

At the end of the day, policy to promote the uptake of ecosystem approaches in agriculture needs to target decision-making at the local farm level, as this is where actions happen. It is therefore important to understand the motivations and underlying drivers (often market or incentive driven) that can lead farmers to conserve biodiversity and ecosystem services in their farming practices.

This chapter presents general recommendations for promoting uptake of the management strategies presented in this publication – for a holistic approach to agricultural production and management in which biodiversity and ecosystem services considerations are mainstreamed.

Cross-cutting policy recommendations

Addressing data and information gaps for evidence-based policies

The biggest hurdle to policy formulation in Pacific Island countries is the lack of data and information because of the limited capacity for field research. To help inform policies in the region, and to support farmers' decision-making towards ecosystem-based farming practices, there is a need for much greater investment in research to provide evidence, for example, on:

» the high costs to society from the use of pesticides, in terms of human health, loss of productivity and adverse impacts on natural resources and ecosystem services;
» the components of agricultural systems that directly or indirectly affect biodiversity and ecosystem services.

In addition, it is necessary to protect, enrich and apply traditional conservation practices and indigenous and local knowledge. Local knowledge about the use of agrobiodiversity and ecosystem services and its changes over time is essential for assessment of the status of agrobiodiversity and ecosystem services. Policy should encourage exploitation of synergies between indigenous and local knowledge and the most up-to-date scientific knowledge (e.g. modern propagation, plant breeding, forest establishment, organic gardening, pest and disease control) as a foundation for addressing the loss of agrobiodiversity and ecosystem services, for example through:

» funding of in-depth research on existing agroforestry systems, their component plants, their natural histories and propagation, cultural ecology and husbandry and their economic (and particularly subsistence) importance in the context of national development;
» establishment of intersectoral working groups or committees to compile published lists (with both vernacular and Latin names) of long-established traditional and potentially important indigenous and introduced agroforestry species, cultivars and practices that should be protected and/or promoted in institutional agroforestry development;
» identification of people and communities with in-depth indigenous and local knowledge who could be made active participants in preserving and recording this knowledge and promoting the conservation of agrobiodiversity and ecosystem services, and who could be formally recognized in a national "Register of Living Treasures" or in another appropriate manner.

Changing behaviour requires knowledge. Acquisition of data and information, especially tangible evidence on human health and ecosystems, to inform policies should be one of the highest priorities for the region.

Strengthening appropriate enforceable legislation and environmental impact assessment

Stronger legislation and enforcement are needed to ensure successful conservation of agrobiodiversity and ecosystem services, including enforcement of existing environmental legislation related to conservation and protected areas, such as restrictions on burning, harvesting of protected species and agricultural encroachment in conservation areas.

Particularly important is the strengthening of environmental impact assessment (EIA) capacity and procedures in most PICTs, for assessment of potential negative impacts of proposed developments, including modern monocultural agricultural developments (e.g. biofuel projects and plantation agriculture and forestry projects), on agrobiodiversity and ecosystem services. In many PICTs EIA processes are weak, non-existent or not enforced, and they often do not take into account impacts on agrobiodiversity and ecosystem services.

Public awareness and education

There is a critical need for comprehensive public awareness and education programmes that emphasize the nature, importance and status of agrobiodiversity and ecosystem services from integrated production systems, with particular emphasis on their use as a foundation for environmental, food, health and livelihood security. This will require:

» development of multimedia programmes in vernacular languages;
» development of curriculum modules that incorporate both indigenous and local knowledge and modern science for use in school curricula on agriculture, science, social sciences, geography, language and other relevant subjects, at appropriate levels;
» allocation of funding to assist appropriate agencies (e.g. cultural centres, dictionary projects, language departments, women's and craft associations, curriculum development units) in systematic compilation and publication of relevant studies and lexicons (dictionaries) about agrobiodiversity and ecosystem services that can be made available to local communities, the general public, policy-makers, planners, ecotourism developers, educationists and other appropriate groups for use in the promotion of agrobiodiversity and ecosystem services conservation.

Capacity building for agrobiodiversity and ecosystem services practitioners and extension personnel

Employees of relevant government sections, NGOs, volunteer organizations and private entities working in the areas of agriculture, forestry, conservation, health and other appropriate agencies require training in agrobiodiversity and ecosystem services related assessment and programme implementation and monitoring. Related activities could include:

» teaching of participatory community-based skills for assessing the status of agrobiodiversity and ecosystem services in rural and urban agricultural areas, to identify species and cultivars considered to be rare or endangered and in need of conservation;
» capacity strengthening and outreach for nursery workers on the propagation and distribution of planting materials of species that communities cannot produce for themselves;
» establishment of local nurseries or propagative capacity at the island, community, school, church or landowner level, where the focus should be on species that could be propagated locally at the community level;

» strengthening of capacity to plant or reintroduce and maintain young plants until they are well established.

Conditional incentives for sustainable resource management

Combining more enforceable regulatory incentives for sustainable management of resources, designed in a participatory way, with support measures that can help farmers adopt better practices can improve both food security and biodiversity conservation.

Protecting remnant forest in hilltops or along riparian strips becomes less costly for the farmer if crop productivity is higher in the rest of the farm. Continuing to grow native crop varieties becomes more interesting if there is a market for them; consumer awareness and education and health campaigns can create it.

If support to increase productivity, provide better access to markets and improve the return on investment is given conditionally, requiring compliance with underlying regulation –preventing deforestation, loss of biodiversity or coastal pollution – this combined package of "carrots and sticks" can reduce the competition of agriculture with conservation goals, reduce public expenditure on enforcement and bring higher co-benefits in food security and community empowerment. Recognizing the barriers farmers face in adopting more sustainable practices and designing adequate incentives will therefore be key to the uptake of the guidance in this publication.

Conclusions

The continuing loss of biodiversity and ecosystem services in PICTs is the most serious obstacle to their sustainable development and makes them particularly vulnerable to all global change. The conservation of biodiversity and ecosystem services is the most important foundation for environmental, food, livelihood, energy and cultural security in PICTs and the first line of defence against climate change and other global drivers of unsustainable development (UNEP, 2014).

Successful conservation of agrobiodiversity and ecosystem services requires their mainstreaming in institutional development agendas. It will require major changes in the planning of conservation, agriculture, forestry and other sectors of development and in formal and non-formal systems of training, education and curriculum development. Synergies must be built between indigenous knowledge and the most up-to-date scientific knowledge about biodiversity. This will require new models and technologies for maintaining interspecific and intraspecific agrobiodiversity in parallel with the introduction of new cash crops or cultivars; agricultural development and land clearance models that preserve arboreal and wildland biodiversity in and around active agricultural areas; and incorporation of the conservation of agrobiodiversity and ecosystem services in relevant initiatives not only in biodiversity hotspots, but also in small islands and rapidly urbanizing areas where the limited remaining biodiversity heritage, much of which is found within agricultural land use systems, is highly threatened.

REFERENCES

ACIAR (Australian Centre for International Agricultural Research). 2013. Taro beetle management in Papua New Guinea and Fiji (CP/2000/044). *In* A. Jilani, D. Pearce & D. Templeton, eds. *Adoption of ACIAR project outputs: studies of projects completed in 2007–08*, pp. 53-60. Canberra.

ACIAR. 2014. *Improving soil health in support of sustainable development in the Pacific.* Project report (available at http://aciar.gov.au/project/smcn/2009/003).

ACIAR. n.d. Pacific Regional Program Summary (available at http://aciar.gov.au/region/pacific). Accessed 1 November 2016.

Allen, B. 1971. Wet-field taro terraces on mangaia, Cook Islands. *Journal of the Polynesian Society*, 80: 371–378.

ALM (Adaptation Learning Mechanism). 2014–2016. Development of Sustainable Agriculture in the Pacific – DSAP (available at www.adaptationlearning.net/project/development-sustainable-agriculture-pacific-dsap). Accessed 1 November 2016.

Altieri, M.A. & Nichols, C.I. 2003. Soil fertility management and insect pests: harmonising soil and plant health in agro-ecosystems. *Soil Tillage Research*, 72: 203–211.

Anand, S. 2015. A taro (*Colocasia esculenta*) production system based on new varieties, organic matter recycling under selected fallow systems and nutrient budgeting for economic and environmental sustainability. *South Pacific Agricultural News (SPAN)*, 40(6): 4.

Andrew, I.K.S., Storkey, J. & Sparkes, D.L. 2015. A review of the potential for competitive cereal cultivars as a tool in integrated weed management. *Weed Research*, 55: 239–248.

Atumurirava, F.A. 2015. *Diamondback moth resistance to commonly used insecticides and its management in Fiji*. Brisbane, Australia, University of Queensland, School of Biological Sciences (MPhil thesis). doi: 10.14264/uql.2015.769.

Aviva Farms. 2016. [Website] (available at www.agrotour.wixsite.com/avivafarms). Accessed 1 November 2016.

Balakrishnan, R. 1998. *Rural women and food security: current situation and perspectives*. Rome, FAO.

Balmford, A., Beresford, J., Green, J., Naidoo, R., Walpole, M. & Manica, A. 2009. A global perspective on trends in nature-based tourism. *PLoS Biology*, 7:e10001444.

Bàrberi, P. 2002. Weed management in organic agriculture: are we addressing the right issues? *Weed Research*, 42: 176–193.

Barrios, E. 2007. Soil biota, ecosystem services and land productivity. *Ecological Economics*, 64: 269–285.

Bastiaans, L., Paolini, R. & Baumann, D.T. 2008. Focus on ecological weed management: what is hindering adoption? *Weed Research*, 48: 481–491.

Beare, M.H., Coleman, D.C., Crossley, D.A., Jr, Hendrix, P.F. & Odum, E.P. 1995. A hierarchical approach to evaluating the significance of soil biodiversity to biogeochemical cycling. *In* H.P. Collins, G.P. Robertson & M.J. Klug, eds. *The significance and regulation of soil biodiversity*, pp. 5–22. Dordrecht, the Netherlands, Kluwer Academic Publishers.

Beketov, M.A., Kefford, B.J., Schäfer, R.B. & Liess, M. 2013. Pesticides reduce regional biodiversity of stream invertebrates. *Proceedings of the National Academy of Sciences of the USA*, 110(27): 11039–11043.

Benbrook, C. 2009. The impacts of yield on nutritional quality: lessons from organic farming. *HortScience*, 44(1): 12–14.

Benbrook, C.M., Butler, G., Latif, M.A., Leifert, C. & Davis, D.R. 2013. Organic production enhances milk nutritional quality by shifting fatty acid composition: a United States–wide, 18-month study. *PLoS ONE*, 8(12): e82429. doi: 10.1371/journal.pone.0082429.

Bishop, R.V. & Fakava, V. 2015. Terminal Statement, TCP/PLW/3401: Strengthening Capacity for Sustainable Organic Crop Production in Palau. FAO Project document.

Boateng, S.A. 2005. *Mucuna pruriens* and its effect on some physical, chemical and biological properties of a forest acrisol. *West African Journal of Applied Ecology*, 8(1).

Bommarco, R., Kleijn, D. & Potts, S. 2013. Ecological intensification: harnessing ecosystem services for food security. *Trends in Ecology and Evolution*, 28(4): 230–238.

Bourke, R.M., Allen, B.J., Humphreys, G.S., Ballard, C., Grau, R., & Hide, H.L. 1991. The composted mounds of the Papua New Guinea Highlands. In *New perspectives on the Papua New Guinea Highlands: an interdisciplinary conference on the Duna, Huli and Ipili peoples*, pp. 1–18. Canberra, Australia, Department of Human Geography, Australian National University.

Brewer, M.J. & Goodell, P.B. 2012. Approaches and incentives to implement integrated pest management that addresses regional and environmental issues. *Annual Review of Entomology*, 57: 41–58.

Brower, A. 2010. *Diversified, localized, and sustainable agriculture on Kaua`i: assessing opportunities and addressing barriers.* Kīlauea, Hawaii, USA, Mālama Kaua`i (available at www.malamakauai.org).

Bryant, L. 2015. Organic matter can improve your soil's water holding capacity. Natural Resources Defense Council (NRDC) expert blog, May 27 (available at www.nrdc.org/experts/lara-bryant/organic-matter-can-improve-your-soils-water-holding-capacity). Accessed 4 November 2016.

Buckley, R. 2003. *Case studies in ecotourism*. Wallingford, UK, CAB International.

Buckley, R. 2004. *Environmental impacts of ecotourism*. Wallingford, UK, CAB International.

Buckley, R., Morrison, C. & Castley, J.G. 2016. Net effects of ecotourism on threatened species survival. *PLoS ONE*, 11: e0147988.

CBD. 1996. Decision III/11. Conservation and sustainable use of agricultural biological diversity. Third Ordinary Meeting of the Conference of Parties to the CBD, Buenos Aires, Argentina, 4–15 November 1996 (available at www.cbd.int/decisions/?m=COP-03&n=11).

CBD. 2000. Decision V/5. Agricultural biological diversity: review of Phase I of the Programme of Work and adoption of a Multi-Year Work Programme. Fifth Meeting of the Conference of Parties to the CBD, Nairobi, Kenya, 15–26 May 2000 (available at www.cbd.int/decisions/?id=7147). Accessed August 2016.

CBD. 2002. Decision VI/15. Incentive measures. Sixth Meeting of the Conference of the Parties to the CBD, the Hague, the Netherlands, 7–19 April 2002 (available at www.cbd.int/decision/cop/?id=7189).

CBD. 2007. *Mainstreaming biodiversity into sectoral and cross-sectoral strategies, plans and programmes*, Module B-3. Montreal, Canada, CBD, UNEP & Biodiversity Planning Support Programme (BPSP).

CBD. 2008. COP 9 Decisions. Ninth Meeting of the Conference of the Parties to the CBD, Bonn, Germany, 19–30 May (available at www.cbd.int/decisions/cop/?m=cop-09).

CBD. 2010a. *Global Biodiversity Outlook 3*. Montreal, Canada (available at www.cbd.int/gbo3).

CBD. 2010b. COP 10 Decisions. Tenth Meeting of the Conference of the Parties to the CBD, Nagoya, Japan, 18–29 October 2010 (available at www.cbd.int/decisions/cop/?m=cop-10).

CBD. 2014a. *Global Biodiversity Outlook 4*. Montreal, Canada (available at www.cbd.int/gbo4).

CBD. 2014b. *How sectors can contribute to sustainable use and conservation of biodiversity*. CBD Technical Series No. 79. The Hague, the Netherlands, PBL Environment Assessment Agency (available at www.cbd.int/doc/publications/cbd-ts-79-en.pdf).

CBD. 2016a. National Biodiversity Strategies and Actions Plans (NBSAPs) (available at www.cbd.int/nbsap).

CBD. 2016b. Recommendation XX/15. Mainstreaming of biodiversity across sectors including agriculture, forests, fisheries and aquaculture. Twentieth Meeting of the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA), Montreal, Canada, 25–30 April 2016. UNEP/CBD/SBSTTA/REC/XX/15 (available at www.cbd.int/doc/recommendations/sbstta-20/sbstta-20-rec-15-en.pdf).

Chen, Y.P., Rekha, P.D., Arun, A.B., Shen, F.T., Lai, W.A. & Young, C.C. 2006. Phosphate solubilizing bacteria from subtropical soil and their tri-calcium phosphate solubilizing abilities. *Applied Soil Ecology*, 34: 33–41.

Christie, M., Fazey, I., Cooper, R., Hyde, T. & Kenter, J.O. 2012. An evaluation of monetary and non-monetary techniques for assessing the importance of biodiversity and ecosystem services to people in countries with developing economies. *Ecological Economics*, 83: 67–78.

Clarke, W.C. & Thaman, R.R., eds. 1993. *Pacific Island agroforestry: systems for sustainability*. Tokyo, United Nations University Press.

Cloutier, D.C., van der Weide, R.Y., Peruzzi, A. & Leblanc, M.L. 2007. Mechanical weed management. *In* M.K. Upadhyaya & R.E. Blackshaw, eds. *Non-chemical weed management: principles, concepts and technology*, pp. 111–134. Wallingford, UK, CAB International.

Costanzo, A. & Bàrberi, P. 2014. Functional agrobiodiversity and agroecosystem services in sustainable wheat production – a review. *Agronomy for Sustainable Development*, 34: 327–348.

Craw, J. 2016. *Niue Pig Management Plan*. Prepared for the Government of Niue (available at www.sprep.org/attachments/VirLib/Niue/pig-management-plan.pdf).

Dadhich, A.P. & Nadaoka, K. 2012. Analysis of terrestrial discharge from agricultural watersheds and its impact on nearshore and offshore reefs in Fiji. *Journal of Coastal Research*, 28: 1225–1235. doi 10.2112/JCOASTRES-D-11-00149.1.

Daily, G. 1997. Introduction: what are ecosystem services? *In* G. Daily, ed. *Nature's services: societal dependence on natural ecosystems*. Washington, DC, Island Press.

Damiani, O. 2002. *Small farmers and organic agriculture: lessons learned from Latin America and the Caribbean*. Rome, IFAD.

Davis, A.D. 2010. Cover-crop roller-crimper contributes to weed management in no-till soybean. *Weed Science*, 58: 300–309.

Davis, A.D., Taylor, E.C., Haramoto, E.C. & Renner, K.A. 2013. Annual postdispersal weed seed predation in contrasting field environments. *Weed Science*, 61: 296–302.

Day, M.D., Bofeng, I., & Nabo, I. 2011. Successful biological control of *Chromolaena odorata* (Asteraceae) by the gall fly *Cecidochares connexa* (Diptera: Tephritidae) in Papua New Guinea. *In* Y. Wu, T. Johnson, S. Sing, S. Raghu, G. Wheeler, P. Pratt, K. Warner, T. Center, J. Goolsby & R. Reardon, eds. *Proceedings of the XIII International Symposium on Biological Control of Weeds*, pp. 400–408. Waikoloa, Hawaii, USA, 11–16 September 2011. United States Forest Service.

Dance, A. 2008. Soil ecology: what lies beneath. *Nature*, 455: 724–725.

de Groot, R.S., Wilson, M.A. & Boumans, R.M.J. 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics*, 41: 393–408.

Devine, G.J. & Furlong, M.J. 2007. Insecticide use: contexts and ecological consequences. *Agriculture and Human Values*, 24: 281–306. doi: 10.1007/s10460-007-9067-z.

Dominati, E., Patterson, M. & Mackay, A. 2010. A framework for classifying and quantifying the natural capital and ecosystem services of soils. *Ecological Economics*, 69: 1858–1868.

Doran, J.W. & Parkin, T.B. 1996. Quantitative indicators of soil quality: a minimum data set. *In* J.W. Doran & A.J. Jones, eds. *Methods for assessing soil quality*, pp. 25–37. Madison, Wisconsin, USA, Soil Science Society of America.

DSAP (Development of Sustainable Agriculture in the Pacific). 2009. *Case studies: lessons from the field – the DSAP experience*. Suva, SPC.

Eagles, P.J.F., McCool, S.F. & Haynes, C.D. 2002. *Sustainable tourism in protected areas: guidelines for planning and management*. Gland, Switzerland, International Union for Conservation of Nature (IUCN).

Emerton, L. & Bos, E. 2004. V*alue: counting ecosystems as an economic part of water infrastructure*. Gland, Switzerland and Cambridge, UK, IUCN (available at https://portals.iucn.org/library/efiles/documents/2004-046.pdf).

FAO. 2007a. *Global Plan of Action for Animal Genetic Resources and the Interlaken Declaration*. Rome (available at ftp://ftp.fao.org/docrep/fao/010/a1404e/a1404e00.pdf).

FAO. 2007b. *The State of Food and Agriculture: innovation in family farming*. Rome.

FAO. 2009a. *Organic agriculture and fair trade in Pacific Island countries* (available at www.fao.org/3/a-ak356e.pdf).

FAO. 2009b. Country pasture and forage resource profiles of the South Pacific (available at www.fao.org/ag/agp/agpc/doc/Counprof/southpacific). Accessed September 2016.

FAO. 2010. *International Code of Conduct on the Distribution and Use of Pesticides. Guidance on Pest and Pesticide Management Policy Development*. Rome (available at www.fao.org/3/a-a0220e.pdf).

FAO. 2011. *Second Global Plan of Action for Plant Genetic Resources for Food and Agriculture.* Rome (available at www.fao.org/docrep/015/i2624e/i2624e00.pdf).

FAO. 2012a. *Pacific Multi-Country Programming Framework (CPF) 2013–2017*. Apia, FAO Subregional Office for the Pacific Islands.

FAO. 2012b. *Agriculture and tourism linkages in Pacific Island countries*. Apia, FAO Subregional Office for the Pacific Islands.

FAO. 2014a. *Global Plan of Action for the Conservation, Sustainable Use and Development of Forest Genetic Resources*. Rome (available at www.fao.org/3/a-i3849e.pdf).

FAO. 2014b. *Linking farmers to markets: improving opportunities for locally produced food on domestic and tourist markets in Vanuatu*. Apia, FAO Subregional Office for the Pacific Islands.

FAO. 2015. Incentives for ecosystem services in agriculture (IES). Brochure (available at www.fao.org/3/a-i4702e.pdf).

FAO. 2016a. *State of food security and nutrition in Small Island Developing States (SIDS)*. Rome (available at www.fao.org/3/a-i5327e.pdf).

FAO. 2016b. FAOSTAT database (available at http://faostat3.fao.org). Accessed September 2016.

FAO. 2016c. Agroforestry (available at www.fao.org/forestry/agroforestry). Accessed September 2016.

FAO. 2016d. Incentives for ecosystem services (available at www.fao.org/in-action/incentives-for-ecosystem-services). Accessed 31 October 2016.

Ferentinos, L. 2000. *Sustainable taro culture in the Pacific: the farmers' wisdom*. Taro Production Systems in the American Pacific, LISA Project (available at www.ctahr.hawaii.edu/adap/Publications/ADAP_pubs/2000-Taro.pdf).

Furlong, M.J., Ju, K.H., Su, P.W., Chol, J.K., Il, R.C. & Zalucki, M.P. 2008. Integration of endemic natural enemies and *Bacillus thuringiensis* to manage insect pests of *Brassica* crops in North Korea. *Agriculture, Ecosystems and Environment*, 125: 223–238. doi: 10.1016/j.agee.2008.01.003.

Furlong, M.J., Shi, Z.H., Liu, Y.Q., Guo, S.J., Lu, Y.B., Liu, S.S. & Zalucki, M.P. 2004. Experimental analysis of the influence of pest management practice on the efficacy of an endemic arthropod natural enemy complex of the diamondback moth. *Journal of Economic Entomology*, 97: 1814–1827.

Furlong, M.J., Wright, D.J. & Dosdall, L.M. 2013. Diamondback moth ecology and management: problems, progress, and prospects. *Annual Review of Entomology*, 58: 517–541. doi: 10.1146/annurev-ento-120811-153605.

Gachene, C. 2016. Enhancing soil fertility. In *Mainstreaming ecosystem services and biodiversity into agricultural production and management in East Africa*, pp. 46–56. Rome, FAO.

Gbehounou, G. & Bàrberi, P. 2016. Weed management. In *Mainstreaming ecosystem services and biodiversity into agricultural production and management in East Africa*, pp. 29–45. Rome, FAO.

GEF (Global Environment Facility). 2016. R2R integrated land and agro-ecosystem management systems (available at www.thegef.org/project/r2r-integrated-land-and-agro-ecosystem-management-systems). Accessed 30 October 2016.

Golabi, M.H., Iyekar, C. & Denney, M.J. 2005. Challenges and actions regarding the rehabilitation of degraded lands: case study from the Pacific Islands of Guam. *Sociadade & Natureza*, Uberlandia, Special Issue: 87–106.

Gómez, R., Liebman, M. & Munkvold, G. 2014. Weed seed decay in conventional and diversified cropping systems. *Weed Research*, 54: 13–25.

Gossling, S. 1999. Ecotourism: a means to safeguard biodiversity and ecosystem functions? *Ecological Economics*, 29: 303–320.

Government of the Republic of Nauru. 2014. Nauru's fifth national report to the Convention on Biological Diversity (available at www.cbd.int/doc/world/nr/nr-nr-05-en.pdf).

Gunua, T. 2015. Improving soil health in support of sustainable development in the Pacific. Annual reports for ACIAR project SMCN/2009/003 (available at http://aciar.gov.au/project/smcn/2009/003).

Hajkowicz, S. & Okotai, P. 2006. *An economic valuation of watershed pollution in Rarotonga, the Cook Islands*. IWP-Pacific Technical Report (International Waters Project) No. 18. Apia, SPREP (available at www.pacificwater.org/userfiles/file/IWRM/Toolboxes/financing%20IWRM/economic%20valuation-CI.pdf).

Hallmann, C.A., Foppen, R.P., van Turnhout, C.A., de Kroon, H. & Jongejans, E. 2014. Declines in insectivorous birds are associated with high neonicotinoid concentrations. *Nature*, 511: 341–343.

Harker, K.N., Clayton, G.W. & O'Donovan, J.T. 2005. Reducing agroecosystem vulnerability to weed invasion. *In* Inderjit, ed. *Invasive plants: ecological and agricultural aspects*, pp. 195–207. Basel, Switzerland, Birkhäuser Verlag.

Havemann, T., Schuster, D., Leigh-Bell, J., Negra, C. & Levonen, A. 2016. *Levering ecosystems: a business-focused perspective on how debt supports investments in ecosystem services.* Credit Suisse.

Hunnam, P. 2002. Lessons in conservation for people and projects in the Pacific Islands region. New York, USA, UNDP.

IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services). 2016. *The assessment report on pollinators, pollination and food production*. Bonn, Germany (available at www.ipbes.net/sites/default/files/downloads/pdf/SPM_Deliverable_3a_Pollination.pdf).

Iwai, N., Shinji, S. & Chiba, S. 2010. Predation impacts of the invasive flatworm *Platydemus manokwari* on eggs and hatchlings of land snails. *Journal of Molluscan Studies*, 76(3): 275–278.

Jansen, T. & Maemouri, R.K. 2000. Traditional slash and mulch on Guadalcanal. *ILEISA Newsletter*, 16: 36 (available at www.agriculturesnetwork.org/magazines/global/farming-in-the-forest).

Jansen, T., Tutua, S.S. & Logan, T. 2011. *Leadership manual: protecting food security through adaptation to climate change in Melanesia*. Melbourne, Australia, Live & Learn Environmental Education.

Jansen, T., Jasperse, J. & Logan, T. 2011. *Farm technology: protecting food security through climate change adaptation in Melanesia*. Melbourne, Australia, Live & Learn Environmental Education.

Jordan, R., Müller, A. & Oudes, A. 2009. *High sequestration, low emission, food secure farming. Organic agriculture – a guide to climate change and food security*. Bonn, Germany, International Federation of Organic Agriculture Movements (IFOAM).

JSSA (Japan Satoyama-Satoumi Assessment). 2010. *Satoyama-Satoumi ecosystems and human well-being: socio-ecological production landscapes of Japan. Summary for decision makers*. Tokyo, Institute of Advanced Studies, United Nations University.

Kabu, R. 2001. Farmer field trials of integrated pest management in North Malaita, Solomon Islands, using a participatory technology development approach. *In* R.M. Bourke, M.G. Allen & J.G. Salisbury, eds. *Food security for Papua New Guinea*, pp. 582–587. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference, Lae, 26–30 June 2000. Canberra, ACIAR.

Keppel, G., Morrison, C., Watling, D., Tuiwawa, M. & Rounds, I. 2012. Conservation in tropical Pacific Island countries: why most current approaches are failing. *Conservation Letters*, 5: 256–265.

Kimblewhite, M.G., Ritz, K. & Swift, M.J. 2008. Soil health in agricultural systems. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 363(1492): 685–701.

Klein, A., Steffan-Dewenter, I. & Tscharntke, T. 2003. Pollination of *Coffea canephora* in relation to local and regional agroforestry management. *Journal of Applied Ecology*, 40: 837–845.

Knudtson, P. & Suzuki, D. 1992. *Wisdom of the elders*. Toronto, Canada, Stoddart Publishing.

Kolbert, E. 2014. *The sixth extinction: an unnatural history*. New York, USA, Henry Holt & Co.

Kong, C.H., Hu, F., Wang, P. & Wu, J.L. 2008. Effect of allelopathic rice varieties combined with cultural management options on paddy field weeds. *Pest Management Science*, 64: 276–282.

Kuenzi, C. & McNeely, J. 2008. Nature-based tourism. *In* O. Renn & K.D. Walker, eds. *Global risk governance: concept and practice using the IRGC framework*, pp. 155–178. Dordrecht, the Netherlands, Springer.

Kukhang, T. 2013. Studies on the use of *Casuarina oligodon* to promote shade grown organic coffee in Papua New Guinea. Presented at the first Technical Exchange Workshop of POETCom, Noumea, New Caledonia, 1–5 July.

Labrada, R. 2008. Allelopathy as a tool for weed management. *Allelopathy Journal*, 22: 283-287.

Lacey, A. 2012. Gender and sustainable livelihoods in urban Honiara. *In* W. Harcourt, ed. *Women reclaiming sustainable livelihoods*, pp. 238–256. Basingstoke, UK, Palgrave Macmillan.

Lairon, D. 2009. Nutritional quality and safety of organic food – a review. *Agronomy for Sustainable Development,* 30(1): 33–41. doi: 10.1051/agro/2009019.

Lal, P. 2003. Economic valuation of mangroves and decision-making in the Pacific. *Ocean and Coastal Management*, 46(9–10): 823–844.

Lal, R. 2013. *Influence of mucuna (*Mucuna pruriens*) fallow crop on selected soil properties and taro yield in Taveuni, Fiji*. Suva, University of the South Pacific (Masters thesis).

Lal, S.N., ed. 2008. *Taro beetle management in Papua New Guinea and Fiji.* Final project report. Noumea, New Caledonia, SPC.

Lambin, E.F. & Meyfroidt, P. 2011. Global land use change, economic globalization and the looming land scarcity. *Proceedings of the National Academy of Sciences of the USA, 108(9): 3465–3472*.

Landis, D.A., Menalled, F.D.A., Costamagna, C. & Wilkinson, T.K. 2005. Manipulating plant resources to enhance beneficial arthropods in agricultural landscapes. Weed Science, 53: 902–908.

Laurans, Y., Pascal, N., Binet, T., Brander, L., Clua, E., David, G., Rojat, D. & Seidl, A. 2013. Economic valuation of ecosystem services from coral reefs in the South Pacific: taking stock of recent experience. *Journal of Environmental Management*, 116: 135–144.

Lavelle, P. 1996. Diversity of soil fauna and ecosystem function. *Biology International*, 33: 3–16.

Lebot, V. 2013. Coping with insularity: the need for crop genetic improvement to strengthen adaptation to climatic change and food security in the Pacific. *Environment, Development and Sustainability*, 15(6): 1405–1423.

Légère, A., Stevenson, F.C. & Benoit, D.L. 2011. The selective memory of weed seedbanks after 18 years of conservation tillage. *Weed Science*, 59: 98–106.

Leng, A.S. 1982. Maintaining fertility by putting compost into sweet potato mounds. *Harvest*, 8: 83–84.

Leo, F., Wong, K.K.Y & Tautai, S.J. 2014. Risks to soil biodiversity on the islands of the South Pacific. *Pacific Conservation Biology*, 20: 313–327

Li, S.S., Wei, S.H., Zuo, R.L., Wei, J.G. & Qiang, S. 2012. Changes in the weed seed bank over 9 consecutive years of rice–duck farming. *Crop Protection*, 37: 42–50.

Liebman, M. & Gallandt, E.R. 1997. Many little hammers: ecological management of crop-weed interactions. *In* L.E. Jackson, ed. *Ecology in agriculture*, pp. 291–343. San Diego, California, USA, Academic Press

Lipper, L. & Neves, B. 2011. *Payments for environmental services: what role in sustainable agricultural development?* ESA Working Paper No. 11-20. Rome, FAO.

Lu, C., Warchol, K.M. & Callahan, R.A. 2014. Sub-lethal exposure to neonicotinoids impaired honey bees winterization before proceeding to colony collapse disorder. *Bulletin of Insectology,* 67(1): 125–130.

MA (Millennium Ecosystem Assessment). 2005. *Ecosystems and human well-being: synthesis*. Washington, DC, Island Press.

Macanawai, A., Kapoor, G., Lal, S., Motu, M. & Mohan, P. 2013. Mucuna pruriens suppresses weeds by reducing their density and biomass weight on fallow land at Koronivia Research Station, Fiji. Technical Bulletin, Issue No. 4. Ministry of Agriculture, Fiji (available at www.agriculture.gov.fj/images/docs/publications/techinical-bulletin/technical-bulletin-issue-4-oct2013.pdf).

MACBIO (Marine and Coastal Biodiversity Management in Pacific Island Countries). n.d. Marine Ecosystem Service Valuation (available at http://macbio-pacific.info/marine-ecosystem-service-valuation).

Mahmood, R., Naseer, M., Shahid, A.A., Usmani, A. & Ali, A. 2014. Screening of indigenous weed extracts against *Fusarium solani* with an emphasis to soil fertility-related microbial activities. *Journal of Food, Agriculture and Environment*, 12: 958–962.

MAL (Ministry of Agriculture and Livestock, Solomon Islands). 2013. The urban supsup garden revival. In *Agrikalsa Nius*, Ministry of Agriculture and Livestock monthly newsletter, May (available at http://knowledge.cta.int/content/download/36567/498068/file/Agrikalsa+Nius+2013-05+%28final%29.pdf).

Moonen, A.C. & Bàrberi, P. 2008. Functional biodiversity: an agroecosystem approach. *Agriculture, Ecosystems and Environment*, 127: 7–21.

Morrison, C. 2012. Impacts of tourism on threatened species in the South Pacific. *Pacific Conservation Biology*, 18: 227–239.

Morrison, C. & Buckley, R. 2010. Oceania. *In* R. Buckley, ed. *Conservation tourism*, pp. 78–87. New York, USA, CAB International.

Morrison, C., Simpkins, C., Castley, J.G. & Buckley, R. 2012. Tourism and the conservation of critically endangered frogs. *PLoS ONE*, 7: e43757.

Mulvaney, D.R. 2008. Identifying vulnerabilities, exploring opportunities: reconfiguring production, conservation, and consumption in California rice. *Agriculture and Human Values*, 25(2): 173–176. doi 10.1007/s10460-008-9123-3.

Mutoko, M.C., Rioux, J. & Kirui, J. 2015. *Barriers, incentives and benefits in the adoption of climate-smart agriculture: lessons from the MICCA pilot project in Kenya*. Rome, FAO.

Naranjo, S.F., Ellsworth, P.C. & Frisvold, G.B. 2015. Economic value of biological control in integrated pest management of managed plant systems. *Annual Review of Entomology*, 60: 621–645. doi: 10.1146/annurev-ento-010814-021005.

NSW Department of Primary Industries. 2015. Water hyacinth (*Eichhornia crassipes*) (available at http://weeds.dpi.nsw.gov.au/Weeds/Details/145). Orange, Australia, Government of New South Wales (NSW). Accessed 9 November 2016.

Oades, J.M. 1993. The role of biology in the formation, stabilization and degradation of soil structure. *Geoderma*, 56: 377–400.

O'Donovan, J.T., Harker, K.N., Turkington, T.K. & Clayton, G.W. 2013. Combining cultural practices with herbicides reduces wild oat (*Avena fatua*) seed in the soil seed bank and improves barley yield. *Weed Science*, 61: 328–333.

PACC (Palau Pacific Adaptation to Climate Change). 2015. *Achieving resilient agriculture and aquaculture: a national policy for strengthening food security in Palau as a priority climate change adaptation measure*, by A. Kitalong, M. Sengebau & T. Holm. Koror, Palau.

PAFPNet (Pacific Agriculture and Forestry Policy Network). 2016. [Website] (available at http://pafpnet.spc.int/policy-bank/countries). Accessed September 2016.

Palomo, I., Martin-Lopez, B., Potschin, M., Haines-Young, R. & Montes, C. 2013. National parks, buffer zones and surrounding lands: mapping ecosystem service flows. *Ecosystem Services*, 4: 104–116.

Pascal, N. & Bulu, M. 2013. *Economic valuation of mangrove ecosystem services In Vanuatu: case study of Crab Bay (Malekula Is.) and Eratap (Efate Is.)*. Suva, IUCN (available at http://www.ircp.pf/wp-content/uploads/20130913_MESCALeconomic-valuation-of-mangrove-ecosystems-in-vanuatu.pdf). Accessed 7 November 2016.

Petersen, J. 2005. Competition between weeds and spring wheat for 15N-labelled nitrogen applied in pig slurry. *Weed Research*, 45: 103–113.

Phalan, B., Green, R.E., Dicks, L.V., Dotta, G., Feniuk, C., Lamb, A., Strassburg, B.B.N., Williams, D.R., zu Ermgassen, E.K.H.J. & Balmford, A. 2016. How can higher-yield farming help to spare nature? *Science*, 351(6272): 450–451.

Phelan, P.L., Norris, K.H. & Mason, J.F. 1996. Soil-management history and host preference by *Ostrinia nubilalis*: Evidence for plant mineral balance mediating insect-plant interactions. *Environmental Entomology*, 25: 1329–1336.

PIAT (Pacific Invasive Ant Toolkit). 2016. Red imported fire ant (available at http://piat.org.nz/problem-ants/worst-5-identification/red-imported-fire-ant). Accessed 13 November 2016.

Picasso, V.D., Brummer, E.C., Liebman, M., Dixon, P.M. & Wilsey, B.J. 2008. Crop species diversity affects productivity and weed suppression in perennial polycultures under two management strategies. *Crop Science*, 48: 331–342.

Pimentel, D., Wilson, C., McCullum, C., Huang, R. & Dwen, P. 1997. Economic and environmental benefits of biodiversity. *BioScience*, 47: 747–757.

Pimentel, D., McNair, S., Janecka, J., Wightman, J., Simmonds, C., O'Connell, C., Wong, E., Russel, L., Zern, J., Aquino, T. & Tsomondo, T. 2001. Economic and environmental threats of alien plant, animal, and microbe invasions. *Agriculture, Ecosystems and Environment*, 84: 1–20.

POETCom (Pacific Organic and Ethical Trade Community). 2012. *POETCom Strategic Plan 2013–2017: growing our future*. Suva, SPC.

POETCom. 2015. *2015 Annual Report: a review of organic growth*. Suva, SPC.

Preston, S.R. 1990. Investigation of compost x fertilizer interactions in sweet potato grown on volcanic ash soils in the highlands of Papua New Guinea. *Tropical Agriculture, Trinidad and Tobago*, 67(3): 239–242.

Puppim de Olivera, J.A. 2008. Obstacles to policy implementation. *In* J.A. Puppim de Olivera, ed. *Implementation of environmental polices: a case of protected areas and tourism in Brazil*, pp. 45–51. New York, USA, State University of New York Press.

Ragone, D. 1997. *Breadfruit.* Artocarpus altilis *(Parkinson) Fosberg*. Promoting the Conservation and Use of Underutilized and Neglected Crops No. 10. Gatersleben, Germany, Institute of Plant Genetics and Crop Plant Research & Rome, International Plant Genetic Resources Institute.

Reaser, J.K., Meyerson, L.A., Cronk, Q., De Poorter, M., Eldrege, L.G., Green, E., Moses, K., Latasi, P., Mack, R.N., Mauremootoo, J., O'dowd, D., Orapa, W., Soetikno, S., Saunders, A., Shine, C., Sigurdur, T. & Vaiutu, L. 2007. Ecological and socioeconomic impacts of invasive alien species in island ecosystems. *Environmental Conservation, 34(2): 98–111.*

RNZ (Radio New Zealand). 2003. Scientist says Cook Islands lagoon polluted (available at www.radionz.co.nz/international/pacific-news/145012). Accessed 3 August 2016.

Rodriguez, H. & Fraga, R., 1999. Phosphate solubilizing bacteria and their role in plant growth promotion. *Biotechnology Advances*, 17: 319–339

SAGE (Sustainable Agriculture Education). 2015. Sunol AgPark (available at www.sagecenter.org/work/agricultural-revitalization/sunol-agpark). Accessed 16 October 2016.

Sangeetha, C. & Baskar, P. 2015. Allelopathy in weed management: a critical review. *African Journal of Agricultural Research*, 10: 1004–1015.

Sanguankeo, P.P. & León, R.G. 2011. Weed management practices determine plant and arthropod diversity and seed predation in vineyards. *Weed Research*, 51: 404–412.

Schellhorn, N.A., Bianchi, F.J.J.A. & Hsu, C.L. 2014. Movement of entomophagous arthropods in agricultural landscapes: links to pest suppression. *Annual Review of Entomology*, 59: 559–581. doi: 10.1146/annurev-ento-011613-161952.

Shelton, A.M., Zhao, J.-Z. & Roush, R.T. 2002. Economic, ecological, food safety, and social consequences of the deployment of Bt transgenic plants. *Annual Review of Entomology*, 47: 845–881 doi: 10.1146/annurev.ento.47.091201.145309

Simmons, D.G. 2013. Tourism and ecosystem services in New Zealand. *In* J.R. Dymond, ed. *Ecosystem services in New Zealand – conditions and trends*, pp. 343–348. Lincoln, New Zealand, Manaaki Whenua Press.

Smestad, B.T., Tiessen, H. & Buresh, R.J. 2002. Short fallows of *Tithonia diversifolia* and *Crotalaria grahamiana* for soil fertility improvement in western Kenya. *Agroforestry Systems*, 55: 181–194.

SPC (Secretariat of the Pacific Community). 2006. *Land Resources Division Annual Report 2005*. Suva.

SPC. 2008. *Pacific Organic Standard*. Suva.

SPC. 2010. Water hyacinth (*Eichhornia crassipes*) (available at http://lrd.spc.int/our-work/water-hyacinth-eichhornia-crassipes). Accessed 9 November 2016.

SPC. 2013. *Land Resources Division Strategic Plan 2013–2017*. Nabua (available at https://lrd.spc.int/strategic-plan).

SPC. 2015. *Glocalising Pacific agri-food through tourism*. 1st Pacific Agritourism Week Summary Report. Nadi, Fiji, 29 June – 3 July 2015 (available at http://pafpnet.spc.int/attachments/article/303/Pacific%20Agritourism%20Week%20Nadi%20FIJI%20July%202015-%20SUMMARY%20REPORT.pdf).

SPC. 2016a. Crop production (available at http://lrd.spc.int/our-work/crop-production). SPC Land Resources Division.

SPC. 2016b. Agenda Item 5: Update on the Pacific Organic and Ethical Trade Community (POETCom) and organic agriculture. Paper 5.2. Forty-sixth meeting of the Committee of Representatives of Governments and Administrations, Noumea, New Caledonia, 28–30 June 2016.

SPC. 2016c. Decisions of the forty-sixth meeting of the Committee of Representatives of Governments and Administrations, Noumea, New Caledonia, 28–30 June 2016.

SPC. 2016d. Launch of Pacific Ridge to Reef programme. Press release, 10 October (available at www.spc.int/en/media-releases/2648-launch-of-pacific-ridge-to-reef-programme.html).

SPC. n.d. SPC collaborates with ACIAR to improve soil health. Media release (available at www.spc.int/en/events/1600-spc-collaborates-with-aciar-to-improve-soil-health.html) Accessed 3 November 2016.

SPG Bio Fetia. 2016. [Website] (available at www.spg-biofetia-tahiti.org). Accessed September 2016.

SPREP (Secretariat of the Pacific Regional Environment Programme). 2009. *Guidelines for invasive species management in the Pacific: a Pacific strategy for managing pests, weeds and other invasive species.* Apia.

SPREP. 2014. *Framework for Nature Conservation and Protected Areas in the Pacific Islands Region 2014–2020*. Apia (available at www.sprep.org/publications/framework-for-nature-conservation-and-protected-areas-in-the-pacific-islands-region-2014-2020).

SPREP. 2016a. Island and oceanic ecosystems (available at www.sprep.org/Island-and-Oceanic-Ecosystems/island-and-oceanic-ecosystems). Accessed August 2016.

SPREP. 2016b. Biodiversity and ecosystem management – overview (available at: www.sprep.org/Biodiversity-and-Ecosystems-Management/bem-overview). Accessed August 2016.

Stintzing, F.C., Kammerer, D., Schieber, A., Adama, H., Nacoulma, O.G. & Carle, R. 2004. Betacyanins and phenolic compounds from *Amaranthus spinosus* L. and *Boerhavia erecta* L. *Zeitschrift fur Naturforschung – Section C: A Journal of Biosciences*, 59: 1–8.

Stone, A.G., Scheuerell, S.J. & Darby, H.M. 2004. Suppression of soilborne diseases in field agricultural systems: organic matter management, cover cropping and other cultural practices. *In* F. Magdoff & R. Weil, eds. *Soil organic matter in sustainable agriculture*, pp. 131–177. Boca Raton, Florida, USA, CRC Press.

Swift, M.J., Izac, A.-M.N. & van Noordwijk, M. 2004. Biodiversity and ecosystem services in agricultural landscapes – are we asking the right questions? *Agriculture, Ecosystems and Environment*, 104: 113–134.

Sznajder, M., Przezbórska, L. & Scrimgeour, F. 2009. *Agritourism*. New York, USA, CAB International.

Talanoa Treks. 2013. Sustainability policy (available at talanoa-treks-fiji.com/wp-content/uploads/2015/06/Sustainability-policy.pdf).

Taylor, M. & Iosefa, T. 2013. *Taro leaf blight manual*. Noumea, New Caledonia, SPC.

Taraken, I.T. & Ratsch, R. 2009. Sweet potato cultivation on composted mounds in the highlands of Papua New Guinea. *In* G. Kirchhof, ed. *Soil fertility in sweet potato-based cropping systems in the highlands of Papua New Guinea*, pp. 24–32. ACIAR Technical Report No. 71. Canberra, ACIAR.

TEEB (The Economics of Ecosystems and Biodiversity). 2010. The economics of valuing ecosystem services and biodiversity. *In* P. Kumar, ed. *The economics of ecosystems and biodiversity: the ecological and economic foundation*. London and Washington, DC, Earthscan (available at www.teebweb.org/wp-content/uploads/2013/04/D0-Chapter-5-The-economics-of-valuing-ecosystem-services-and-biodiversity.pdf).

TEEB. 2013. [Interview with Sangeeta Mangubhai, IUCN on the Marine and Coastal Biodiversity Management in Pacific Island Countries and Atolls (MACBIO) project, at the first TEEB training workshop on Mainstreaming the Values of Water and Wetlands into Decision-Making, 31 August, Bali, Indonesia] (available at www.teebweb.org/media/2013/10/interview-Sangeeta-Mangubhai_DM.pdf).

Tengberg, A., Fredholm, S., Eliasson, I., Knez, I., Saltzman, K. & Wetterberg, O. 2012. Cultural ecosystem services provided by landscapes: assessment of heritage values and identity. *Ecosystem Services*, 2: 14–26.

Tetepare. 2016. Tetepare, the last wild island (available at www.tetepare.org). Accessed September 2016.

Thaman, R.R. 1994. Ethnobotany of Pacific Island coastal plants. *In* R.J. Morrison, P.A. Geraghty & L. Crowl, eds. *Science of Pacific Island peoples*, Vol. 3, *Fauna, flora, food and medicine*, pp. 147–184. Suva, University of the South Pacific, Institute of Pacific Studies.

Thaman, R.R. 1995. Urban food gardening in the Pacific Islands: a basis for food security in rapidly urbanising small-island states. *Habitat International*, 19(2): 209–224.

Thaman, R.R. 2002. Trees outside forests as a foundation for sustainable development in the Small Island Developing States of the Pacific Ocean. *International Forestry Review*, 4(4): 268–276.

Thaman, R.R. 2007/2008. Restoring the Pacific Islands' rich agricultural traditions: an urgent priority. *Pacific Ecologist*, 15(Summer): 51–57.

Thaman, R. 2008a. A matter of survival: Pacific Islands' vital biodiversity, agricultural biodiversity and ethno-biodiversity heritage. *Pacific Ecologist*, 16(Winter): 53–61.

Thaman, R.R. 2008b. Pacific Island agrobiodiversity and ethnobiodiversity: a foundation for sustainable Pacific Island life. *Biodiversity: Journal of Life on Earth*, 9(1 & 2): 102–110.

Thaman, R.R. 2009. Sustainability. *In* R.G. Gillespie & D. Clague, eds. *Encyclopedia of islands*, pp. 888–896. Berkeley, California, USA, University of California Press.

Thaman, R.R. 2013a. Ethno-biodiversity, taxonomy and bioinformatics for all ages: engaging and educating the next generation of taxonomists as a foundation for sustainable living on planet Earth – challenges and opportunities. *In* L.A. Brooks & S. Aricò, eds. *Tracking key trends in biodiversity science and policy*, pp. 23–25. Based on the proceedings of a UNESCO International Conference on Biodiversity Science and Policy. Paris, United Nations Educational, Scientific and Cultural Organization (UNESCO) (available at http://unesdoc.unesco.org/images/0022/002205/220530E.pdf).

Thaman, R.R. 2013b. Islands on the frontline against the winds and waves of global change: emerging environmental issues and actions to build resilience in Pacific Small Island Developing States (PSIDS). *In* H.-M. Tsai, ed. *Proceedings of the IGU Commission on Islands International Conference on Island Development: Local economy, culture, innovation and sustainability*, pp. 3-H-1 1–10. Makong, Taiwan Province of China, 1–5 October 2013.

Thaman, R.R. 2013c. Silent alien invasion of our islands and seas: A call for action against invasive alien species (IAS). *In* H.-M. Tsai, ed. *Proceedings of the IGU Commission on Islands International Conference on Island Development: Local economy, culture, innovation and sustainability*, pp. 2-D-3 1–6. Makong, Taiwan Province of China, 1–5 October 2013.

Thaman, R.R. & Clarke, W.C. 1993. Pacific island agroforestry: functional and utilitarian diversity. *In* W.C. Clarke & R.R. Thaman, eds. *Pacific Island agroforestry: systems for sustainability*, pp. 17–33. Tokyo, United Nations University Press.

Thaman, R.R., Clarke, W.C., Tebano, T., Taniera, T. & Eritaia, B. 1995. North Tarawa Conservation Area: South Pacific Biodiversity Programme Project Preparation Document. Bikenibeu, Tarawa, Kiribati, Environment Unit, Ministry of Environment and Social Development.

Thaman, R.R., Elevitch, C.R. & Wilkinson, K.M. 2000. Multipurpose trees for agroforestry in the Pacific Islands. *In* Elevitch, C.R. & Wilkinson, K.M. eds. *Agroforestry guides for Pacific Islands*, pp. 24–69. Holuahua, Hawaii, Permanent Agriculture Resources (PAR).

Thaman, R.R., Gregory, M. & Takeda, S. 2011. *Trees of Life: a guide to the trees and shrubs of the University of the South Pacific.* Suva, University of the South Pacific Press.

Thaman, R., Smith, A. & Faka'osi, T. 2011. Coastal reforestation in Tonga to protect coastlines. *In* C. Wilkinson & J. Brodie, eds. *Catchment management and coral reef conservation: a practical guide for coastal resource managers to reduce damage from catchment areas based on best practice case studies*, pp. 82–83. Townsville, Australia, Global Coral Reef Monitoring Network and Rainforest Research Centre.

Thaman, R.R. & Whistler, W.A. 1996. *A review of uses and status of trees and forests in land-use systems in Samoa, Tonga, Kiribati and Tuvalu with recommendations for future action*. Working Paper 5 (RAS/92/361). Suva, South Pacific Forestry Development Programme.

Tiemann, L.K., Grandy, A.S., Atkinson, E.E. Marin-Spiotta, E. & McDaniel, M.D. 2015. Crop rotational diversity enhances belowground communities and functions in an agroecosystem. *Ecology Letters*, 18(8): 761–771. doi: 10.1111/ele.12453.

Tuivavalagi, P. 2016. *Investigating the impacts of the natural enemy* Trichogramma chilonis *Ishii on populations of* Crocidolomia pavonana *in Samoa*. Brisbane, Australia, University of Queensland, School of Biological Sciences (MPhil thesis). doi: 10.14264/uql.2016.447.

Tutua, J. & Jansen, T. 1994. *Sapa: the natural way of growing food in Solomon Islands*. Sydney, Australia, Appropriate Technology for Community and Environment (APACE).

Uelese, A., Ridland, P.M., Stouthamer, R., He, Y.-R., Ang, G., Zalucki, M.P. & Furlong, M.J. 2014. *Trichogramma chilonis* Ishii: a potential biological control agent of *Crocidolomia pavonana* in Samoa. *Biological Control*, 73: 31–38. doi: 10.1016/j.biocontrol.2014.03.011.

UN (United Nations). 1992. *Convention on Biological Diversity* (available at www.cbd.int/doc/legal/cbd-en.pdf).

UN. 2012. *Synthesis of national reports from Rio+20*. New York, USA, United Nations Department for Economic and Social Affairs (UN DESA) & UNDP (available at https://sustainabledevelopment.un.org/content/documents/742RIO+20_Synthesis_Report_Final.pdf).

UN. 2014. Annex: SIDS accelerated modalities of action (S.A.M.O.A.) Pathways. *In* Draft outcome document of the third International Conference on Small Island Developing States, Apia, 1–4 September. A/CONF.223/3 (available at www.sids2014.org/content/documents/336SAMOA%20Pathway.pdf).

UN. 2015. Transforming our world: the 2030 Agenda for Sustainable Development. A/RES/70/1. New York, USA, United Nations.

UNEP (United Nations Environment Programme). 2014. *Emerging issues for Small Island Developing States – Results of the UNEP Foresight Process.* Nairobi (available at www.unep.org/pdf/Emerging_issues_for_small_island_developing_states.pdf).

UNWTO (World Tourism Organization). 2015. *Tourism highlights, 2015 Edition*. Madrid.

van Beukering, P., Brander, L., Tompkins, E. & McKenzie, E. 2007. *Valuing the environment in small islands – an environmental economics toolkit*. Peterborough, UK, Joint Nature Conservation Committee (JNCC) (available at http://jncc.defra.gov.uk/page-4065#download).

van Lexmond, M.B., Bonmatin, J.M., Goulson, D. & Noome, D.A. 2015. Worldwide integrated assessment on systemic pesticides – global collapse of the entomofauna: exploring the role of systemic insecticides. *Environmental Science and Pollution Research*, 22(1): 1–4. doi: 10.1007/s11356-014-3220-1.

Vaqalo, M. 2014. *Biology and ecology of* Nisotra basselae *(Bryant) on* Abelmoschus manihot *Medicus in Solomon Islands.* Brisbane, Australia, University of Queensland, School of Biological Sciences (PhD thesis). doi: 10.14264/uql.2015.204.

Ward, R.G. 2000. Land tenure in Pacific Islands: changing patterns and implications for land acquisition. In *Resettlement policy and practice in South East Asia and the Pacific*, pp. 75–87. Manila, Asian Development Bank.

Washington Organic Recycling Council. 2016. Why build healthy soil? (available at www.soilsforsalmon.org/why.htm). Accessed 20 October 2016.

Waterhouse, D.F. & Norris, K.R. 1987. *Biological control: Pacific prospects*. Melbourne, Australia, Inkata Press.

WIBDI (Women in Business Development Inc.). 2016. Farm to Table Samoa (available at www.womeninbusiness.ws/farm-to-table.html). Accessed October 2016.

Willcox, M.L., Graz, B., Falquet, J., Sidibé, O., Forster, M. & Diallo, D. 2007. *Argemone mexicana* decoction for the treatment of uncomplicated falciparum malaria. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, 101: 1190–1198.

Wittenberg, R. & Cock, M.J.W., eds. 2001. *Invasive alien species: a toolkit of best prevention and management practices*. Wallingford, UK, CAB International.

World Bank. 2016. *Doing business 2016: measuring regulatory quality and efficiency*. 13th edition. Washington, DC.

Wright, J., Amudavi, D., McAllister, G. & Miga, Z.W. 2016. Organic farming research in Africa: some constraints, lots of positive developments. Presented at BIOFACH Congress 2016, Nuremberg, Germany, 10–13 February (available at http://orgprints.org/29777). Accessed 8 November 2016.

Yahya, M.F.Z.R., Ibrahim, M.S.A., Zawawi, W.M.A.W.M. & Hamid, U.M.A. 2014. Biofilm killing effects of *Chromolaena odorata* extracts against *Pseudomonas aeruginosa. Research Journal of Phytochemistry*, 8: 64–73.

Zalucki, M.P., Adamson, D. & Furlong, M.J. 2009. The future of IPM: whither or wither? *Australian Journal of Entomology*, 48: 85–96.

Zehnder, G., Gurr, G.M., Kühne, S., Wade, M.R., Wratten, S.D. & Wyss, E. 2007. Arthropod management in organic crops. *Annual Review of Entomology*, 52: 57–80.

Zhang, W., Ricketts, T., Kremen, C., Caney, K. & Swinton, S.M. 2007. Ecosystem services and dis-services to agriculture. *Ecological Economics, 64: 253–260.*

Zwickle, S., Wilson, R. & Doohan, D. 2014. Identifying the challenges of promoting ecological weed management (EWM) in organic agroecosystems through the lens of behavioral decision making. *Agricultural and Human Values*, 31: 355–370.

APPENDIX
100 "STAR TREES OF LIFE"

"Star Trees of Life" are trees or treelike shrubs or plants of particular importance that should be considered for protection or planting as part of agrobiodiversity and ecosystem service efforts in PICTs (adapted from Thaman, Gregory and Takeda, 2011).

Where two or more species in the same genus are included, e.g. breadfruit, they are considered together as a single "Star Tree of Life". Note that efforts to conserve agrobiodiversity and ecosystem services must also include conservation of the diversity of cultivars or genetic diversity of important species.

★★★ 3-Star (10)

"Superstar" multipurpose trees of widespread importance in almost all PICTs, without which conservation of agrobiodiversity and ecosystem services would be very difficult

Artocarpus altilis and *A. mariannensis* (breadfruit)

Bambusa vulgaris (common bamboo) and *Schizostachym glaucifolium* (Pacific bamboo)

Bruguiera gymnorrhiza (oriental mangrove, brown mangrove)

Cocos nucifera (coconut palm)

Hibiscus tiliaceus (beach hibiscus, hibiscus tree)

Morinda citrifolia (beach mulberry, Indian mulberry, noni)

Musa cultivars (bananas and plantains)

Pandanus tectorius and *Pandanus* cultivars (pandanus, screw pine)

Rhizophora spp. (red or stilt mangroves)

Scaevola taccada (beach saltbush, half-flower)

★★ 2-Stars (50)

Species of widespread importance or abundance in a number of PICTs or of great importance in at least two or more PICTs

Abelmoschus manihot (bush hibiscus spinach, bele)

Agathis microphylla and *Agathis* spp. (kauri, kauri pines)

Areca catechu (betelnut palm)

Barringtonia edulis and *Barringtonia* spp. (pili nut, cut nut)

Bischofia javanica (Java cedar, koka)

Broussonetia papyrifera (paper mulberry)

Calophyllum inophyllum (Alexandrian laurel, beach mahogany)

Cananga odorata (ylang-ylang, perfume tree)

Canarium indicum and *Canarium* spp. (canarium almond, galip nut)
Capsicum frutescens and *Capsicum annuum* vars. (perennial and annual chili peppers)
Carica papaya (papaya, papaw)
Casuarina equisetifolia and *Gymnostoma* spp. (casuarinas, ironwood, she-oak)
Citrus limon (rough lemon, lemon)
Citrus reticulata (tangerine, mandarin orange)
Citrus sinensis (orange, sweet orange)
Cordia subcordata (beach cordia, sea trumpet
Cordyline fruticosa (cordyline, ti-plant)
Delonix regia (poinciana, flame tree
Endospermum macrophyllum (whitewood)
Erythrina variegata var. *orientalis* (coral tree, dadap)
Euodia hortensis (island musk, uci)
Fagraea berteroana (pua)
Ficus tinctoria, Ficus prolixa and *Ficus* spp. (native figs, edible figs, banyans)
Leucaena leucocephala (leucaena, false tamarind)
Flueggea flexuosa (poumuli)
Gardenia taitensis (Tahitian gardenia, tiare Tahiti)
Guettarda speciosa (guettarda)
Hernandia nymphaeifolia (lantern tree, hernandia)
Hibiscus rosa-sinensis (common hibiscus, China rose)
Inocarpus fagifer (Tahitian chestnut)
Intsia bijuga (ipil tree, vesi)
Mangifera indica (mango)
Manihot esculenta (cassava, manioc, tapioca)
Metroxylon spp. (sago palm)
Pinus caribaea (Caribbean pine)
Piper methysiticum (kava)
Plumeria spp. (frangipani, plumeria)
Polyscias spp. (hedge panax)
Pometia pinnata (Island lychee, oceanic lychee)
Psidium guajava (guava)
Saccharum officinarum (sugar cane, noble cane)
Samanea saman (raintree, monkeypod)
Santalum yasi (Fiji sandalwood)
Spondias dulcis (Polynesian vi-apple)
Swietenia macrophylla (bigleaf mahogany, West Indian mahogany)
Syzygium malaccense (Malay apple)
Terminalia catappa (tropical almond, Indian almond)
Thespesia populnea (Thespians tree, milo)
Tournefortia argentea (beach heliotrope)
Xylocarpus granatum (cannonball tree, puzzle nut)

★ 1-Star (40)

Species of importance in most PICTs or of considerable importance in at least one member country

Acalypha wilkesiana (copper leaf, beefsteak plant)
Adenanthera pavonina (red-bead tree, red sandalwood)
Aglaia saltatorum (langakali)
Aleurites moluccana (candlenut tree, kukui)
Alpinia purpurata (red ginger)
Annona muricata (soursop)
Artocarpus heterophyllus (jackfruit)
Azadirachta indica (nim, neem tree)
Barringtonia asiatica (fish-poison tree, barringtonia)
Cajanus cajan (pigeon pea, arhar dhal)
Cassia fistula (golden shower tree)
Citrus maxima and *Citrus* spp. (pomelo, lime, sour orange)
Codiaeum variegatum (croton)
Coffea arabica and *C. canephora* (Arabian and robusta coffee)
Cycas rumphii and *Cycas* spp. (cycad, sago palm, king sago)
Dracontomelon vitiense (dragon plum)
Dysoxylum richii and *Dysoxylum spp*. (stinkwood)
Elaeis guineensis (oil palm)
Eucalyptus spp. (eucalyptus, gum trees)
Excoecaria agallocha (blinding tree, poison mangrove)
Gliricidia sepium (gliricidia, mother of cocoa
Glochidion spp. (buttonwood)
Lumnitzera littorea (red-flowered black mangrove)
Macaranga spp. (macaranga)
Millettia pinnata (pongam, beach walnut)
Moringa oleifera (horseradish tree, drumstick tree)
Murray koenigii (curry leaf, Indian bay leaf, tejpatti)
Neisosperma oppositifolium (neisosperma)
Persea americana (avocado, avocado pear)
Polyalthia longifolia (ashoka, ashok tree)
Pimenta racemosa (bay rum tree)
Pipturus argenteus (pipturus)
Premna serratifolia (premna, false elderberry)
Pritchardia pacifica (Pacific fan palm)
Senna alata and *Senna* spp. (golden candelabra bush, ringworm bush, shower trees)
Syzygium cumini (jambolan, Java plum)
Tabernaemontana divaricata (paper gardenia, crepe jasmine)
Tectona grandis (teak)
Terminalia littoralis (beach almond)
Vitex trifolia (blue vitex, beach vitex)

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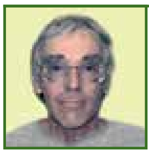

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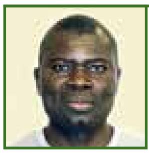

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This guidance document is designed to assist Pacific Island countries and territories in finding synergies between two important realms of policies and international commitments: sustainable management of chemicals and biodiversity conservation and use. It details the linkages between ecosystem services and biodiversity in agriculture, specifically in relation to soil health, ecological management of pests, weeds and invasive alien species, agroforestry, organic farming systems and ecotourism. It analyses current policies and best practices across the subregion and highlights key policy entry points for mainstreaming approaches to agriculture that reduce the use of agrochemicals. Produced under the EU-funded project "Capacity Building Related to Multilateral Environmental Agreements (MEAs) in Africa, Caribbean and Pacific (ACP) countries – Phase 2", the document will guide countries in revising their strategies or policies related to chemical and biodiversity management. In particular, it will assist countries in revising or implementing their National Biodiversity Strategies and Action Plans (NBSAPs) to help them meet a number of Aichi Biodiversity Targets relevant to the agriculture sector.




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