VANUATU

Ecosystem and Socio-economic Resilience Analysis and Mapping

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Our vision: The Pacific environment, sustaining our livelihoods and natural heritage in harmony with our cultures.

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Statement of limitations

Available data used in the report may be limited in its precision and accuracy. Therefore any use of information from the report will be based on an informed assessment of the limitations of the data, information and methodologies described.

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1 Introduction

Approaches to planning and decision-making that use Ecosystem-based Adaptation (EbA) and resilience-thinking provide a significant opportunity for small island developing states, such as Vanuatu, to deal with climate change threats while addressing other sustainable development goals. The Pacific Ecosystem-based Adaptation to Climate Change (PEBACC) project, led by the Secretariat of the Regional Environment Programme (SPREP), aims to build capacity for developing and implementing EbA and resilience projects within Vanuatu and the Pacific region. Funded by the German Government and implemented by SPREP, the project investigates and promotes ecosystem-based options for adapting to climate change impacts. The overall intended outcome of PEBACC is for EbA to be integrated into development, climate change adaptation and natural resource management policy and planning processes in three Pacific island countries (Vanuatu, Fiji, and Solomon Islands), while providing replicable models for other countries in the region.

Ecosystem and Socio-economic Resilience Analysis and Mapping (ESRAM) is the first stage of PEBACC. This report presents the results of the ESRAM undertaken by Griffith University for the Republic of Vanuatu (hereafter 'Vanuatu') and Tanna Island (heareafter 'Tanna').

The report addressed three main tasks:

1. the mapping of key ecosystems for Vanuatu and Tanna in terms of their type, condition and the ecosystem services they potentially generate;
2. an economic evaluation of the benefits to local communities arising from these ecosystem services; and
3. an assessment of the risk to community sustainability from threats and pressures on ecosystem health, including climate change-related hazards, for three of the most important ecosystem/land use types: coral reefs, *kastom* forest, and subsistence gardens).

The information provided in this report will be used to inform the identification, costing and prioritisation of EbA options for adaptation planning and will feed into site-specific EbA implementation plans. Based on these plans, the PEBACC project will support a number of demonstration EbA activities at project sites.

1.1 Background on Vanuatu and Tanna Island

Vanuatu is a country located in the South-western Pacific Ocean, about 1,750 kilometres east of Australia and 500 kilometres north-east of New Caledonia. It is a Y-shaped archipelago of volcanic origin, comprised of approximately 83 islands (65 of them inhabited). Vanuatu covers a total area of approximately 1.4 million hectares and its coastline is 2,528 km long and is mostly is rocky, with fringing reefs and no continental shelf. Most of the islands are steep, with unstable soils and little permanent fresh water (Government of Vanuatu 2016; Peace Corps 2013).

Vanuatu has long been regarded as one of the most vulnerable countries in the world due to the occurrence of multiple natural hazards, including cyclones, earthquakes, and tsunamis, together with underlying societal vulnerabilities (World Risk Report 2015). The majority of Vanuatu's population relies on subsistence farming for their livelihood, with 75% of the population living in rural areas (Malvatumauri 2012). High population concentration in rural areas is typical of Melanesian countries and often poses challenges for service delivery and disaster recovery (Wickham et al. 2009). These characteristics have consequences for food security, climate adaptation and disaster risk reduction strategies (Republic of Vanuatu 2015).

In Vanuatu, small-scale subsistence farming is undertaken by 98% of the rural population. These farming systems now typically comprise three components: (1) a shifting cultivation system; (2) a perennial plantation cultivation system; and (3) a forest and arboricultural system (Blanco et al. 2013; Clarke and Thaman 1993). In the shifting cultivation component (i.e. that based on traditional subsistence gardening), each family slashes and burns secondary forest in two to five locations per year to grow taro or yam. Large trees are often left for their economic or cultural use. Then, having depleted the plots' soil fertility, the family leaves them fallow, allowing for secondary forest re-growth, before returning to start the cycle again. The perennial cultivation system constitutes the main source of cash income for families and in Vanuatu can involve growing coconut, cacao, coffee or sandalwood. The traditional shifting cultivation crops of taro and yam are being supplemented with more recently introduced crops, especially peanuts and sweet potato. Traditional wealth items, such as kava, pigs, mats and yams, are particularly important in Vanuatu in terms of traditional ceremonies and form a part of the informal economy (Malvatumauri 2012).

Administratively, Vanuatu is organised into six provinces, comprising a total of 83 islands (Figure 1). The provinces from the largest to smallest are: Sanma, Malampa, Tafea, Shefa, Penama and Torba. Tanna is in the southern province of Tafea (black box in Figure 1) and covers an area of 58,793 hectares. According to the latest population census, in 2016 there were 32,280 people living on Tanna (Vanuatu National Statistics Office, 2016). However, the current number is likely higher, given rapid population growth. For example, during government disaster recovery and food relief operations after 2015 Tropical Cyclone Pam, 44,000 people were reported as residing on the Island. Seven different indigenous languages are spoken on Tanna, with some people also speaking Bislama, one of the official languages of Vanuatu. Many of the tribes on Tanna live in traditional housing and have a long history of coping with cyclones.

Tanna is often referred to as the stronghold of *kastom*; a place where people still know traditional songs, can trace their lineage, and still participate and organise *kastom* rituals and ceremonies (Lindstrom 2011). Tanna is regarded as an example of how *kastom* and modernity coexist hand in hand (Lindstrom 1982).

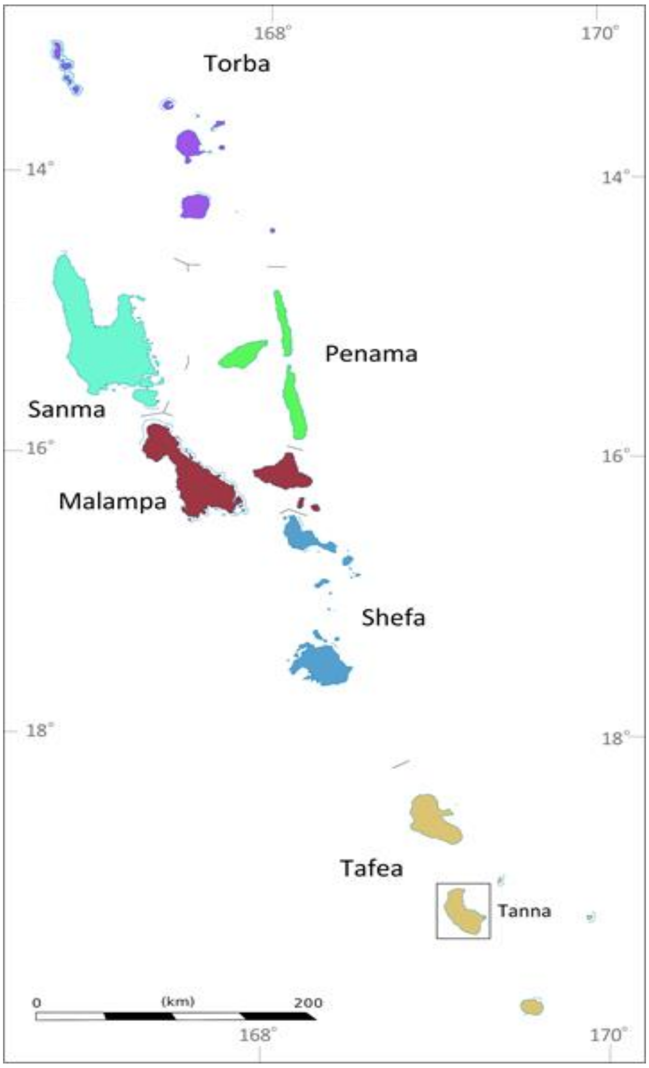


Figure 1. The official provinces of the Republic of Vanuatu. Tanna Island (black box) is located in the southern Tafea Province

1.2 Structure of this report

This report is structured as follows: The remainder of Section 1 outlines the conceptual frameworks, approaches and data sources adopted for: (a) mapping of key ecosystems for Vanuatu and Tanna, in terms of their type, condition and the ecosystem services they generate; (b) an economic evaluation of the benefits flowing to local communities arising from these ecosystem services; and (c) an assessment of the risk to community sustainability from threats and pressures on ecosystem condition, including climate change-related hazards, for three of the most important ecosystem/landuse types (coral reefs, *kastom* forest, and subsistence gardens). Section 2 presents the results of the economic evaluation of the flow of ecosystem service benefits at a national level for all of Vanuatu and then for Tanna. Section 3 discusses the drivers, barriers, and enablers of ecosystem-based adaptation, again at the national level and for Tanna. Chapter 4 presents a preliminary analysis of how climate is projected to change for Vanuatu and Tanna by the year 2070. Chapter 5 presents the results of the risk assessment.

1.3 Connecting ecosystem services with resilience

1.3.1 Concepts

In implementing ESRAM we draw upon the conceptual framework developed by the UN Statistical Commission's Experimental Ecosystem Accounting system (EU 2013; ABS 2012), which describes ecosystem accounting as a coherent and integrated approach to the assessment of the environment through the measurement of ecosystems and the flows of services from ecosystems into economic and other human activity (Figure 2).

The commission adopts a standard definition of ecosystems as '… a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit.' The commission notes that the scale of ecosystem accounting may vary for specific land

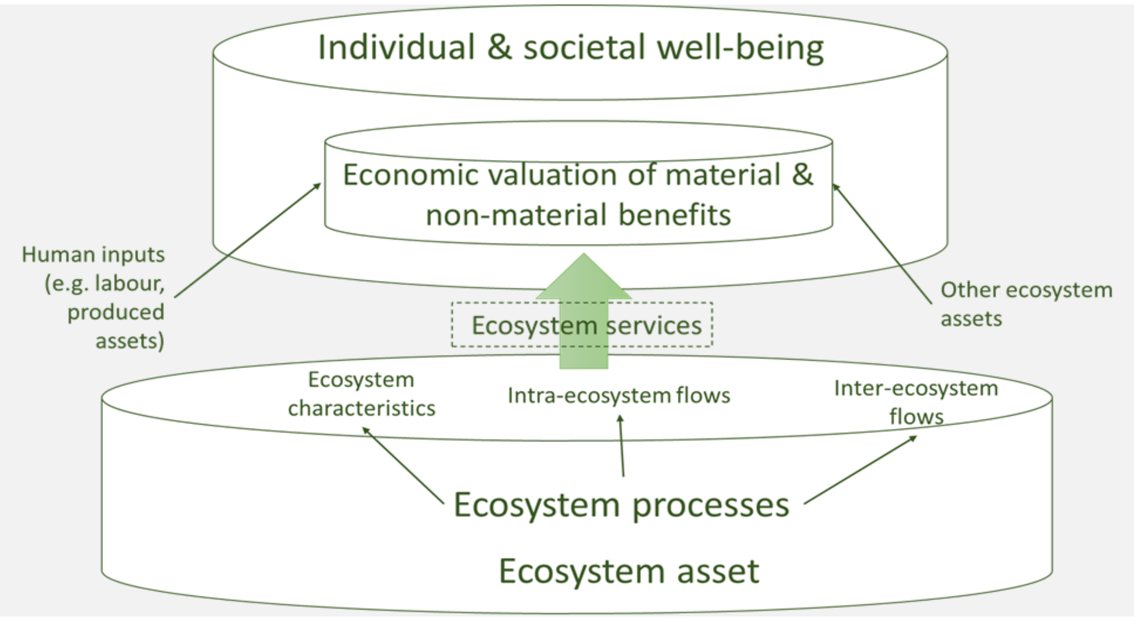


Figure 2. Relationship between ecosystems and ecosystem service flows, as conceptualised by Experimental Ecosystem Accounts (adapted from UN 2015)

cover types, such as forests, to larger integrated areas, such as river basins, and can include areas that may be considered relatively natural and those that may be heavily influenced by human activity, such as agricultural areas. According to the commission's system, ecosystem accounting goes beyond other approaches to ecosystem analysis and assessment through the explicit linking of ecosystems to economic and other human activity. The links are seen both in terms of the services provided by ecosystems and also in the impacts that economic and other human activity may have on ecosystems and their future capacity to continue to deliver ecosystem service flows.

A key term the commission introduces is 'ecosystem assets', defined as spatial areas containing a combination of biotic and abiotic components and other characteristics that function together. Ecosystem assets are measured in terms of: (i) ecosystem type; (ii) ecosystem extent; (iii) ecosystem condition; and (iv) ecosystem services. A particular combination or 'basket' of ecosystem services can be generated at a particular point in time from a specific ecosystem asset. The aggregation of all future ecosystem services for a given basket provides, at a point in time, an estimated stock of expected ecosystem service flows (EU 2013).

Ecosystem services do not result only from the harvesting or extraction of materials from ecosystems. They also result from the general functioning of the ecosystem (e.g. air filtration services from trees providing clean air) and extend to other characteristics of an ecosystem (e.g. the physical structure and composition of mountain landscapes providing scenic views). Thus, the term 'services' is used here in an all-encompassing manner, covering the various ways in which humans may benefit from ecosystems (EU 2013).

Categories of ecosystem services are summarised in Figure 3, based on the system developed by the Millennium Assessment Report (2005). However, we have modified their system to better reflect the Melanesian context by recognising two new categories: (1) 'non-extractive use services', which includes recreation and tourism, education and research; and (2) '*kastom* services', which includes customary and spiritual practices, among other things.

The IPCC (2014) defines resilience as the 'capacity of social, economic, and environmental systems to cope with a hazardous event or trend or

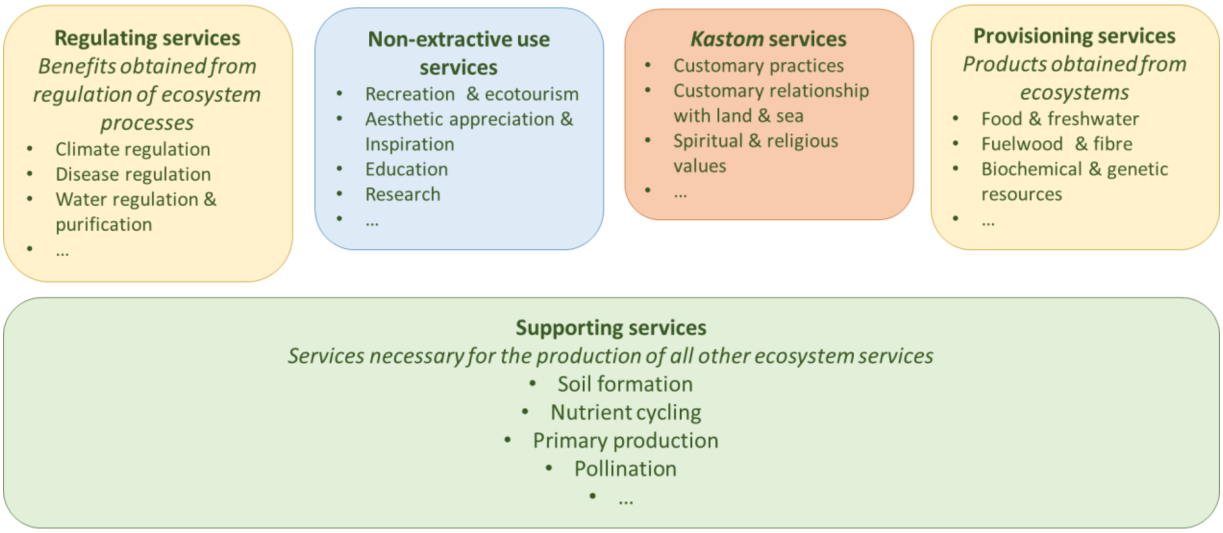


Figure 3. Categories of ecosystem services modified for the Melanesian context, adapted from the Millennium Ecosystem Assessment Report (2005)

disturbance, responding or reorganising in ways that maintain their essential function, identity, and structure'. A system, or one of its components, can be more or less resilient with respect to a given 'shock'.

However, being resilient can in some instances be counterproductive. For example, if the context within which the system operates changes significantly, it is not necessarily beneficial for a system to remain in (or return to) its original state (Nalau and Handmer 2015). Therefore, part of a resilience-thinking approach is to consider the transformability of a system – the capacity to create a fundamentally new system when ecological, economic, or social (including political) conditions make the existing system untenable (Walker et al. 2004). It follows that application of EbA approaches require consideration of the capacity of a system for self-stabilisation, adaptation or transformation, depending on the circumstances.

Central to EbA and resilience is the concept of 'socio-ecological systems', where the focus of study are systems defined in terms of closely coupled human societies, together with the supporting biophysical environments, with the latter typically defined in terms of ecosystems (Constanza et al, 1993; Berkes and Folke 1998). Socio-ecological system thinking is consistent with the conceptual frameworks of the UN Statistics Commission and the Millennium Ecosystem Assessment.

In a Melanesian context it makes sense to identify community resilience as the focal point of analysis, with resilience being enhanced by ongoing access to ecosystem service benefits (Figure 4). The quality of these services in turn is a function of the condition of the ecosystem; with degraded ecosystems providing lower benefit flows (or none at all). There are pressures arising from both natural processes and human activities that can degrade ecosystem condition, including climate change and the impacts of inappropriate capital works. In Vanuatu (and the Pacific generally) a major pressure on ecosystem condition is from rising human populations and the increased demand for subsistence food. These impacts can be addressed through appropriate governance arrangements, such as land use planning. As discussed further below, in Vanuatu these will

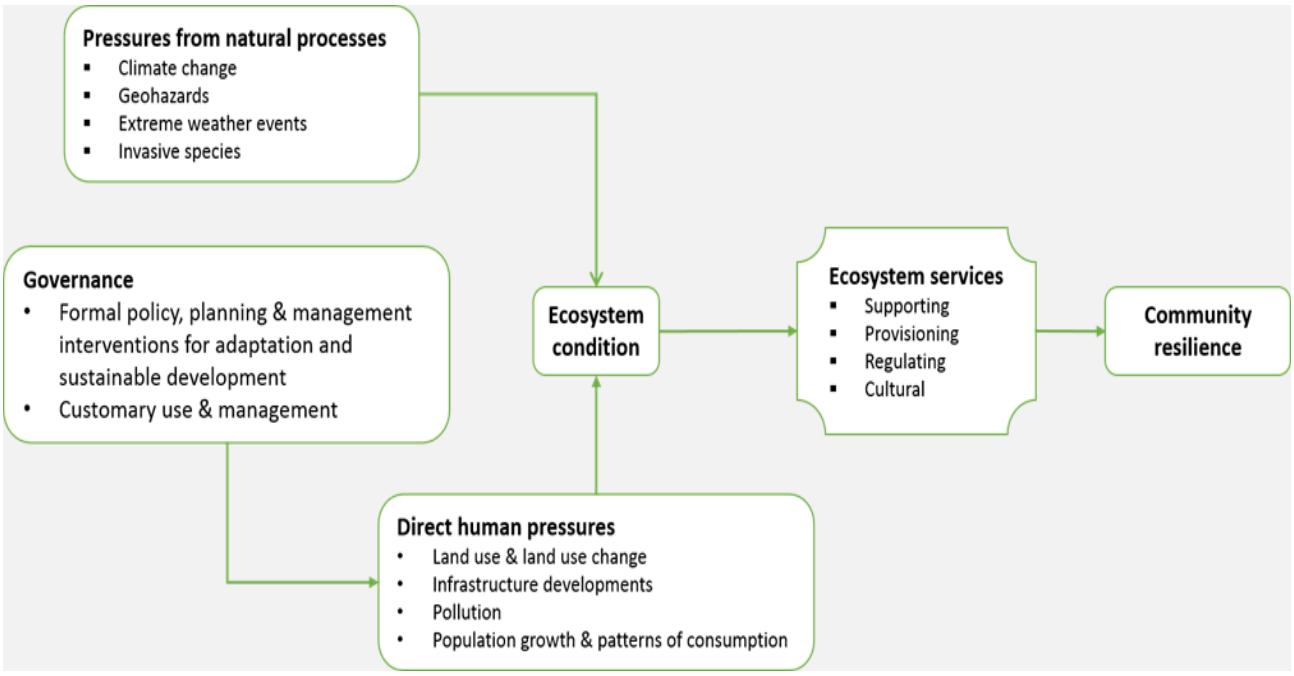


Figure 4. A conceptual framework illustrating (in a highly generalised way) the relationship between ecosystem-based approaches, ecosystem services and community resilience

involve both formal policy, planning and management interventions for adaptation and sustainable development, along with customary land and sea use and management.

In terms of policy and programmatic interventions, options are needed that enhance community resilience through EbA approaches, such as: avoiding or reducing activities that degrade ecosystems through, for example, over-use or pollution; restoring ecosystem condition through ecological restoration of degraded forests and coral reefs; providing appropriate technologies that reduce environmental waste, such as solar power systems in place of diesel generators; or by establishing community conservation areas. In these ways, the condition of ecosystems can be maintained or improved and communities can continue to benefit from the flow of ecosystem services.

1.4 Ecosystem types

While terrestrial ecosystems can be identified and mapped using various criteria, from a practical perspective (and in a Melanesia context) they have been defined here according to the major vegetation types that have been recognised by biodiversity and forest surveys. In addition, we recognised the general coastal ecosystem categories of coral reefs (particularly fringing reefs), mangroves, and sea grass. At the national level, Table 1 lists the main vegetation types that have been recognised in Vanuatu. However, the only national mapping available for terrestrial ecosystems was a vegetation map published by the Vanuatu Forestry Department (Schwetter 2012); the categories for which are listed in Table 2. For coastal marine ecosystems we were able to use GIS data layers generated from global inventories of coral reef and sea grass GIS data layers (See also Table 2).

Table 1. Vegetation types in Vanuatu (Source: Munzinger et al. 2006)

1. Lowland rain forest
a. High stature forest on old volcanic soil
b. Medium stature forest heavily covered with lianas
c. Complex forest scrub densely covered with lianas
d. Alluvial and floodplain forest
e. *Agathis-Calophyllum* forest
f. Mixed species forest without gymnosperms and *Calophylum*
2. Montane cloud forest and related vegetation
3. Seasonal forest, scrub and grassland
a. Semi-deciduous transition forest
b. *Acacia spirorbis* forest
c. *Leucaena* thicket, savanna and grassland
4. Vegetation on new volcanic soil
5. Coastal vegetation including mangroves
6. Secondary and cultivated woody vegetation

1.4.1 Tropical forest

A comprehensive overview of Vanuatu's tropical forests is given in Rhind (2010). Vanuatu supports three main forest ecosystem types: lowland tropical rainforest, montane cloud forest, and *Acacia spirorbis* forest.

Up to about 600 m altitude, lowland rain forest is the natural vegetation on the south eastern, windward sides of all Vanuatu islands, referred to as mixed lowland rainforest. On old volcanic ash, rich in plant nutrients, trees can reach more than 30 m in height, with large crowns.

Important trees are *Antiaris toxicaria*, *Castanospermum australe*, *Intsia bijuga* and *Kleinhovia hospitat*.

Montane cloud forests range from about 500 - 1000 m in altitude. They are all characterised by stunted, gnarled trees, covered in bryophytes and filmy ferns. The main tree genera are Ascarina, Geissois, Metrosideros, Quintinia, Syzygium and Weinmannia. In addition, tree ferns of Cyathea and Dicksonia are locally common, together with various other large ferns. Many of the tree crowns are covered with epiphytic orchids, particularly species of Dendrobium, and ferns. Astelia (Liliaceae) is another conspicuous epiphyte. Lianas, on the other hand, are less numerous but include the pandanaceous climber Freycinetia. Scattered among the trees are various herbaceous patches with plants such as large leaved Gunnera, the grass Isachne and the sedge Machaerina. Shrubs such as Eurya, Gaultheria, Pipturus and Vaccinium can also be found in these treeless, herbaceous zones. *Acacia spirorbis* forests are known locally and this open formation can be found on various islands, including Anatom and Erromango. The trees usually have a low to medium stature, growing to a maximum of about 15 m, and typically have wide-branching crowns. Dominant among undergrowth shrubs are Croton, Symplocos and Xylosma. In canopy openings, heliophytic grasses predominate. These include *Miscanthus floridulus* in moist areas and *Heteropogon contortus* in the dryer areas.

Vanuatu's forests have been subjected to a long history of human use, including for non-timber products, customary practices, fuel wood and, more recently, industrial logging. Here we drew upon the in-depth account provided by Regenvanu et al. (1997). Vanuatu's first commercial tree harvest began in 1825, with the cutting of

Table 2. Categories of ecosystems used in the Vanuatu ecosystem assessment

Ecosystem type	1. Data source
Tropical forest – medium	2012 Vanuatu Vegetation Map
Tropical forest – low	2012 Vanuatu Vegetation Map
Tropical forest – thicket	2012 Vanuatu Vegetation Map
Tropical forest – shrub	2012 Vanuatu Vegetation Map
Plantation cropping	2012 Vanuatu Vegetation Map
Bare soil	2012 Vanuatu Vegetation Map
Built-up	2012 Vanuatu Vegetation Map
Freshwater wetlands	2012 Vanuatu Vegetation Map
Freshwater water bodies	2012 Vanuatu Vegetation Map
Coastal – mangroves	2012 Vanuatu Vegetation Map
Coastal – seagrass	2005 Global Distribution of Seagrass UNEP World Conservation Monitoring Centre – Marine metadata catalogue
Coastal – coral reef	2010 Global Distribution of Coral Reefs UNEP World Conservation Monitoring Centre – Marine metadata catalogue

sandalwood (*Santalum austro-caledonicum*) for export to China. This collapsed after 40 years and subsequently the commercial use of the forest ecosystems expanded with the logging and sawing of trees for timber. As discussed further below, the principal form of subsistence farming involved rotating the use of plots with the length of the fallow period, and thus the length of vegetation regeneration, varying with soil fertility, suitability for cultivation, and population density. In pre-European times, those areas of Vanuatu allocated for such cultivation would have been dominated by secondary forest, often in quite mature tree stands.

In addition to the subsistence agriculture and arboriculture, a conservation-oriented use of trees and forest areas was also ensured by other traditional customs. As Regenvanu and colleagues (1997) noted: '… the traditional landscape was replete with places or sites that were 'tabu' (taboo) meaning that access to them—either physically or through oral narrative—was restricted in some way. In many cases the taboo meant that the area immediately surrounding a site was off-limits to almost everyone and, in a few cases, everyone. As a result, such sites would appear (and still do) as wooded groves, some of considerable size, within an environment of secondary forest. Oral traditions indicate that large tracts of the landscape may have been declared off-limits at different times by such customs, effectively creating reserved areas.'

1.4.2 Grassland

The extensive areas of grassland occur in Vanutatu can be largely attributed to clearing of natural vegetation cover and pasture establishment for beef production. Major pasture types include Carpet (*Axonopus compressus*) and T grass (*Paspalum conjugatum*) in combination with native legumes, which are the major grazing resource. Of next significance is buffalo grass *(Stenotaphrum secundatum)* pastures under old, moderately shaded plantation coconuts. Heavily shaded native grass, and to a minor extent buffalo grass pastures, under dense coconuts and bush comprise an estimated 25 - 30% of the total grazed area. The principal native grasses are carpet grass and T grass, while some consider buffalo grass to have become naturalised (Macfarlane and Shelton 1986). The impacts of introduced grassland species, including elephant grass (*Panicurn purpureum*) have also been noted (Department of Environment 1999).

1.4.3 Coral reefs, mangroves and sea grass

Vanuatu's 200 nautical mile exclusive economic zone is extensive and encompasses mangrove, sea grass, lagoon, coral and pelagic habitats. Consequently, coastal and marine biodiversity are important national considerations (Department of Environment, 1999). The coral reefs of Vanuatu are described by Naviti and Aston (2000) and Done and Navin (1990). There are, however, relatively few extensive shallow-water reefs surrounding the 80 high islands in the Vanuatu archipelago. Inner reef areas are limited to narrow fringing reefs and reef platforms surrounding islands and a few lagoons and barrier reefs, totalling an area of approximately 70,000 hectares. Exposed coral reef slopes and crests are dominated by coralline algae and robust plating and branching corals (Acropora and Pocilloporidae), changing to dominance of a mix of massive and branching corals three to five metres below the level of the reef flat. Sheltered parts of the outer reef are characterised by various species of Acropora and Montipora. Massive Porites are prevalent in open embayments, while sheltered embayments are strongly dominated by soft corals. It has been postulated that the colonisation of coral reefs in Vanuatu is assisted by a dispersal pathway through Solomon Islands to the Great Barrier Reef in Australia.

1.4.4 Freshwater wetlands and freshwater bodies

In Vanuatu, freshwater ecosystems are scattered, localised and small in extent. (Department of Environment 1999), and little information is available on their location and condition.

1.4.5 Thickets and shrublands

This ecosystem type covers a range of vegetation types and conditions from cleared or degraded tropical forests through to natural vegetation communities. For example, as described by Rhind (2010), on the lava fields of Yasur Volcano on Tanna, the ferns *Histiopteris incisa*, *Nephrolepis hirsutula* and *Cyathea* species are widely, but sparsely, distributed, but a completely different flora occurs on the disturbed cinder cones. Here the dominant species include shrubs such as *Melastoma denticulatum, Piper latifolium* and *Pipturus argenteus,* the grasses *Imperata cylindrical* and *Miscanthus floridulus,* and the annual herb *Emilia sochifolia*. Surprisingly, orchids have also been recorded in these inhospitable areas, including species of *Spathoglottis,* while on the volcanic ash of Erromango the endemic orchid *Trichochilus neoebudidus* (Orchidaceae) can be found.

1.5 Ecosystem assessment

In a general sense, ecosystem assessment involves gathering information regarding the location, extent and condition of ecosystems in a format suitable for informing decision-making. As suggested in Figure 4, the quality of the flow of ecosystem service benefits is a function of the condition of the ecosystem; that is, the degree to which it has been degraded by human pressures and the impacts of a rapidly changing climate. Ecosystems across Vanuatu are under pressure from multiple sources, including climate change impacts and increasing demand for natural resources from population growth and economic development. Ecosystem assessments were conducted at both the national (Vanuatu) and island (Tanna) scales. At each scale, the assessment involved establishing the type, location, extent and condition of ecosystems. Further details on the ecosystem assessment methodology are provided in the Appendices.

1.5.1 Terrestrial ecosystem condition assessment

The vegetation classification and map of Schwetter (2012) reflects a combination of vegetation type, vegetation condition and land use. We endeavoured to separate out these variables by producing two separate GIS data layers of: (i) ecosystem type; and (ii) ecosystem condition.

Table 3. Categories of vegetation condition. Source: Adapted from Thackway and Lesslie (2006) and Schwetter (2012)

Category	**0**	**I**	**II**	**2. III**	**3. IV**	**4. V**	**VI**
Description	Naturally bare	Intact largely unmodified	Modified	Transformed (highly modified)	Replaced by invasive species	Replaced by crops	Removed
Example	Volcano	Primary forest	Commercially logged native forest	Traditional subsistence farming	Lantana infestation	Coconut plantations	Airport

For condition of the terrestrial ecosystems we used a modified version of the Vegetation Assets, States and Transitions (VAST) method developed by Thackway and Lesslie (2006). The primary source of information on ecosystem condition was the Schwetter (2012) vegetation map, which provides an assessment of areas of forest and thicket considered as degraded or intact (Table 3).

1.5.2 Coral reef condition assessment

The condition of coral reefs was modelled based on an empirically established relationship between reef condition and the density of human populations in the coastal zone. This strategy for estimating ecosystem condition via a metric based on available data is particularly relevant for marine habitats, as costs preclude broad scale direct assessments and remote sensing techniques cannot at this stage estimate condition reliably. While to some extent the science underpinning the use of proxy metrics to indicate ecosystem condition is still developing, for coral reefs it is now widely accepted that there is a negative relationship between ecosystem condition and proximity to human populations. The deleterious effects of humans on coral reefs are largely a result of land-based pollution and the cascading trophic effects of harvesting fish, invertebrates and turtles (McClanahan et al. 2011).

The results from field studies have highlighted the importance of several potential indicators relating human proximity to reef condition, including coastal population density, socio-economic status of populations, distance from population, and travel time from population centres to reefs (Brewer et al. 2013; Cinner et al. 2013; and Maire et al. 2016). Where fishing is for profit (rather than subsistence), distance to market is another measure that can be used to predict reef condition (Brewer et al. 2013).

It should be noted, however, that one recent global analysis could not find a predictive relationship between human populations and reef condition (Bruno and Valdivia, 2016). The authors suggest two principal reasons for the apparent lack of a clear relationship: (1) the different intensities of fishing practices in different locations, from small-scale subsistence fishing to large-scale, industrialised harvesting; and (2) natural variation in measures of coral reef health among different biogeographic provinces. In Vanuatu, however, we consider the use of a human proxy to be valid, as the range of fishing practices is narrower than that occurring globally and reefs are all in the same biogeographic region.

For Vanuatu, we were able to access reliable, spatially-explicit data on human populations from national census surveys. For the entire coastline of the country we calculated population density (persons per km^2) in a 1-km wide strip, based on 10 km grid cells and categorised into three levels of impacts following the principles in Table 3. However, note that for coastal assessments the 'Transformed' category in Table 3 typically represents a higher level of impact on condition than 'Modified', but does not imply that an alternative habitat has resulted.

1.6 Tanna Island ecosystem types mapping

Our ecosystem assessment for Tanna drew on the national level vegetation data, complemented by satellite image classification, field survey observations, and digital terrain analysis. We employed the same terrestrial ecosystem classes developed for the national assessment (Table 1). However, we remapped the extent of the ecosystems using a new land cover map for Tanna, based on a high-resolution mosaic of RapidEye satellite imagery compiled by the Griffith University team. The most recent cloud-free images were used, noting that, due to continuous volcanic activity, the Island is rarely, if ever, cloud free. The RapidEye mosaic was classified using the segmentation approach in Terrset (2016) and calibrated using a combination of the vegetation map and field survey observations. The UNEP coral reef layer was also used for Tanna and cross-validated with a near-coastal marine classification of the RapidEye mosaic.

A 30 m resolution Aster-derived Digital Elevation Model was also used to model key topographic and surface hydrology attributes, including water catchments, which provide a useful spatial unit of analyses for some of the indicators used for the risk assessment detailed in section 5.

1.7 Ecosystem service valuation

Although the importance of ecosystems to human society has many dimensions (ecological, socio-cultural and economic), expressing the value of ecosystem services in terms of monetary units is an important tool to raise awareness and convey the relative importance of ecosystems and biodiversity to policy makers. 'Money talks', it is said, and information on monetary values can be effectively used as a tool to strengthen the argument for allocating resources towards ecosystem conservation or repair. Valuation also enables more efficient use of limited funds by identifying where ecosystem protection and restoration is economically most important and can be provided at lowest cost. Several different techniques for valuing ecosystem services in monetary terms are now well established in the literature.

1.7.1 Valuation in the absence of local data: benefit transfer

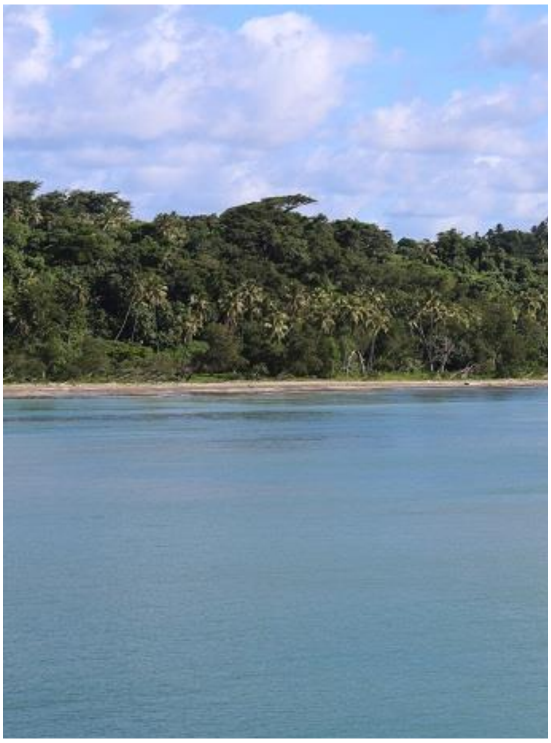
There was not sufficient time and resources to conduct primary research into the valuation of ecosystem services specifically for Vanuatu, or Tanna. Given this, a 'benefit transfer' approach was employed, which is a method of estimating the value of an environmental good or service at a *target* site, using information from an existing study (or studies) conducted at another *source* site.

In practice, benefit transfer typically involves searching the relevant empirical literature to identify existing studies that value goods or services that have similar social and biophysical contexts to those in which the researcher is interested. For example, if the objective of the study is to estimate the value of subsistence fishing from a coastal coral ecosystem in a target area, researchers can apply values from studies undertaken under similar socio-economic conditions. Note that the value of commercial recreational fishing in a developed country would be an inappropriate source site study in this case.

When using a benefit transfer approach, in the absence of a highly relevant study, it is prudent to use the median value derived from as many appropriate studies as time permits discovering. It is important to note that benefit transfers can only be as accurate as the value estimates in the source site studies.

1.7.2 Relevant studies for benefit transfer

The most comprehensive analysis of ecosystem service values published to date is that of de Groot et al. (2012). In this analysis, the authors assess 665 studies obtained from the Ecosystem Service Valuation Database (Ecosystem Services Partnership, 2016). Of the assessed studies, only three relate directly to the Pacific Islands. Caution, therefore, is needed in interpreting the values derived from their analysis for Vanuatu. On a more general note, this points to the paucity of studies valuing ecosystem services in the context of the Pacific Islands and Vanuatu in particular – there is clearly scope for further research in this area.



The studies included within de Groot et al. (2012) assess a suite of ecosystem services, including the provision of food; genetic and medicinal resources; regulating services, including erosion prevention and nutrient cycling; habitat to fauna; and cultural services. In their analysis, the authors provide monetary values for ten 'biomes', which in this report we refer to as 'ecosystem types': open oceans, coral reefs, coastal systems, coastal wetlands, inland wetlands, freshwater lakes and rivers, tropical forests, temperate forests, woodlands, and grasslands. For each ecosystem type, 22 ecosystem services are taken into account, following The Economics of Ecosystems and Biodiversity (TEEB) classification (de Groot et al., 2010). Alternative sources to de Groot et al. (2012) were used where no appropriate study or studies could be found for particular ecosystem types and/or ecosystem service flows, or conversely where there were, in fact, Vanuatu-specific reports available. Conducted as part of the IUCN Oceania Mangrove Ecosystems for Climate Change Adaptation and Livelihoods (MESCAL) project, Pascal and Bulu (2013) provide one of the two Vanuatu-specific valuation studies included within our analysis. In this study, the authors use a combination of desktop research and field studies to determine the cultural and commercial uses of mangrove resources at Crab Bay (Malekula) and Eratap (Efate). The authors present economic valuations for seven ecosystem services (subsistence fishing, commercial fishing, recreational fishing, coastal protection, mangrove tourism, wood extraction and carbon sequestration). In Crab Bay, the authors find the highest values to be associated with carbon sequestration, subsistence fishing, commercial fishing and wood extraction. In Eratap, the highest values are associated with carbon sequestration, mangrove tourism, coastal protection and subsistence fishing.

For coral reef's contribution to erosion prevention we derived per hectare values from Pascal et al.'s (2015) report on the Economic Assessment and

Valuation of Marine Ecosystems: Vanuatu. The authors evaluated coral reefs' contribution to erosion prevention for the islands of Efate (separate east and west coast values were determined), Espiritu Santo and Malekula, using the avoided damage cost method. As Vanuatu's emerging tourism sector is concentrated on Efate and (to a lesser extent) Espiritu Santo, these islands host high value property and infrastructure, such as hotels and airports, which are of considerably higher value than on Malekula, where no hotel infrastructure was identified. In addition, as Malekula's settlement pattern is similar to that of the majority of coastal Vanuatu, the Malekula-derived value for coral reef's contribution to erosion prevention was considered the most representative for Vanuatu at the national scale. [1]

1.7.3 *Our approach*

For the ecosystem service valuation we used the GIS maps of ecosystem types and condition to estimate ecosystem service benefits from the identified ecosystem types. For six of these we used values derived from de Groot et al. (2012) after making appropriate adjustments: coral reefs[2], coastal systems, freshwater (inland) wetlands, freshwater lakes and rivers, tropical forests, and grasslands. For each of these six, starting from de Groot et al. (2012) we: (1) removed studies that were conducted in high income countries on the basis that the primary benefits derived from ecosystem services in these countries (e.g. recreation) bear little resemblance to the primary benefits derived from ecosystems services in a developing nation, such as Vanuatu (e.g. subsistence fishing); and (2) adjusted the 2007 International dollar values reported by de Groot et al. (2012) in order to report values in 2015 Vatu and USD. In all of these estimates we employ the median value rather than the mean, as the median is less likely to be influenced by a small number of outliers – that is, values that are substantially different from the norm. Note also that for tropical forest medicinal resource values we subtracted the value that de Groot et al.'s (2012) source paper (Yaron 2001) assigned to the bark of a locally endemic tree species in Cameroon that has an established (high) market value as a medicinal treatment for prostate cancer.

For the coastal wetlands category, where possible, we employed the values derived by Pascal and Bulu (2013) for mangroves in Crab Bay and Eratap. As Pascal and Bulu (2013) reported two sets of values (one for Crab Bay and one for Eratap), we used the mean of the two. In both cases we make inflation and currency adjustments in order to report values in 2015 Vatu and USD. For ecosystem service components within the coastal wetlands category, which are not valued in Pascal and Bulu's Vanuatu mangrove study[3], we used median values from de Groot et al. (2012) as explained previously.

For coral reef's contribution to erosion control, we divided the total annual contribution to erosion control for the island of Malekula from Pascal et al. (2015) by the area of coastal coral reef around the island identified from GIS sources to derive a per hectare per annum value.

Table 4 provides a summary of ecosystem types, the valuation approach employed and the per hectare values used. In this, and all subsequent

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[1] It should be noted that future development of the tourism sector across Vanuatu as a whole will entail an increase in the value of coral reef contribution to erosion control.

[2] With the exception of erosion protection, as noted above.

[3] Pascal and Bulu (2013) provide Vanuatu-specific valuations for the following ecosystem services from mangrove wetlands: food, raw materials, climate regulation, erosion prevention, recreation. Valuations for the following ecosystem services from coastal wetlands are drawn from de Groot et al. (2012): water, medicinal resources, disturbance moderation, waste treatment, nutrient cycling, nursery services, genetic services.

tables, conversion of USD to Vatu is at the median exchange rate for Vatu to USD through 2015 and 2016 of 1 US$ = 107.6 Vatu.[4]

The next step was to use the derived per hectare values to estimate a monetary value for each of the seven ecosystem types for each ecosystem service flow for Vanuatu. Values are reported in 2015 Vatu and additionally summarised USD. A separate ecosystem valuation was conducted for Tanna using the same approach as applied to all of Vanuatu, except the updated and higher resolution ecosystem type and condition GIS maps. Table 5 presents the monetary values employed for each ecosystem service flow per ecosystem type (2015 Vatu per hectare per year).

Table 4. Valuation approach and value per hectare per year for each ecosystem type

Ecosystem type	**Valuation approach**	**Value per hectare per annum (2015)**	
		USD	**Vatu**
Coral reefs	For erosion control: benefit transfer from Pascal, et al. (2015); for other ecosystem service values: benefit transfer derived from de Groot, et al. (2012)	81,129	8,731,117
Coastal seagrass*	Benefit transfer derived from de Groot, et al. (2012)	750	80,698
Coastal mangroves**	Benefit transfer derived from Pascal and Bulu (2013) and de Groot el al. (2012) in combination	23,560	2,535,527
Inland wetlands	Benefit transfer derived from de Groot, et al. (2012)	8,440	908,315
Freshwater lakes and rivers	Benefit transfer derived from de Groot, et al. (2012)	7,071	760,934
Tropical forest	Benefit transfer derived from de Groot, et al. (2012)	1,488	160,151
Grasslands	Benefit transfer derived from de Groot, et al. (2012)	1,473	158,524

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[4] Source: Author estimates derived from Anderson (2006); de Groot, et al. (2012); Pascal and Bulu (2013); Queensland Government (2016); McGregor (1999). * Coastal systems include estuaries, continental shelf area and seagrass, but exclude wetlands like tidal marsh, mangroves and saltwater wetlands. ** Coastal wetlands include an appropriate combination of values from the Vanuatu-specific valuation by Pascal and Bulu (2013) [denoted by ‡ in Tables 4 and 5] and – for those categories,¬¬¬¬¬¬¬¬¬¬ which are not valued by Pascal and Bulu – values from de Groot et al. (2012) [denoted by † in subsequent tables].

Table 5. Monetary values employed for ecosystem service flows per ecosystem (2015 Vatu per ha per year

Service	Coastal - Coral	Coastal - Seagrass	Coastal - Mangroves	Freshwater - Wetlands	Freshwater - Waterbodies	Tropical Forests	Grasslands
Provisioning services							
Food	21,632	14,842	354,716‡	5,644	169,286	2,699	146,256
Water	-	-	5,811†	13,614	333,192	4,539	-
Raw materials	3,946,641	123	109,665‡	3,742	-	5,092	491
Genetic resources	4,054,584	-	-	-	-	-	-
Medicinal resources	-	-	37,021†	12,086	-	47	123
Ornamental resources	96,320	-	-	13,991	-	-	-
Regulating services							
Air quality regulation	-	-	-	-	-	-	-
Climate regulation	213,626	-	825,388‡	2,515	-	40,605	10,551
Disturbance moderation	185,860	-	250,109†	372903	-	3,435	-
Regulation of water flows	-	-	-	147,322	-	83,675	-
Waste treatment	10,439	-	127,207†	9,815	43,431	736	-
Erosion prevention	8,825	-	206,415‡	1,718	-	1,595	-
Nutrient cycling	-	-	5,489†	2,454	-	-	-
Pollination	-	-	-	-	-	6,502	-
Biological control	-	-	-	-	-	-	-

Table 5 continues overleaf

Service	Coastal - Coral	Coastal - Seagrass	Coastal - Mangroves	Freshwater - Wetlands	Freshwater - Waterbodies	Tropical Forests	Grasslands
Habitat							
Nursery service	14	11,408	274,969†	314,896	-	-	-
Genetic service	5,058	22,062	134,095†	6,502	-	859	-
Cultural services							
Aesthetic information	-	-	-	-	-	-	-
Recreation	178,434	32,264	204,463‡	1,104	215,025	10,367	1,104
Inspiration	-	-	-	-	-	-	-
Spiritual experience	-	-	-	-	-	-	-
Cognitive development	9,676	-	-	-	-	-	-
TOTAL (Vatu)	**8,731,117**	**80,698**	**2,535,527**	**908,315**	**760,934**	**160,151**	**158,524**
TOTAL (USD)	**81,129**	**750**	**23,560**	**8,440**	**7,071**	**1,488**	**1,473**

Source: Author estimates derived from Anderson (2006); de Groot et al. (2012); Pascal et al. (2015); Pascal and Bulu (2013); Queensland Government (2016); McGregor (1999).

2 Results of ecosystem service assessment and valuation

2.1 National level

2.1.1 Ecosystem types and extent

Vanuatu's largest ecosystem by area is tropical forest (66%), comprising low forest (22%), medium forest (18%), thickets (24%) and shrubs (2%). The coastal ecosystems (coral, mangroves and seagrass) are the second largest with 14%, even though most of the coastline is steeply sloping, resulting in only a relatively narrow fringe of tidal and/or shallow sub-tidal habitat. Table 6 provides a detailed breakdown of ecosystems types by area, also represented in a pie chart in Figure 5.[5]

Table 6. Total area of different ecosystem types for Vanuatu

Ecosystems	Area (ha)	Percentage of national land area (%)
Bare soil	7,687	0.65
Grassland	39,776	3.37
Tropical Forest - Low	305,509	25.87
Tropical Forest - Medium	254,550	21.55
Tropical Forest - Shrubs	30,886	2.61
Tropical Forest - Thickets	343,886	29.11
Coastal - Seagrass	124,038	10.50
Coastal - Mangroves	1,665	0.14
Coastal - Coral	70,238	5.95
Freshwater - Wetlands	406	0.03
Freshwater - Waterbodies	539	0.05
Unknown	1,961	0.17
Total	**1,259,188**	**100**

2.1.2 Ecosystem condition

There was insufficient data at the national level to undertake a conclusive assessment of the conditions of Vanuatu's ecosystems. Based on the published literature, it is likely the available mapping over-estimates the proportion of ecosystem types in an intact condition and there is, for example, probably more shrub and thicket in a modified state.

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[5] Note that the map analysis identified some areas as being of 'unknown' ecosystem type. The only provinces in which area has been assigned to this 'unknown' category were Penama (210 ha) and Torba (1751 ha), giving a total area of 1961 ha, which is equivalent to 0.16% of the total national land area.

With these caveats, Table 7 and Figure 6 provide the summary statistics for the condition of ecosystem types for Vanuatu based on the available data. These data suggest that several ecosystems have been heavily modified, including grassland ecosystems (65%), low tropical forest (24%) and medium tropical forest (63%). Sea grass and mangrove coastal ecosystems appear to be in a relatively intact condition, while coral ecosystems have been more modified (39%) and transformed (20%), leaving only 41% in an intact condition.

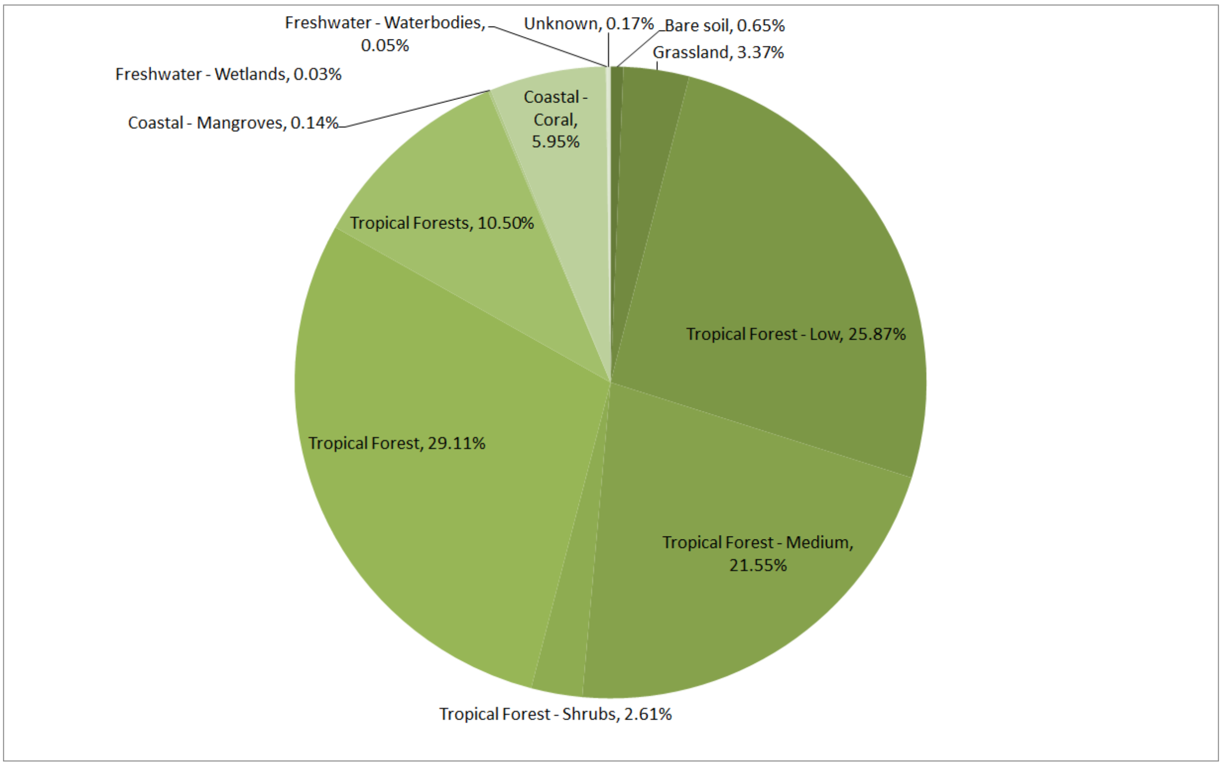

Figure 5. Proportion of ecosystem types for Vanuatu (%)

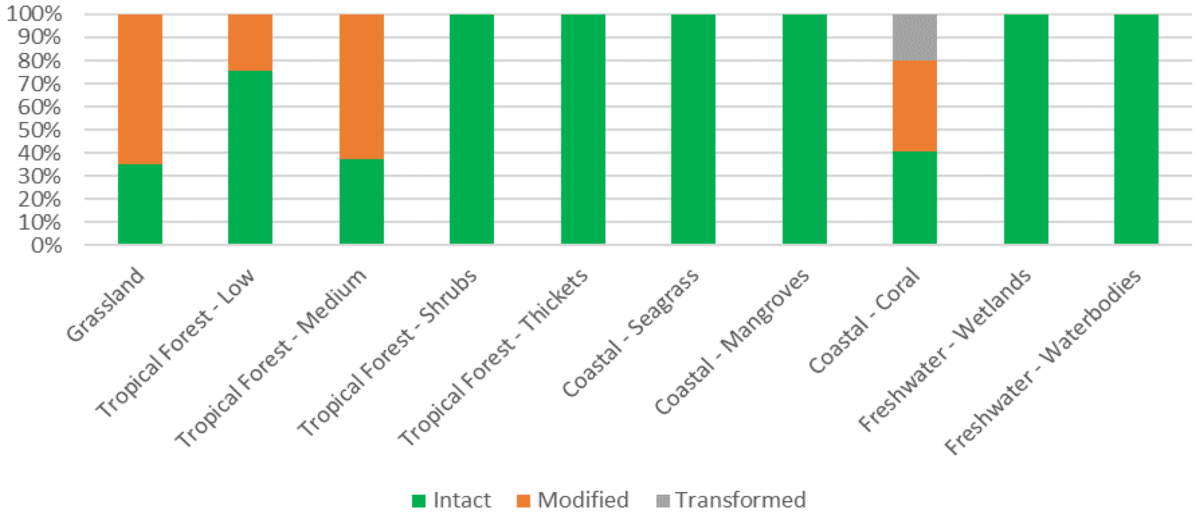

Figure 6. Ecosystem condition in Vanuatu

Table 7. Ecosystem condition in Vanuatu

Ecosystem	Intact	Modified	Transformed	Naturally bare	Removed	Total
Bare soil	-	-	-	-	7,687	**7,687**
Grassland	14,057	25,719	-	-	-	**39,776**
Tropical forest – low	231,408	74,102	-	-	-	**305,510**
Tropical forest – medium	94,576	159,974	-	-	-	**254,550**
Tropical forest - shrubs	30,886	-	-	-	-	**30,886**
Tropical forest - thickets	343,886	-	-	-	-	**343,886**
Coastal seagrass	124,038	-	-	-	-	**124,038**
Coastal mangrove	1,665	-	-	-	-	**1,665**
Coastal coral	28,662	27,464	14,111	-	-	**70,237**
Freshwater wetlands	406	-	-	-	-	**406**
Freshwater water bodies	539	-	-	-	-	**539**
Unknown	-	-	-	1,961	-	**1,961**
Total	**870,123**	**287,259**	**14,111**	**1,961**	**7,687**	**1,181,141**
Percent	**73.67**	**24.32**	**1.19**	**0.17**	**0.65**	

2.1.3 Ecosystem valuation

Values of ecosystem service flows at a national level were calculated by multiplying ecosystem areas (Table 6) by the relevant per hectare valuations (Table 5).

These valuations assume that the condition of each ecosystem in Vanuatu is the same as the condition of the ecosystems that were assessed in the primary studies collated by de Groot et al. (2011).[6]

Valuation results by ecosystem service sub-category and ecosystem type are reported in Vatu and totals in USD in Table 7.

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[6] de Groot et al. (2011) do not report the condition of the ecosystems that were assessed in their collated primary studies, so our assumption of equivalent condition here is strong.

Table 8. National scale estimate of annual monetary value of ecosystem service flows per ecosystem service type (million Vatu per ha per year / USD per ha per year)

	Coastal coral	Coastal seagrass	Coastal mangrove	Freshwater wetlands	Freshwater water bodies	Tropical forests	Grassland	Total
Area	**70,238**	**124,038**	**1,665**	**406**	**539**	**934,831**	**39,776**	**1,171,493**
Provisioning services								
Food	1,519	1,841	591	2.29	91	2,523	5,817	**12,385**
Water	-	-	10	5.53	180	4,244	-	**4,438**
Raw materials	277,204	15	183	1.52	-	4,760	20	**282,183**
Genetic resources	284,786	-	-	-	-	-	-	**284,786**
Medicinal resources	-	-	62	4.91	-	44	4.88	**116**
Ornamental resources	6,765	-	-	5.68	-	-	-	**6,771**
Regulating services								
Air quality regulation	-	-	-	-	-	-	-	**-**
Climate regulation	15,005	-	1,374	1.02	-	37,959	420	**54,758**
Disturbance moderation	13,054	-	416	151	-	3,211	-	**16,834**
Regulation of water flows	-	-	-	60	-	78,222	-	**78,281**
Waste treatment	733	-	212	3.98	23	688	-	**1,661**
Erosion prevention	620	-	344	0.70	-	1,491	-	**2,455**
Nutrient cycling	-	-	9.14	1.00	-	-	-	**10**
Pollination	-	-	-	-	-	6,079	-	**6,079**
Biological control	--	-	-	-	-	-	-	**-**

Table 8 continued overleaf

	Coastal coral	Coastal seagrass	Coastal mangrove	Freshwater wetlands	Freshwater water bodies	Tropical forests	Grasslands	Total
Habitat								
Nursey service	0.98	1,415	458	128	-	-	-	2,002
Genetic service	355	2,737	223	2.64	-	803	4,121	4,121
Cultural service								
Aesthetic service	-	-	-	-	-	-	-	-
Recreation	12,533	4,002	341	0.45	116	9,691	44	26,727
Inspiration	-	-	-	-	-	-	-	-
Cognitive development	680	-	-	-	-	-	-	680
Total (million Vatu)	613,256	10,010	4,222	369	410	149,715	6,305	784,286
Total (USD)	5,698,347,833	93,008,654	39,227,400	3,426,648	3,811,032	1,391,140,708	58,590,048	7,287,552,323
Percent contribution	78.19	1.28	0.54	0.05	0.05	19.09	0.80	

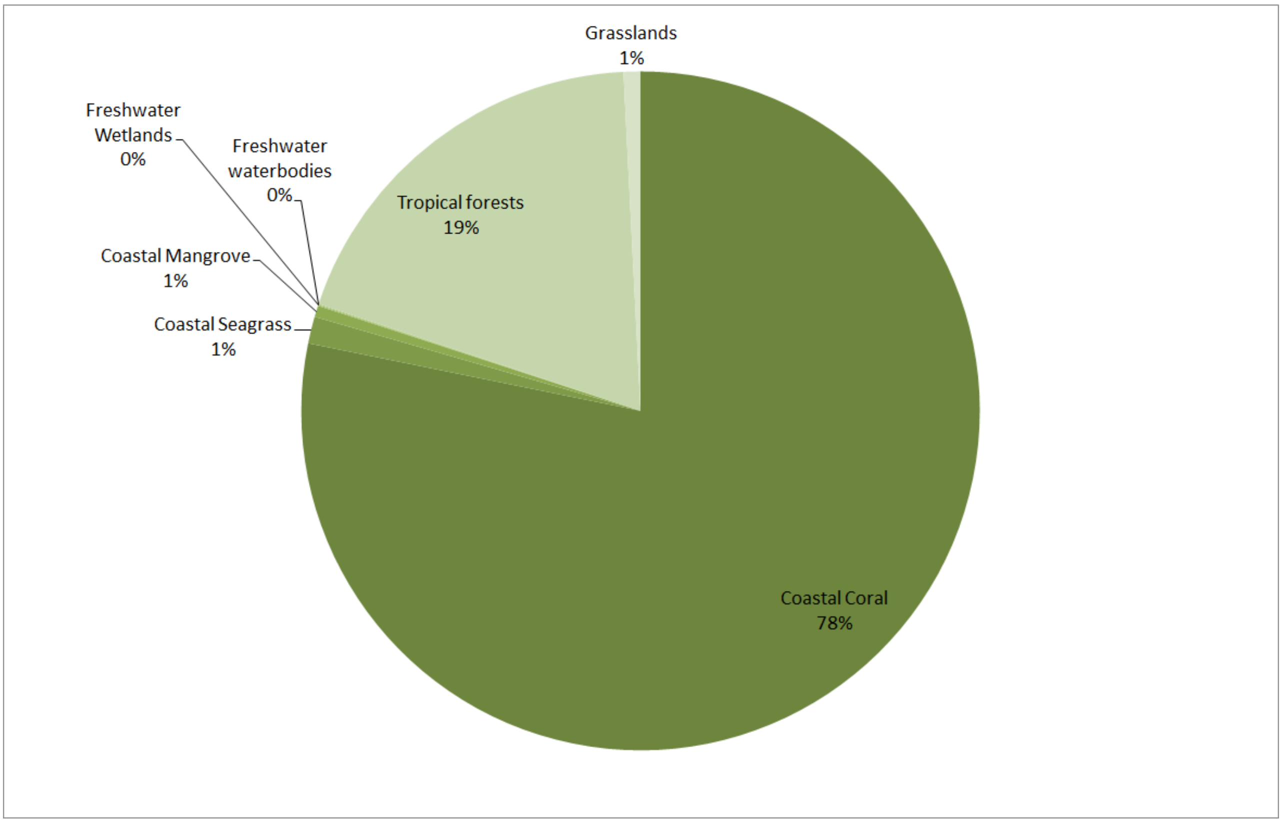

Figure 7. Ecosystem service value delivery by ecosystem type

2.1.4 Analysis

The ecosystem service values per ecosystem per hectare (Table 5) and the national ecosystem service valuations (Table 8) demonstrate the following:

- The value of Vanuatu's ecosystem services to human society is considerable: VUV 784 bn (or USD 7.3 bn) per annum. By comparison, Vanuatu's gross domestic product in 2015 was USD 742 million (World Bank 2016); smaller by a factor of 10. More than 97% of Vanuatu's ecosystem service value comes from three ecosystem types: coral reefs (78%), and tropical forest (19%) (Figure 7).
- More than 89% of Vanuatu's ecosystem service value is supplied via four ecosystem services: genetic resources (36%), raw materials (10%), and climate regulation (7%).

These values reflect the following:

- Coastal ecosystems (coastal coral, seagrass beds and mangroves combined) deliver particularly high ecosystem service value per hectare, despite the total areas of these systems being small. It is therefore important that coastal ecosystems are maintained in good ecological condition to ensure sustainable delivery of these high value flows.
- Almost 76% of Vanuatu's land area is classified as tropical forest, from which the most valuable per hectare ecosystem service flows are regulation of water flows and climate regulation.

Overall, these valuation results emphasise the considerable contribution that Vanuatu's natural capital stock delivers to human society, locally, nationally and globally each year, which is not captured in national accounts and to a large extent falls outside traded market values.

It is important to note that our analyses are based on two key assumptions: first, that the ecosystem types mapped for Vanuatu are commensurate with the biomes defined by de Groot et al. (2012); and second, that the total area of each ecosystem is in sufficiently good condition to deliver the determined ecosystem service values in full.

It follows that ecosystems in a poor condition now or that suffer degradation in the future will provide a diminished flow of ecosystem service benefits.

2.1.5 Social and demographic data

The importance of ecosystem services, such as food and water supply, water regulation, waste treatment and provision of raw materials, to Vanuatu's population is highlighted by the considerable proportions of Vanuatu's households that draw on these services (Tables 9 and 10).

Table 9. Proportion of households reliant on provisioning ecosystem services by province (Source: Vanuatu National Statistics Office, 2009)

	Use of traditional materials for construction			Households reliant on natural sources of water			Households deriving *some* income from			Households with *main* source of income from
Province	**Walls**	**Floors**	**Roof**	**Drinking water (river/lake/spring)**	**Drinking water (well)**	**Washing water (river/lake/spring)**	**Cash crops**	**Fresh-water fishing**	**Marine fishing**	**Sale of fish/crops/handcrafts**
Malampa	64%	31%	70%	8%	15%	16%	95%	23%	85%	60%
Penama	71%	21%	65%	7%	0.3%	21%	95%	19%	80%	68%
Sanma	42%	22%	52%	14%	4%	23%	71%	25%	62%	50%
Shefa	8%	9%	10%	3%	4%	8%	40%	6%	86%	21%
Tafea	67%	46%	65%	33%	7%	45%	91%	18%	89%	60%
Torba	80%	34%	78%	12%	0.2%	40%	86%	22%	99%	61%

Table 10. Proportion of households with tenure over livestock by province

	Households with tenure over livestock				
Province	**Cattle**	**Pigs**	**Goats**	**Horses**	**Poultry**
Malampa	43%	52%	6%	1%	81%
Penama	35%	66%	3%	1%	87%
Sanma	39%	40%	6%	9%	67%
Shefa	10%	22%	6%	1%	32%
Tafea	42%	77%	23%	7%	90%
Torba	30%	56%	1%	~0%	79%

2.2 Tanna

An ecosystem assessment and ecosystem service valuation was performed separately for Tanna, applying the national methodologies to higher resolution spatial data.

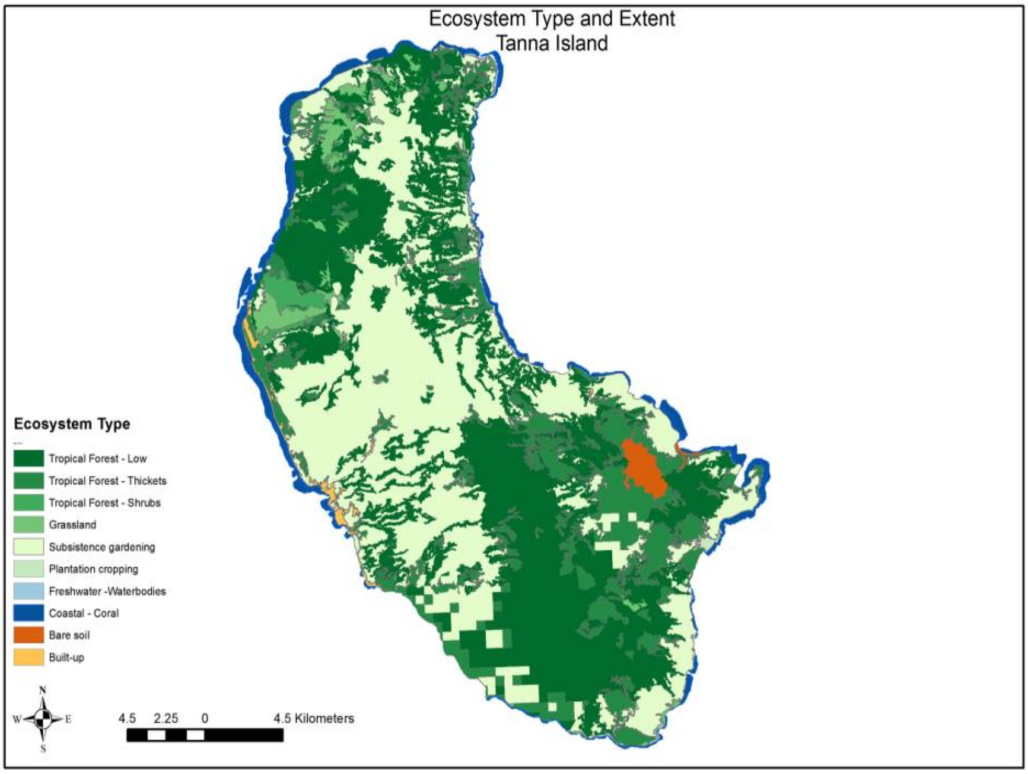

Figure 8. Tanna ecosystems. For data source and methods see Appendix A

2.2.1 Ecosystem types, extent and condition

Maps of the distribution of Tanna ecosystem types and their condition are shown in Figures 8 and 9, and the percentage of Tanna covered by each type is illustrated in Figure 10.

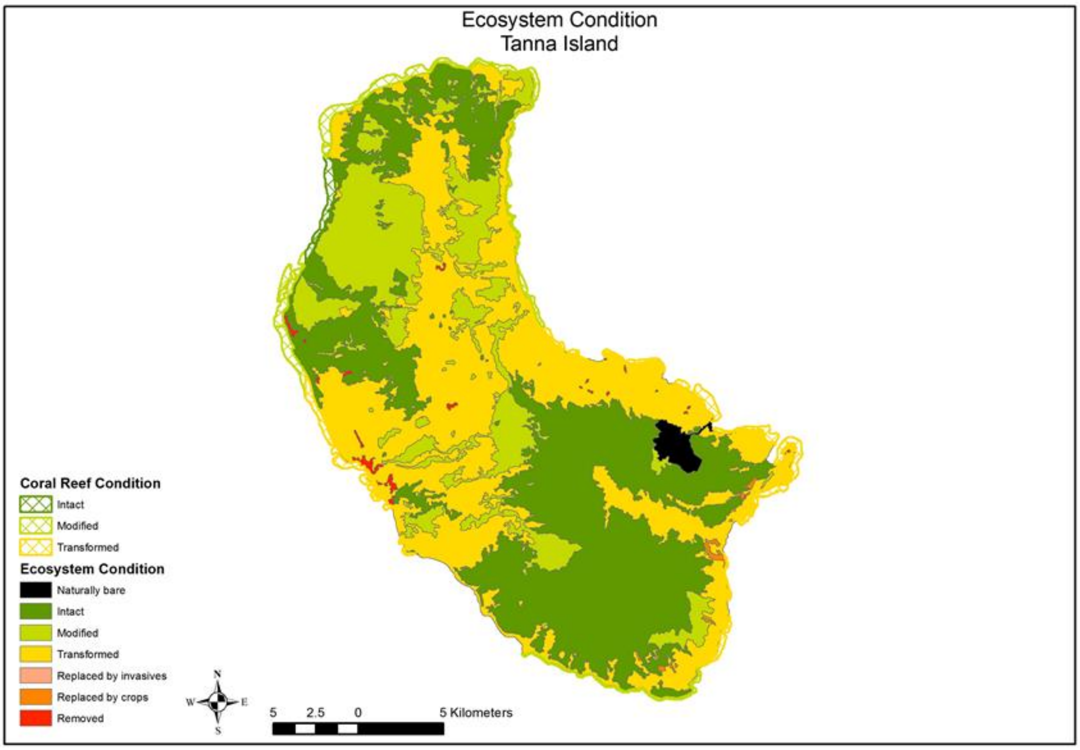

Figure 9. Ecosystem condition and land uses for Tanna

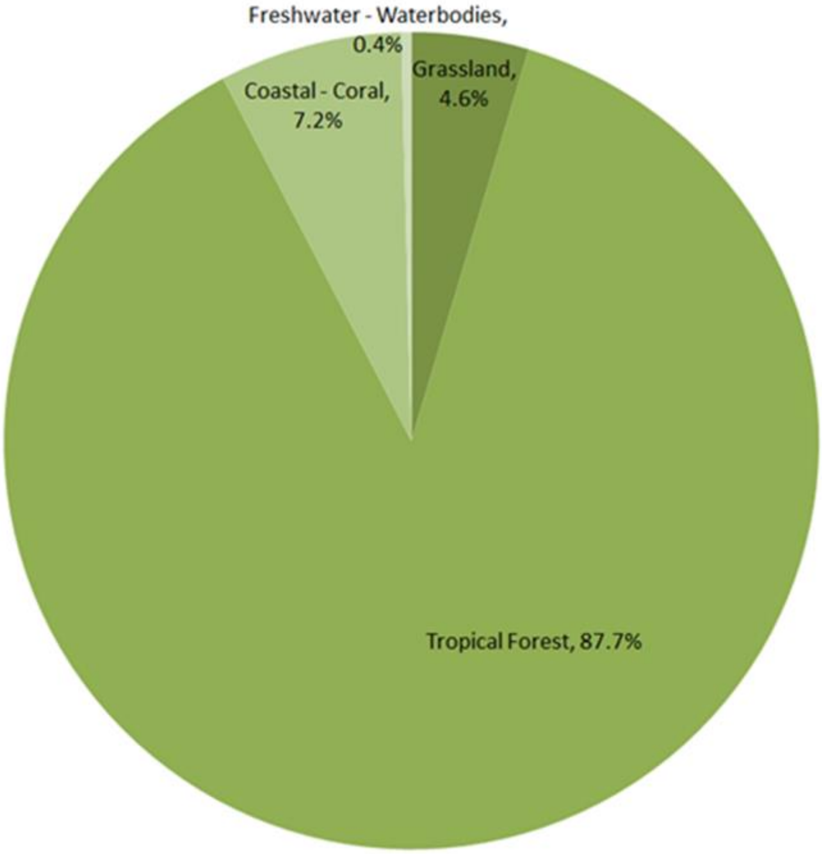

Figure 10. Proportion of ecosystem types by area on Tanna (%)

2.2.2 Ecosystem valuation

Replicating the national approach, but using higher resolution ecosystem mapping, values of ecosystem service flows for Tanna were calculated by multiplying ecosystem areas (Figure 10) by the relevant per hectare valuations for the different service flows (Table 5). Valuation results are shown in Table 11.

Local examples specific to Tanna of the ecosystem services used for the valuation were identified via a stakeholder workshop and community consultation sessions (Table 11).

Table 11. Examples of ecosystem services used by Tanna local communities

Type	Service	Coastal	Tropical Forest
Provisioning	Food	Fish, Shellfish, Seaweed, Crabs	Pigs, Asian Fowl, Fruit bats
	Water	Groundwater wells	Creeks and streams
	Raw materials	Sand and reef for construction	Timber for construction and firewood Leaves for wrapping and carrying food Leaves for weaving Leaves and grasses for shelter and construction
	Genetic resources		
	Medicinal resources	Yes but details were not able to be shared	Yes but details were not able to be shared
	Ornamental resources	Shells for ceremony	
Regulating	Air quality regulation Climate regulation Disturbance moderation Regulation of water flows Waste treatment Erosion prevention Nutrient cycling Pollination	Reefs provide protection from storms and waves	Shelter during cyclone events

	Biological control		
Habitat	Nursery services Genetic services		
Tourism and Recreation	Aesthetic information Recreation Inspiration Cognitive development	Tourism – Diving and snorkelling tours - Swimming - Bathing - Playground	Tours and artefacts
Kastom	Spiritual experience	Turtles	- Plant material for ceremony - *Tabu* areas - Hunting pigs and birds - Carving - Meeting place - Totem animals

Table 12. Estimate of the annual monetary value of ecosystem service flows per ecosystem type for Tanna (2015 million Vatu / USD)

	Coastal coral	Coastal seagrass	Coastal mangrove	Freshwater wetlands	Freshwater water bodies	Tropical forests	Grasslands	Total
Area	**2,493**	**-**	**-**	**-**	**138**	**30,165**	**1,598**	**34,394**
Provisioning services								
Food	54	-	-	-	23	81	234	**392**
Water	-	-	-	-	46	137	-	**183**
Raw materials	9,839	-	-	-	-	154	0.8	**9,993**
Genetic resources	10,108	-	-	-	-	-	-	**10,108**
Medicinal resources	-	-	-	-	-	1.4	-	**1.4**
Ornamental resources	240	-	-	-	-	-	-	**240**
Regulating services								
Air quality regulation	-	-	-	-	-	-	-	**-**
Climate regulation	533	-	-	-	-	1,225	17	**1,774**
Disturbance moderation	463	-	-	-	-	104	-	**567**
Regulation of water flows	-	-	-	-	-	2,524	-	**2,524**
Waste treatment	26	-	-	-	6	22	-	**54**
Erosion prevention	22	-	-	-	-	48	-	**70**
Nutrient cycling	-	-	-	-	-	-	-	**-**
Pollination	-	-	-	-	-	196	-	**196**
Biological control	-	-	-	-	-	-	-	**-**

Table 12 continued overleaf.

Table 12 cont. Estimate of the annual monetary value of ecosystem service flows per ecosystem type for Tanna (2015 million Vatu / USD).

	Coastal coral	Coastal seagrass	Coastal mangrove	Freshwater wetlands	Freshwater water bodies	Tropical forest	Grassland	Total
Habitat								
Nursery service	-	-	-	-	-	-	-	**-**
Genetic service	13	-	-	-	-	26	-	**39**
Cultural services								
Aesthetic information	-	-	-	-	-	-	-	**-**
Recreation	445	-	-	-	30	313	2	**789**
Inspiration	-	-	-	-	-	-	-	**-**
Cognitive development	24	-	-	-	-	-	-	**24**
Total (millions Vatu)	**21,767**	**-**	**-**	**-**	**105**	**4,831**	**253**	**26,956**
Total (USD)	**202,254,921**	**0**	**0**	**0**	**975,737**	**44,889,140**	**2,353,854**	**250,473,652**

The proportional contribution of ecosystem type on Tanna to total ecosystem service value is shown in Figure 11.

Ecosystem service valuations for Tanna (Table 11, Figure 11) indicate that 99% of Tanna's ecosystem service value is generated from two ecosystem types, coastal coral (80.7%) and subsistence gardens (17.9%).

2.2.3 Comparing Vanuatu and Tanna

Figures 12 and 13 compare ecosystem service benefit and ecosystem type contributions to the total values for Vanuatu and Tanna. It demonstrates that Vanuatu (nationally) and Tanna communities are broadly the same in their high dependence on ecosystem service benefits from the range of ecosystem types. Both derive between 97% and 99% of their ecosystem service benefit from coastal coral reefs and tropical forests and approximately 90% of this benefit is realised through provision of raw materials and genetic resources and the regulation of water flows and climate.

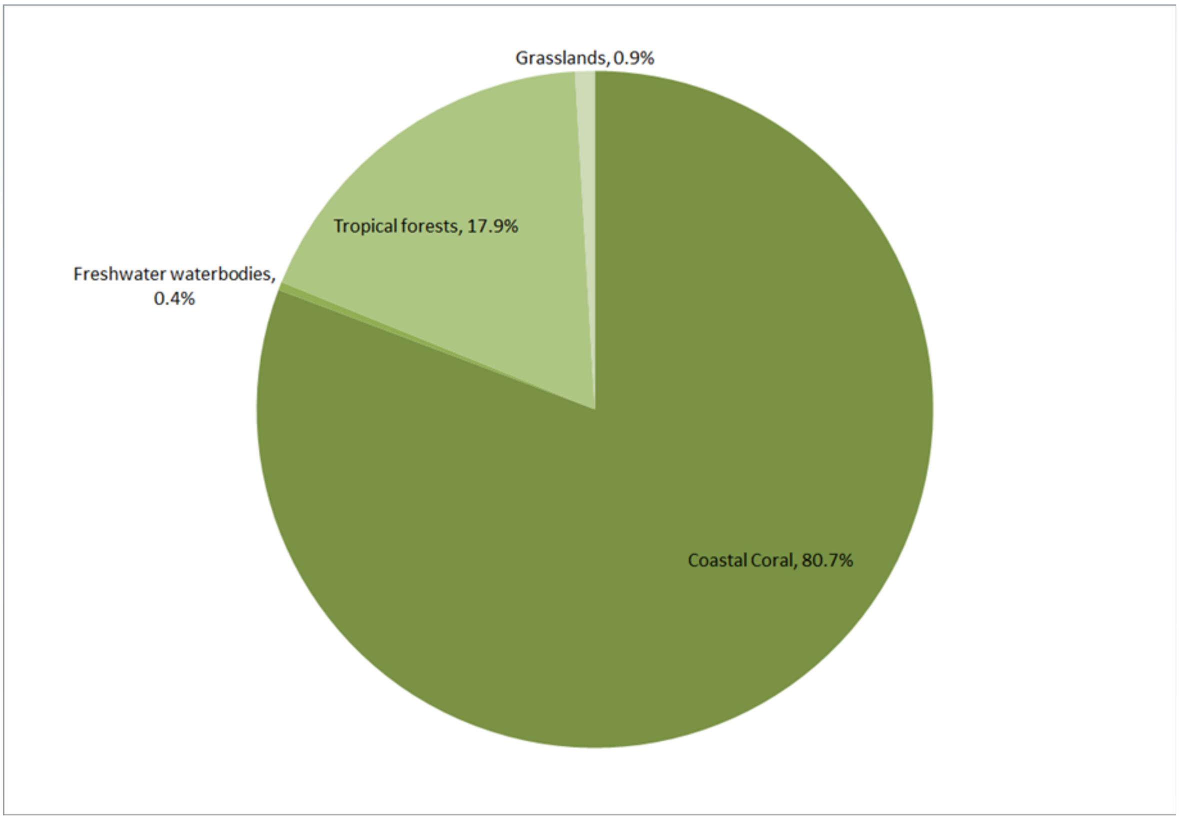

Figure 11. Ecosystem service value delivery by ecosystem type for Tanna (%)

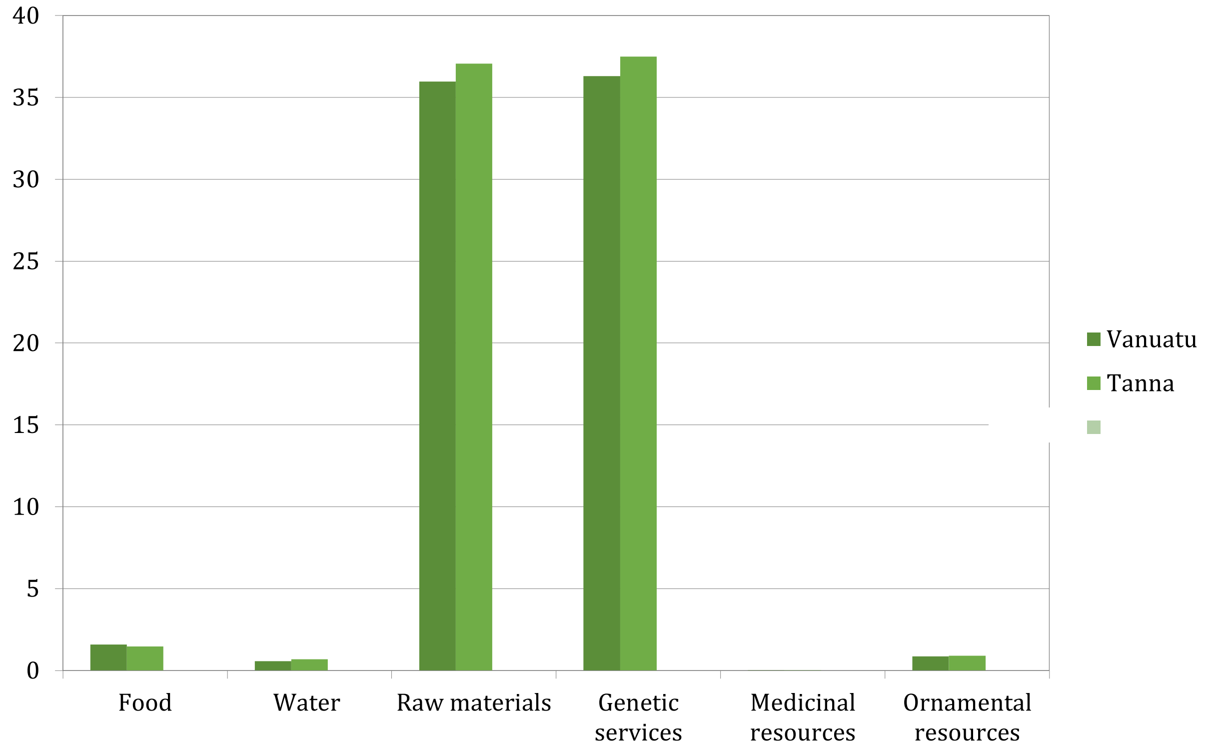

Figure 12. Comparison of contribution to ecosystem service benefits (%) for each ecosystem service for Vanuatu and Tanna

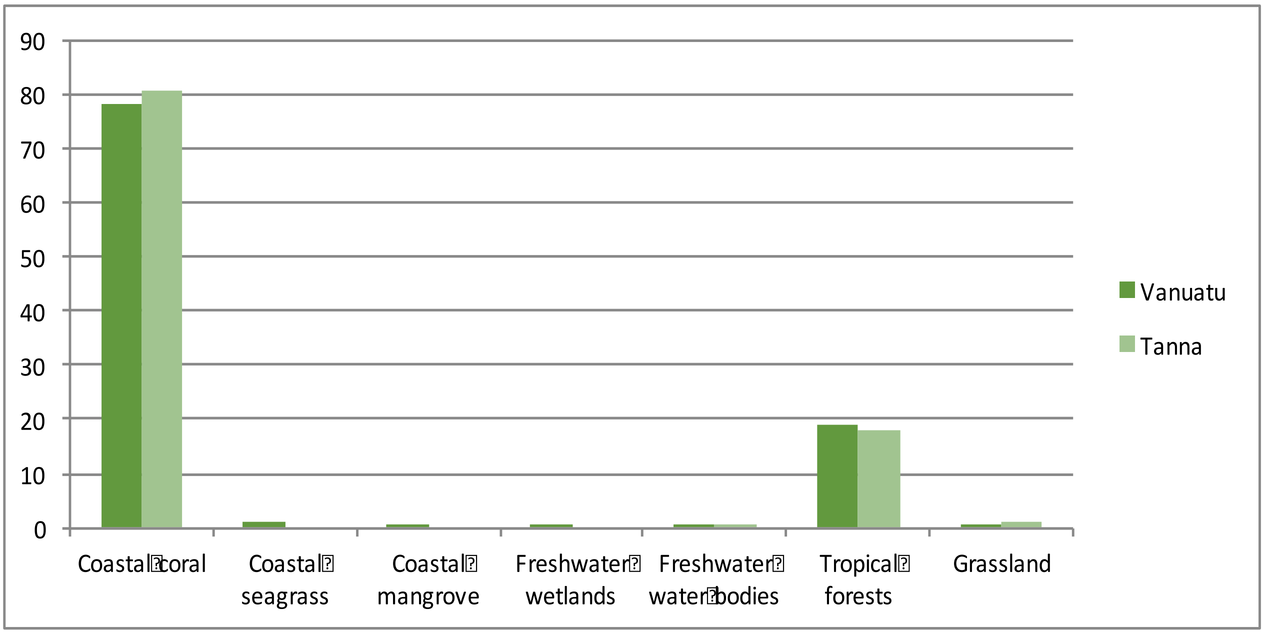

Figure 13. Comparison contribution to ecosystem service benefits (%) for ecosystem type for Vanuatu and Tanna

2.3 Ecosystem service benefits discussion

Valuation of ecosystem service benefit flows can provide information that assists planners and decision-makers in gaining a more comprehensive understanding of the benefits that arise from protecting and restoring ecosystems; the contribution the associated ecosystem services make to sustainable livelihoods of communities, as well as the national economy; the costs that can be avoided when inappropriate developments and unsustainable uses degrade ecosystem condition; and the trade-offs that need to be considered when designing policies and interventions.

However, ecosystem service monetised values should not be automatically considered fungible, as they cannot necessarily be exchanged for another form of capital, liquidated and 'cashed in', or substituted for an equivalent service. For example, it may not be possible or desirable to sell the purified water from a forest, and pollination services cannot be readily replaced by human capital. Also, the suite of ecosystem services examined here is not an exhaustive list of the ways in which people value these ecosystems, such as their role in the conservation of biodiversity, including species that have special cultural values, and in the context of Tanna, their *kastom* value.

It is also important to note that our landscape-level ecosystem service assessments did not include consideration of:

- *who* benefits and at what *scale* (spatially and temporally);
- are the benefits captured privately or socially (including customarily); and
- whether communities actually *realise* the ecosystem service benefits, either by exploiting provisioning services or by receiving a stream of payments in return for social benefits experienced elsewhere.

The benefit transfer approach we used here can be thought of as identifying *potential* benefits, but whether they are actually translated into *realised* benefits for a local community is another matter. For example, in the absence of a payment for ecosystem services schemes (also called a 'localised value capture mechanism'), the benefits from conservation management may not flow to the local community.

However, there are circumstances where one ecosystem type can be *transformed* into another type, which potentially provides a different basket of ecosystem service benefits. An ecosystem can be transformed through unsustainable human use, which results in its ecological degradation, causing it to lose resilience and irreversibly 'flip' into a different kind of system. An example of this unintended transformation is where a coral reef becomes so polluted from sediment and nutrients that the coral is taken over by macro-algae, which supports a very different biological community. The macro-algae based coastal ecosystem will still provide some ecosystem services but these will be of a different kind, quality, and quantity from the coral reef ecosystem it replaced.

Therefore, there are trade-offs between different kinds of ecosystems and their condition, which decision-makers need to consider. External pressures, such as climate change impacts and increased demand for food from population growth, will undoubtedly result in growing pressures on ecosystems, increased likelihood of degradation in their condition, and the likelihood of transformational changes.

Conversion of tropical forest to subsistence gardens is occurring at a significant rate on

Tanna; 7,315 hectares of forest were cleared for gardening between 2011 and 2016 across Tanna. At that same time, the island's population has increased from 29,731 to 32,934[7], with most census areas experiencing an increase. Despite the increase in the area of cultivated land, there has been a reduction in the cultivated area per person. These trends suggest that increasing demand for food is resulting in the over-use of current agricultural land, leading to encroachment on forests in the search for more fertile soil for subsistence gardening. While tropical forests provide important ecosystem services, the benefits from the subsistence farming system meets that most basic and daily-pressing of human needs: food supply. Reported reductions in agricultural yields[8], most likely from root crop diseases and falling soil fertility from insufficient fallow periods, coupled with population growth that increases the demand for food, will likely lead to further deforestation pressures. This trend has implications for the ongoing protection of tropical forests on Tanna and their associated ecosystem services (particularly regulatory services), on which the subsistence gardens are dependent.

For Tanna's local communities, protein is sourced locally from either subsistence gardening, fish caught on the fringing coral reefs, the consumption of livestock (poultry, pigs and some cattle) or livestock products. Census data suggest that a larger proportion of households in Tafea[9] compared to the national average earn *some* income from catching marine fish, which can include coral reef fish being sold to the tourist resorts. Stakeholder interviews conducted for this study indicated declining fish populations in some of the fringing coral reefs as the result of (over-)fishing. Currently the condition (determined by proxy measures) of the coastal coral in Tafea remains relatively sound, when compared across Vanuatu's provinces, with 38% considered 'intact', 51% considered 'modified' and 11% 'transformed'. However, pressure from increasing population numbers and tourist demand points to a trend of deteriorating reef condition, in the absence of improved management responses (Brewer et al., 2012). Experience elsewhere highlights that the risks of reductions in future yields may not become evident before thresholds have already been breached[10] and state change becomes inevitable and thus the current reef condition is not necessarily the final equilibrium outcome of present drivers. It is unclear therefore if current fishing effort is within thresholds—the "safe operating space for coral reefs" (Hughes, et al., 2017).

2.4 Gaps in information

The benefit transfer approach enables a 'first pass' valuation of the contribution of ecosystem services to the Vanuatu and Tanna economy and the resilience of local communities. A major limitation of this study, however, has been the lack of data based on studies and surveys conducted within Vanuatu and Tanna with respect to both (i) whether the identified ecosystem service benefits are

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[7] Estimate only, from Vanuatu Population Projections from 2015 UN Revision of World Population Prospects.

[8] A reduction in yields from subsistence gardens has been reported directly on several occasions by villagers during field trip visits on Tanna.

[9] Statistics for Tanna are not available in the census, however 88.5% of Tafea Province residents reside on Tanna, therefore these values for Tanna as a whole are assumed to hold for Tanna.

[10] As there is a non-linear relationship between fishing intensity and fish stocks; the threshold is undetected as greater fishing effort, particularly from poorer fishers who cannot source protein from elsewhere, is devoted to catching the remaining fish (Hughes et al. 2017).

applicable; and (ii) whether or not their potential benefit is realised in practice by the local community.

Our study also lacks the information needed to be able to match the actual condition of Vanuatu and Tanna ecosystems with either the potential or realised flow of benefits. As a general rule of thumb, the quality and quantity of the flow in ecosystem service benefits will decline with ecosystem condition. While Tanna's coral reef ecosystems were judged to be a consistent condition, there is a wide range in the condition of the island's tropical forests, which range from young secondary re-growth to old growth, primary forest. Again, site-specific survey data are needed in order for these relationships to be quantified.

We did not attempt to derive a monetised valuation of one of the most important benefits of tropical forest ecosystems, namely, their *kastom*, or traditional customary use. The *kastom* use of forests is largely of a non-extractive nature, including cultural practices and harvesting of some non-timber based products. The cloud forest on Tanna, in particular, has both high biodiversity and *kastom* values. While it is not essential to obtain monetised valuations for every category of ecosystem service, it would be worth investigating whether there are feasible approaches to valuing these to gain a more comprehensive set of ecosystem accounts.

Another limitation of our approach is that the valuations are based on a per unit area basis (hectares), which ignores the fact that there are significant ecosystem characteristics and services that are scale- (and linkage-) dependent. Such scale-dependent characteristics include the capacity of a large area of tropical forest to regulate micro-climatic conditions, providing a buffer against droughts and fire. However, we lack the information to identify threshold values in the area of tropical forests below which specific services begin to degrade or disappear.

3 Drivers, enablers and barriers

There is a range of governance-related factors that influence how communities can utilise ecosystem-based adaptation (EbA) approaches and access the benefits that flow from ecosystem services, and the extent to which ecosystems can be managed in ways that sustain their health and resilience. Government commitments, public policies, legislative frameworks, institutional structure and mandates, and cross-sector coordinating mechanisms can all help drive and enable the effective use of EbA or present barriers and disincentives.

More generally, the socio-economic context for a community is also relevant to the implementation of EbA solutions. For example, Andrade et al. (2011:4) listed 'meteorological hazards, poverty and unequal access to resources, food insecurity, trends in economic globalisation, conflict and incidence of disease', as relevant factors. Bourne et al. (2016:2) added to this list: 'the distribution and level of access to resources, such as wealth, municipal services, infrastructure, education and natural resources'. Such factors influence community vulnerability, even before climate change impacts are considered. Chong (2014:402) noted that resilience in Cambodia is severely impeded by factors such as 'spiralling and intertwined drivers of poverty, illegal resource extraction, poor law enforcement, corruption, lack of political will, and the historical dismantling of a society and its customs'.

Here we review some of the main governance-related factors that are likely to influence EbA implementation in Vanuatu and on Tanna.

3.1 National

The Vanuatu economy is highly reliant on tourism and offshore finance services. (It acts as a tax haven.) Economic opportunities are very limited, partly due to geography, with the population distributed across 83 islands. Consequently, the majority of the population living outside the capital (Port Vila) depend heavily on subsistence farming for their livelihood. The national government is highly dependent on foreign aid and it has few opportunities to raise revenue from mechanisms such as import tax. Tourism has been a growth sector in Vanuatu but visitor numbers are still down after Tropical Cyclone Pam (March 2015), which devastated Port Vila and the southern islands in particular. Cyclone Pam, one of the first category five cyclones to hit Vanuatu, demonstrated clearly the vulnerability of Vanuatu's aid- and tourism-dependent economy.

There have also been problems, both political and economic, with the main airport in Port Vila. For example, recently, Air New Zealand cancelled all flights to Port Vila, citing safety concerns regarding the condition of the tarmac. The Vanuatu government has obtained a large loan (USD 59.9 million) from the World Bank to upgrade the airport (World Bank 2015). Given the important role that tourism plays, both for the informal and formal sectors, strengthening the sector is seen as critical for economic growth. If poorly planned and managed, however, associated infrastructure and related development activities can cause environmental impacts, including adverse consequences for ecosystem service values. Tourism-driven growth will have to be managed appropriately to balance development opportunities against erosion of the natural capital stock on which the flow of vital ecosystem service benefits depends.

3.2 Tanna Island

The level of economic development on Tanna Island is relatively low, including for the tourist sector. Currently, most of the population on Tanna depend on subsistence farming for their livelihoods, although a small number of people are engaged in tourism services and service industry jobs, such as operating small shops or selling produce at roadside stalls. Remittances are also sent by relatives who have managed to find work opportunities in Port Vila or overseas. Rapid population growth is exerting pressure on the environment and alternative cash income opportunities could potentially reduce this pressure.

Yasur volcano is the main attraction for tourists on the island and trips to the volcano often consist of a day trip from Port Vila or a one-night stay on Tanna. The tourism industry comprises both formal and informal operators; for example, close to the Whitegrass Airport there are larger hotel developments, such as Evergreen and Whitegrass. In Lenakel there are several smaller bungalow type accommodation facilities, which cater for both local and international tourists. Until recently, the main roads were only really suitable for 4WD vehicles. However, through a concessional loan from a Chinese bank, many of the main roads have been upgraded and a road has been constructed south of Lenakel. The improved road infrastructure is expected to create new opportunities for tourism and also improve connectivity between villages and the main market place in Lenakel.

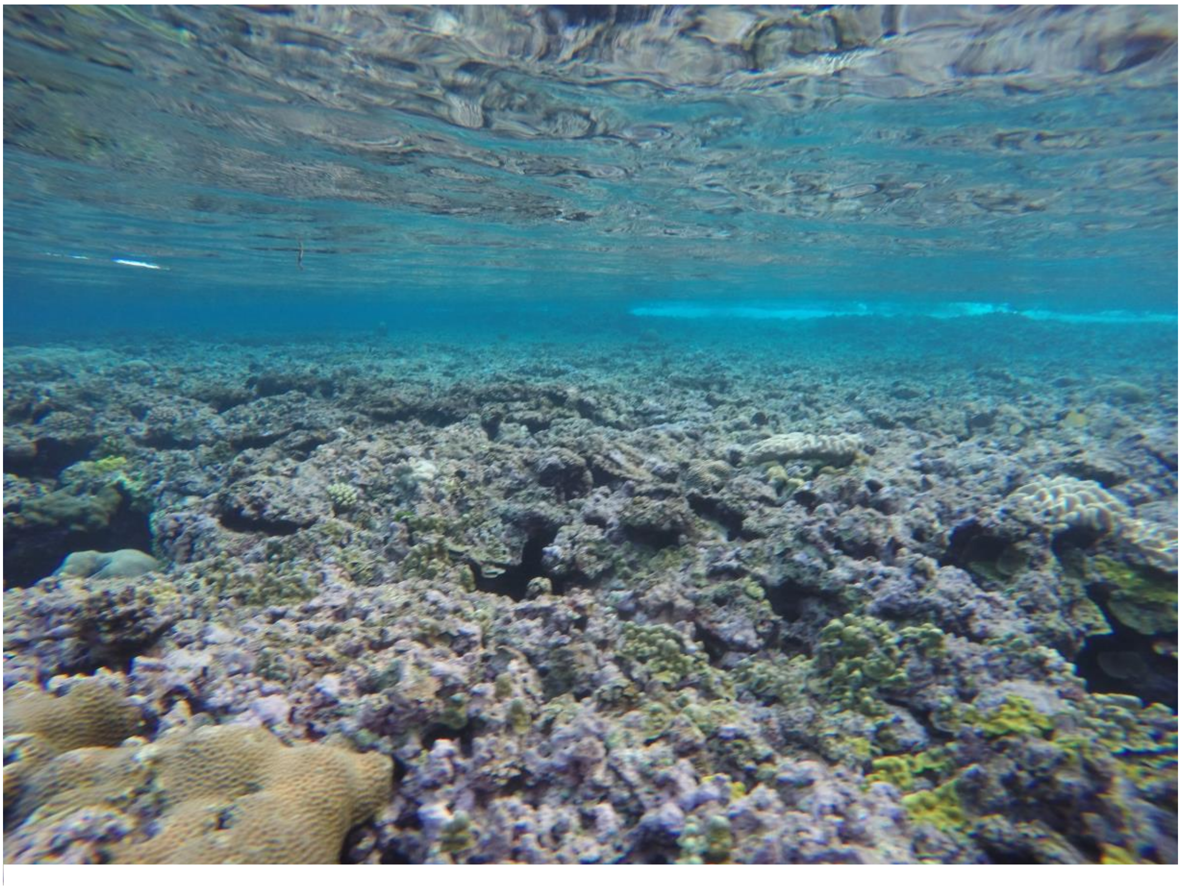
3.3 Social and cultural considerations

Tanna has not been isolated from the political and economic processes shaping the region. So-called 'blackbirding' was particularly rife on the island, with many Tannese men taken by force to Queensland to work on sugar cane plantations over a period of 40 years, from the mid-19th century to the early 20th century (Lindstrom 2011). With the Europeans arriving on the islands in the late 1800s, trading in sandalwood and labour demand for plantation work disrupted subsistence-based lifestyles, and brought three significant changes to communities: (i) an increase in the number of places where villagers could live and work; (ii) intensified cultural exchange and influence, including the use of the common language (Bislama) to communicate, missionary influence, and a decrease in inter-community barriers (social and linguistic) through interaction; and (iii) changes in livelihood practices and community organisation due to the introduction of steel tools, weapons and other goods, contributing to a shift away from subsistence living towards a cash crop economy (Bredford 1983:196-197).

A circular migration pattern still exists where many Tannese live in Port Vila for extended periods of time and then return to Tanna. The main reasons for Tannese moving to the capital are education, income opportunities and *kastom* ceremonies, such as weddings. Funerals are also held in Port Vila but in most cases (where finances allow) the deceased person is flown back to Tanna to be buried in the *kastom* ground. While most of the population still rely on subsistence farming, this is often complemented, particularly in the Lenakel area, with income from services such as small shops and restaurants, selling of livestock, and formal and informal tourism activities (renting cars, tour guides).

Most of the tribes on Tanna still follow *kastom* ceremonies (e.g. funerals and weddings) to a large extent (Lindstrom 1982; 2011). The traditional calendars are still used to signal particular activities such as planting of the yam and its harvest, and associated ceremonies. Circumcision ceremonies are still held for the boys. These ceremonies require boys to live away from their families in the bush for two months where they learn about *kastom* and mens' roles. Each tribe on Tanna consists of several *nakamals*, which are local meeting places, in particular for men. Men gather in the *nakamal* in the early afternoon to discuss issues in their community and seal the discussion with a cup of kava. Women and children are not allowed in the *nakamal* area once men begin drinking kava.

3.4 Political considerations



3.4.1 National

Vanuatu operates a dual governance system that allows both the Westminster system and the traditional governance system to co-exist. The Vanuatu Constitution provides authority for *Malvatumauri* (National Council of Chiefs) to represent the chiefs in Vanuatu. Each island has a Council of Chiefs, which represents the main tribes on each island. In Vanuatu, the country's colonial history is a major factor that continues to influence today's political governance. The two colonising powers, the British and the French, signed a convention in 1906 to establish a joint court to deal with land registration and ownership matters, heavily geared to benefit Europeans (Van Trease 1984). This led to the establishment of three governments: the French, the British and the Joint Government. The indigenous ni-Vanuatu[11] were not part of the government prior to independence.

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[11] ni-Vanuatu are "indigenous individuals or groups whose ownership claims are based on customary principles and practices" (Rodman, 1995, p. 65)

Vanuatu gained its independence in 1980 and land ownership, decentralisation of services, and citizenship were the biggest items for discussion for the newly independent nation. Now the majority of land ownership resides with the customary owners, the indigenous 'ni-Vanuatu'. Lindstrom (2008) notes that the birth of the term 'kastom' to signify a Melanesian-specific identity emerged in the late 1960s and early 1970s, when people began to speak about independence in colonial states. *Kastom* was first seen as backward when compared to Christianity, but after the 1960s the positive potential of *kastom* was recognised as a way to facilitate political unification. *Kastom* simultaneously refers to a Melanesian regional identity, whilst still remaining rooted in local community and particular traditions of place (Lindstrom, 2008). As discussed above in the section on tropical forest ecosystems, people in Vanuatu have always used forests and other ecosystems for their livelihoods; *kastom* in particular had traditionally regulated the way people use and access natural resources (Regenvanu et al. 1997).

3.4.2 Tanna Island

On Tanna, the Westminster system and the *Malvatumauri* are both represented. The headquarters of Tafea Provincial Government is located at Isangel on Tanna. The Nikoletan Council of Chiefs in turn represents *Malvatumauri* on Tanna Island. There are also area councils which were set up by the Tafea Provincial Government to increase communication and interaction between communities and the government. The Tafea Provincial Government undertook consultations during 2014 - 2015 to develop a 'Tafea Vision', which would inform development paths for the next 30 years. The plan is still under development.

In the traditional Tannese culture, leadership positions follow patriarchal lines and are passed down from father to son. However, there are also instances in which people who move into a new *nakamal*, following a *kastom* arrangement, can obtain a leadership role through negotiation (Lindstrom 2011). Three types of leaders exist in Tannese society: the *Iani* (Spokesperson for the tribe, who is also responsible for *Suatu* knowledge (conflict resolution, networks, relationships)), the *Iaramara* (the custodian of the tribe, responsible for overall community welfare and traditional knowledge (stories), and the *Tipunus* (expert for gardens, development and knowledge regarding flora, fauna and weather). The concept of community consensus is particularly important in Vanuatu and also on Tanna. Many conflicts and social relationships are negotiated by talking and by arriving at a consensus regarding preferred action and outcomes.

3.5 EbA policy and institutional considerations

3.5.1 Policies

Here we review national level policies in terms of how they reference EbA and ecosystem services using the categories of Pramova et al. (2012:397-398). These categories were used to identify the prevalence of ecosystem services in National Adaptation Plans of Action (NAPAs) under the UNFCCC process.

1. *Policies without ecosystem activities or ecosystem-based adaptation*. These policies do not include any activities that relate directly to ecosystems or climate change adaptation within the context of ecosystems.

2. *Policies with ecosystem activities for the environment*. These policies include activities, such as trying to reduce negative impacts on ecosystems through changes in land use, but do not explain that these services deliver a direct benefit to society, nor do they establish a link with climate change.
3. *Policies with ecosystem activities for social well-being*. These policies explicitly identify the kinds of benefits that ecosystem management provides to society.
4. *Policies with ecosystem activities for social adaptation*. These policies aim to explicitly secure healthy ecosystems whilst also reducing society's vulnerability to climate change and/or major other stressors.

The results of our analysis are summarised in Table 12. The majority of these policies do make clear linkages to ecosystems, either in terms of ecosystems and social well-being (category 3) and/or the linkages between ecosystems and social vulnerability reduction (category 4). The strongest links to ecosystems, EbA and climate change were found in policies addressing the coast, forests, sustainable development, and climate change and disaster risk reduction. This is not surprising, given that Vanuatu's population and policy context is strongly based on the environment and associated natural capital resources.

The policies addressing invasive species, environmental policy, biodiversity, and water all make explicit linkages to ecosystems and social well-being (Category 3). For example, Vanuatu National Environment Policy and Implementation Plan 2016 - 2030 (VNEPIP) does mention climate change as one of the factors but does not make explicit linkages between ecosystems and vulnerability reduction. The National Water Strategy mentions impacts such as sea-level rise and extreme storms, but again does not offer an explicit linkage between these impacts and the need to protect coastal ecosystems as a method for reducing social vulnerability.

Polices that make the fewest references to ecosystems or their role in reducing social vulnerability (Category 1) are those relating to gender, trade, energy and provincial responses

to climate change and disaster risk reduction. Given that the majority of livelihoods in rural areas of Vanuatu are still heavily reliant on the environment and ecosystem services, it would be beneficial to have climate change impacts and the role of ecosystems in climate change adaptation represented in policies relating to areas such as trade and energy. The Vanuatu Agricultural Policy 2015-2030 does mention climate change and disaster risk reduction, but it does not articulate how ecosystem-based approaches can help communities to adapt to climate change other than by increasing food security. Also, the gender equality policy draws few linkages between ecosystems and assisting women and men to adapt to climate change. This is an area in which stronger consideration of ecosystem-based adaptation could be valuable because access and usage rights to particular resources are typically still mandated through gender and *kastom* practices.

A caveat on this analysis is that many of the earlier policies (e.g. National Biodiversity Strategy 1999) were written before there was widespread public and policy awareness of climate change and EbA. The National Biodiversity Strategy is currently under review and this provided an opportunity to include relevant linkages between climate change, EbA, societal well-being and vulnerability reduction – linkages that are articulated in the more recent National Oceans Policy 2016 and the National Sustainable Development Plan 2017.

Table 13. National policies in Vanuatu that are potentially relevant to EbA and the extent to which they acknowledge the importance and relevance of climate change, the role of ecosystems and ecosystem-based adaptation

Policy[1]	Acknowledgement of climate change and EbA/ecosystems
National Integrated Coastal Management Framework 2010 (NICMF)	Category 4: The plan explicitly notes climate change adaptation, and the multiple societal benefits from maintaining healthy and intact ecosystems now and in the future
Vanuatu National Adaptation Programme of Action (NAPA) 2007	Category 4: Recognises the importance of ecosystems in helping communities to adapt; NAPA projects that use ecosystems as part of their adaptation strategy further emphasise these linkages
Vanuatu Climate Change and Disaster Risk Reduction Policy 2016-2030	Category 4: makes explicit linkages to ecosystem-based approaches and social adaptation
Draft National Climate Change Adaptation Strategy for Land-Based Resources (2012-2022)	Category 4: recognises the role of ecosystems and ecosystem services in enhancing societal well-being; also recognises links with climate change
Vanuatu Forest Policy 2013-2023	Category 4: makes a clear link between climate change and ecosystem services that enhance human well-being and reduce vulnerability; links made between forests and climate change mitigation
National Ocean Policy 2016	Category 4: clear links acknowledged between climate change and social vulnerability reduction, whilst also acknowledging traditional governance and knowledge; whole policy formulated around an ecosystem-based approach

National Sustainable Development Plan (NSDP) 2017	Category 4: Clear links between healthy ecosystems, social resilience and climate change
Vanuatu National Plan of Action on Food and Nutrition Security 2013-2015	Category 3: The policy identifies environmental conditions as important for generating societal well-being (in the context of nutrition and food security); climate change noted as an additional stressor.
National Invasive Species Strategy and Action Plan 2014-2020	Category 3: Recognises the important links between ecosystem services and biodiversity and human well-being; does not make a clear link between invasive species and impacts of climate change
Vanuatu National Biodiversity Conservation Strategy (1999, under current review)	Category 3: Does not link to climate change (not surprising given its early date of publication) but does acknowledge that ecosystems make important contributions to social well-being
Vanuatu National Environment Policy and Implementation Plan 2016-2030 (VNEPIP)	Category 3: Climate change is mentioned as one of the goals but there is there is no promotion of an explicit link under the goal for ecosystem-based approaches and reducing social vulnerability. There is, however, recognition that ecosystems need to be protected for social well-being.
National Water Strategy 2008-2018	Category 3: Notes the importance of protecting ecosystems for water management; recognises vulnerability to sea-level rise and extreme storms
Vanuatu National Land Use Planning Policy: Kastom, Equity and Sustainable Development	Category 2: Mentions climate change as an impact on land use planning, but does not address links to social vulnerability reduction or the use of ecosystems for adaptation
National Gender Equality Strategy 2015-2019	Category 1: Notes environment as an enabling factor for achieving gender strategies, but does not make other linkages, e.g. with climate change
Vanuatu Agricultural Policy 2015-2030	Category 1: Does not mention ecosystems in the document directly but has linkages to other policy directives which do acknowledge the role of ecosystems, e.g. Policy Directive 8 Environmental Protection and Sustainable Farming; Policy Directive 12.1 ‘Mainstream climate variability, climate change and disaster risk reduction using adaptation and mitigation strategies in all agriculture initiatives and developments”’ (includes 17 climate and disaster risk reduction-related actions)
National Energy Road Map 2016-2030	Category 1: Climate considered with respect to renewable energy issues, but ecosystems not otherwise mentioned
Vanuatu Trade Policy Framework 2012	Category 1: Recognises ecosystems (word not used) as the basis for livelihood activities; does not make explicit links to climate change except as a new challenge noted with respect to the Forest Policy
Provincial Disaster & Climate Response Plan (PDCRP) 2016	Category 1: Does mention climate change but does not make an explicit link between ecosystems and social vulnerability

	reduction; ecosystems are not mentioned explicitly except indirectly under ‘Food security and livelihoods’

[1] Policies are listed in descending order of categorisation (Category 4 to Category 1) using the categorisation proposed by Pramova et al. (2012:397-398).

3.5.2 *Institutions at the national level*

At the national level, Vanuatu has thirteen ministries, and as is typically the case, these ministries reflect the focus areas of the government currently in power and thus ministries and focus areas may change with a change of government (Table 13). A description of the departments, agencies and responsibilities of these ministries is provided in Appendix B.

Table 14. Vanuatu national level ministries (as of June 2017)

Prime Minister’s Office
Ministry of Agriculture, Livestock, Forestry, Fisheries and Biosecurity
Ministry for Climate Change Adaptation, Meteorology, Geo-Hazards, Environment, Energy and Disaster Management
Ministry of Education
Ministry of Finance
Ministry of Health
Ministry of Infrastructure and Public Works Utilities
Ministry of Internal Affairs
Ministry of Justice and Community Services
Ministry of Lands and Natural Resources
Ministry of Ni-Vanuatu Business
Ministry of Trade, Tourism, Commerce and Industry
Ministry of Youth and Sport

In terms of climate change adaptation and disaster risk governance, Vanuatu was one of the first countries in the Pacific to consolidate these two portfolios under one Ministry (Nalau et al. 2015). *The Ministry for Climate Change Adaptation, Meteorology, Geo-Hazards, Environment, Energy and Disaster Management* hosts the *National Advisory Board on Climate Change and Disaster Risk Reduction* (NAB) and the *Vanuatu Meteorological and Geo-hazards Department* (VMGD) with the aim of coordinating and managing all Vanuatu’s climate change adaptation and disaster risk reduction projects. The Vanuatu Climate Change and Disaster Risk Reduction Policy 2016-2030, aims to further strengthen a coordinated and participatory approach to adaptation and disaster risk reduction in the country.

3.5.3 Institutions at the Tanna Island level

In Vanuatu, provincial governments are established through the *Decentralization Act* under which they represent the national government. The Nikoletan Council of Chiefs, which represents the chiefs of Tanna, has been active on climate change-related issues, signing a declaration on climate change (http://nab.eightyoptions.com.au/press-release-nikoletan-chiefs-declaratio%E2%80%8Bn-climate-change-vanuatu). Tafea supports a sub-campus of the University of the South Pacific and a tourism vocational education centre, which focuses on training and capacity-building in the tourism sector. Two main provincial strategies driving tourism and skill development are the Tafea Tourism Development Plan and the Tafea Province Skills Plan 2015-2018 (Tafea Provincial Government n.d. and 2015). In addition, the Tafea Tourism Council provides information and advice regarding travel and accommodation in Tafea Province.

4 Climate change pressures

The climate projections used here are to the year 2070 and are largely drawn from two sources of data and information, along with some more recent scientific publications. The first source is a report by the Australia Bureau of Meteorology (BOM) and CSIRO (2014), which provides regional-scaled projections. The second source of data is GIS layers for Tanna from WorldClim, which map downscaled current climatic conditions and projected climate change at a 1-km spatial resolution. Future climate is examined here for Tanna using indices of temperature and rainfall, which are commonly applied in natural resource management. We have assumed a business-as-usual emissions scenario and thus future climate is based on the so-called 'Representative Concentration Pathway 8.5' (RCP 8.5) developed for the IPCC (2014). The aim of these climatic analyses is to provide the background information required to inform the risk assessment and business cases that are to be developed in the next phase of the PEBACC project.

4.1 Increasing climate change pressures – national level

4.1.1 Temperature

Annual mean temperatures and extremely high daily temperatures will continue to rise (*very high confidence*). Figure 16.8 in the BOM and CSIRO report (2014) shows the smoothed (20-year running average) multi-model mean anomaly in annual surface air temperature (SAT). By 2070, for the RCP8.5 scenario, the increase is 2.0°C, compared to the 1986–2005 average. The multi-model 5th percentile shows a 1.5°C increase in SAT, and the 95th percentile shows a 2.9 degree increase. However, this range in model results is *within* the 5–95th percentile range of the observed inter-annual variability for the 1986-2005 period. This indicates that actual 2070 surface air temperatures could be above or below the projected long-term averages due to inter-annual variability (Australian Bureau of Meteorology and CSIRO 2014).

The projected increase in maximum temperature, under RCP8.5, in 2070 is 2.1°C (with 1.4–3.1 degrees falling within the 5–95th percentile range of uncertainty). There is medium confidence regarding the magnitude of this change. The projected increase in minimum temperature, under RCP 8.5, in 2070 is 2.2°C (1.6–2.7°C falling within the 5–95th percentile range of uncertainty). There is medium confidence in the magnitude of this change (from Table 16.6, in Australian Bureau of Meteorology and CSIRO 2014).

The temperature on extremely hot days is projected to increase by about the same amount as the average temperature. The frequency of extremely hot days is also expected to increase. The temperature of the 1-in-20-year hot day is projected to increase by approximately 0.7°C by 2030, and by 3°C by 2090, for RCP8.5 (Australian Bureau of Meteorology and CSIRO 2014).

4.1.2 Precipitation

The year-to-year rainfall variability over Vanuatu is generally larger than the projected change in precipitation, except for the models with the largest projected change under the highest emission scenario by 2090. Consequently, the effect of climate change on average rainfall may not be obvious in the short- or medium-term due to natural variability. Dynamic downscaling of climate models (Australian Bureau of Meteorology and CSIRO 2011, Volume 1, Chapter 7) suggests that under a wet scenario, the rainfall increase may be enhanced on the southeast side of islands and reduced on the northwest side of islands in the May–October season.

There is no agreement as to the direction of change in the models and many models project little change in annual rainfall. This lowers confidence regarding the most likely direction of change in annual rainfall and makes the actual level of change difficult to determine. The 5–95th percentile range of projected values for precipitation change from CMIP5 climate models is large, e.g. for RCP8.5 (very high emissions) the 5–95th percentile range is -6 to +8% by 2030 and -15 to +34% by 2090 (Australian Bureau of Meteorology and CSIRO 2014).

The projected change in annual total rainfall, under RCP8.5, in 2070 is a 2% increase (with changes of -16% to +15% falling within the 5–95th percentile range of uncertainty). There is a low confidence surrounding the projected magnitude of change. The projected change in November - April (summer) rainfall, under RCP8.5, in 2070 is a 3% increase (with a -14% to +17% change falling within the 5–95th percentile range of uncertainty). Here again there is a low confidence in the magnitude of change. The projected change in May - October (winter) rainfall, under RCP8.5, in 2070 is a 1% decrease (with a -21% decrease to a 17% increase falling within the 5–95th percentile range of uncertainty). There is again low confidence in the magnitude of this change (From Table 16.6 in Australian Bureau of Meteorology and CSIRO 2014).

4.1.3 Frequency of extreme events including cyclones.

The frequency and intensity of extreme rainfall events is projected to increase. The current 1-in-20 year daily rainfall amount is projected to increase by approximately 8 mm by 2030 under RCP8.5. By 2090, it is projected to increase by approximately 40 mm under RCP 8.5. The majority of models project the current 1-in-20 year daily rainfall event will become, on average, a 1-in-5 year event under RCP8.5 by 2090.

For Vanuatu, the overall proportion of time spent in drought is expected to decrease slightly under RCP8.5 and stay approximately the same under all other scenarios. Under RCP8.5 the frequency of drought events in all categories is expected to decrease while the duration of drought events in all categories is expected to remain stable (Figure 16.10 in Australian Bureau of Meteorology and CSIRO 2014). The projection is for a decrease in cyclone formation frequency for the southwest Pacific basin (Australian Bureau of Meteorology and CSIRO 2014).

A recent study, however, using more updated modelling, concluded that there is likely to be in increase of 20-40% in the frequency of tropical cyclones during future (i.e. 2070-2100) climate El Niño events compared with present-climate El Niño events around the western Pacific island countries near the Date Line including Fiji, Vanuatu, Samoa and Marshall Islands. On the other hand, for future-climate La Niña events, tropical cyclone frequency is projected to decrease significantly in the southwest Pacific (20-60%) Chand et al. (2017). The authors concluded that these results indicate the importance of isolating ENSO (El Niño Southern Oscillation)-driven changes in tropical cyclone frequency for projections, particularly in the Pacific, where future projections of tropical cyclones may differ significantly between the different ENSO phases.

4.1.4 Ocean temperature, chemistry and sea level rise

The projected change in annual mean sea level, under RCP8.5, in 2070 is a 43 mm increase with 29 mm to 59 mm falling within the 5–95th percentile range of uncertainty. There is medium confidence in the magnitude of this change. The projected change in annual Aragonite saturation state (Ωar) is a decrease of -1.2, under RCP8.5, in 2070, (with a decrease of -1.4 and -0.9 falling within the 5–95th percentile range of uncertainty). There is medium confidence in the magnitude of change. Surface air temperatures in the Pacific are closely related to sea-surface temperatures (SST), so the projected changes in air temperature (see above) can be used as a guide to the expected changes in SST (from Table 16.6, in Australian Bureau of Meteorology and CSIRO 2014). Dynamic downscaling of climate models (Australian Bureau of Meteorology and CSIRO 2011, Volume 1, Chapter 7) suggests that temperature rises may be about 0.3°C greater over land than over the ocean in this area.

For coral reef ecosystems, a major impact of human-forced climate change is from an increase in heat stress that causes coral bleaching, which can be assessed using a metric of accumulated heat stress, the 'Degree Heating Week' (Heron et al. 2016). Coral communities typically take at least 15 to 25 years to recover from mass mortality events, such as destructive cyclones and mass bleaching events. If the frequency of mass mortality events increases to a point where the return time of mortality events is less than the time it takes to recover, the abundance of corals on reefs will decline (Baker et al. 2008). A recent UNESCO report (Heron et al. 2017) noted that global warming of 1.5°C above pre-industrial levels is recognised by many scientists to be a maximum for coral reefs to survive in the long term, although even this will result in significant reef loss and they cited multiple studies that support the conclusion that corals will not thrive again until atmospheric CO_2 has been reduced to 320-350 ppm from the current ~400 ppm. Furthermore, Heron and colleagues concluded that local management is no longer sufficient to ensure the future of coral reefs and that complementary national and global efforts are required as per the Paris Agreement to reduce greenhouse gas emissions and limit warming to the 1.5°C guardrail.

4.2 Climate change pressures - Tanna Level

Each pair of maps in Figures 14-18 compare current climate and the year 2070 for a selection of parameters that are commonly used in bioclimatic modelling and impact assessment: annual precipitation, annual mean daily temperature, mean monthly rainfall for summer months, mean monthly rainfall for winter months, and mean monthly daily maximum temperature for summer months (Hallgren et al. 2016).

The climate change analyses for Tanna were generated using data sourced from WorldClim Version 1.4, which comprises a set of global gridded climate data layers with a spatial resolution of about 1 km^2; the data are actually gridded at 30" of arc which corresponds to a distance of about 900 m at the equator. The 'current' data represent a mean for the period 1960-1990 (http://www.worldclim.org/current). The projected data for 2070 are downscaled CMIP5 projected data from http://www.worldclim.org/cmip5_30s.

The projected data used in this report are from the MIROC5 global climate model, which was chosen on the basis that it is the model that was ranked as best, representing the maximum consensus of all the CMIP5 models for the 'most likely' climate future for Vanuatu in 2070, under RCP8.5. The 'most likely' case is the climate future represented by the largest number of models, where 'most likely' is defined as the climate future that contains more than 1/3 of the total number of models, and which comprises at least 10% more models than any other climate future (Whetton et al. 2012; Clarke et al. 2011) (www.pacificclimatefutures.net).

The results of the climate change analysis for Tanna are presented in Figures 14-18. As to our knowledge, the error associated with the WorldClim data for Tanna has not yet been estimated, therefore the results need to be interpreted with caution. We stress that the Tanna climate analyses presented here are merely indicative of the kinds of within-island climatic gradients that are not apparent from global and regional scaled model outputs. They are helpful in illustrating the key point that significant climatic differences can be experienced even across a small island such as Tanna. These differences can be largely attributed to the influence of its mountain range in intercepting moisture-bearing weather systems and causing precipitation and temperature adiabatic lapse rate effects. Despite the data's limitations, from an impact and adaption perspective, some useful conclusions can be drawn.

There is sufficient within-island climatic variability to likely require different adaptation options to be considered between the north and the south of the Island, and between the coast and the uplands, with respect to promoting the resilience of subsistence farming and forest management, among other things. In addition to rising temperatures, the projections suggest an overall wetting trend largely associated with summer rainfall. However, while estimates of parameters based on long term mean monthly climate are helpful in identifying the relative strength and direction of change, monthly averages smooth over a lot of important information, such as that which characterises the behaviour of extremes that are usually responsible for impacts of concern to people and that are needed to answer questions, such as 'has the heaviest daily precipitation event in a year changed significantly over time?' or 'are droughts becoming longer or more intense?' (Zhang et al. 2011). While we have no insight at this point of time into changes in the frequency of such extreme events, anecdotal evidence from community consultations in the north of the island suggests that weather patterns are altering and people are experiencing more intense dry and wet seasons.

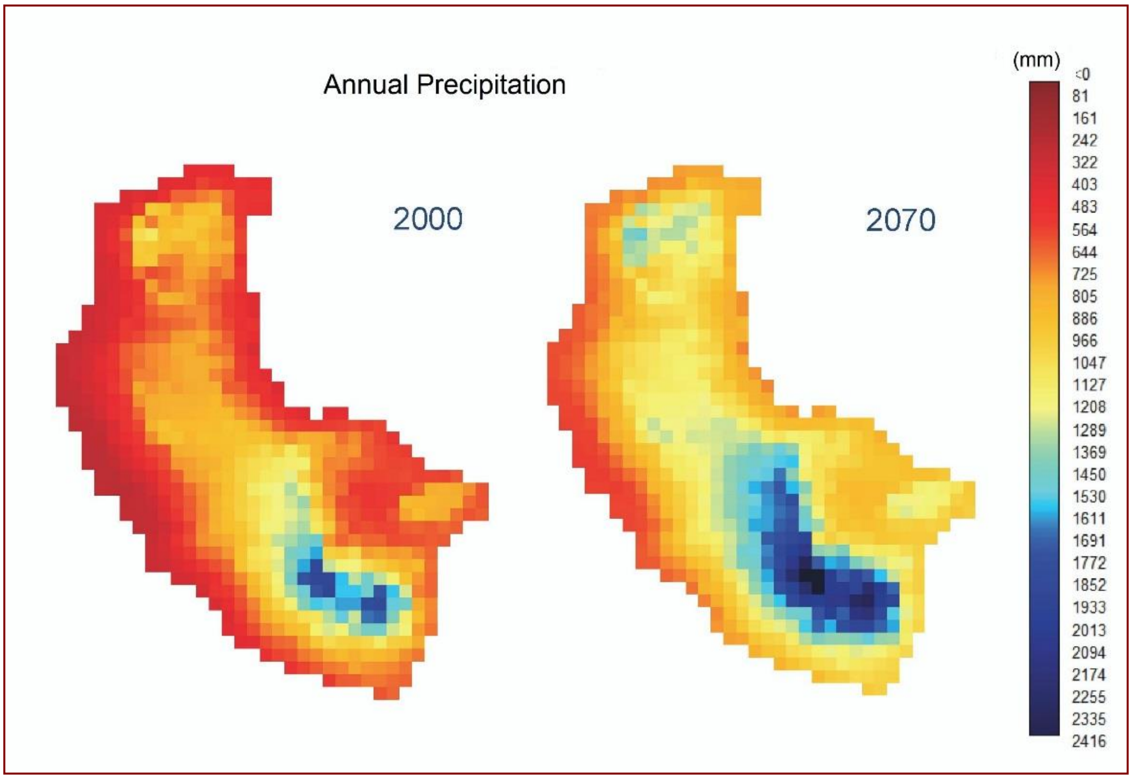

Figure 14. Annual precipitation (mm) for Tanna for current climate and projected for 2070.

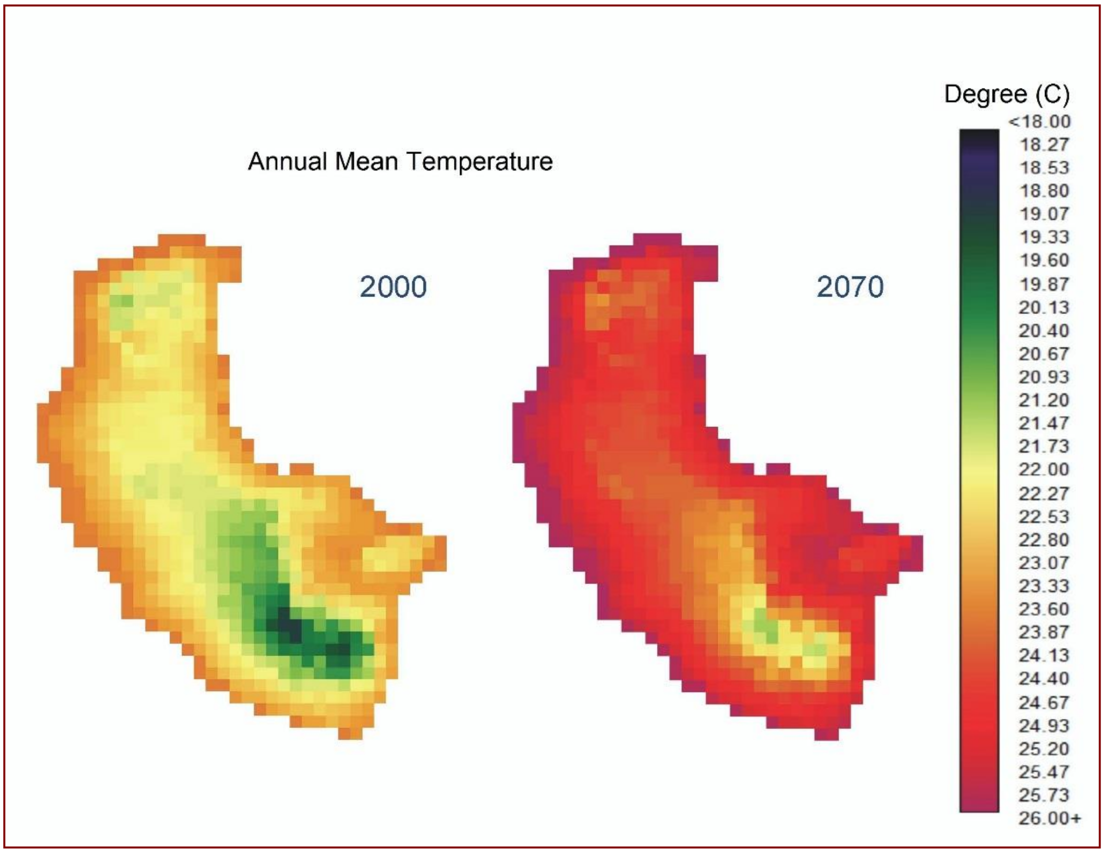

Figure 15. Annual mean daily temperature (degree Celsius) for Tanna for current climate and projected for 2070.

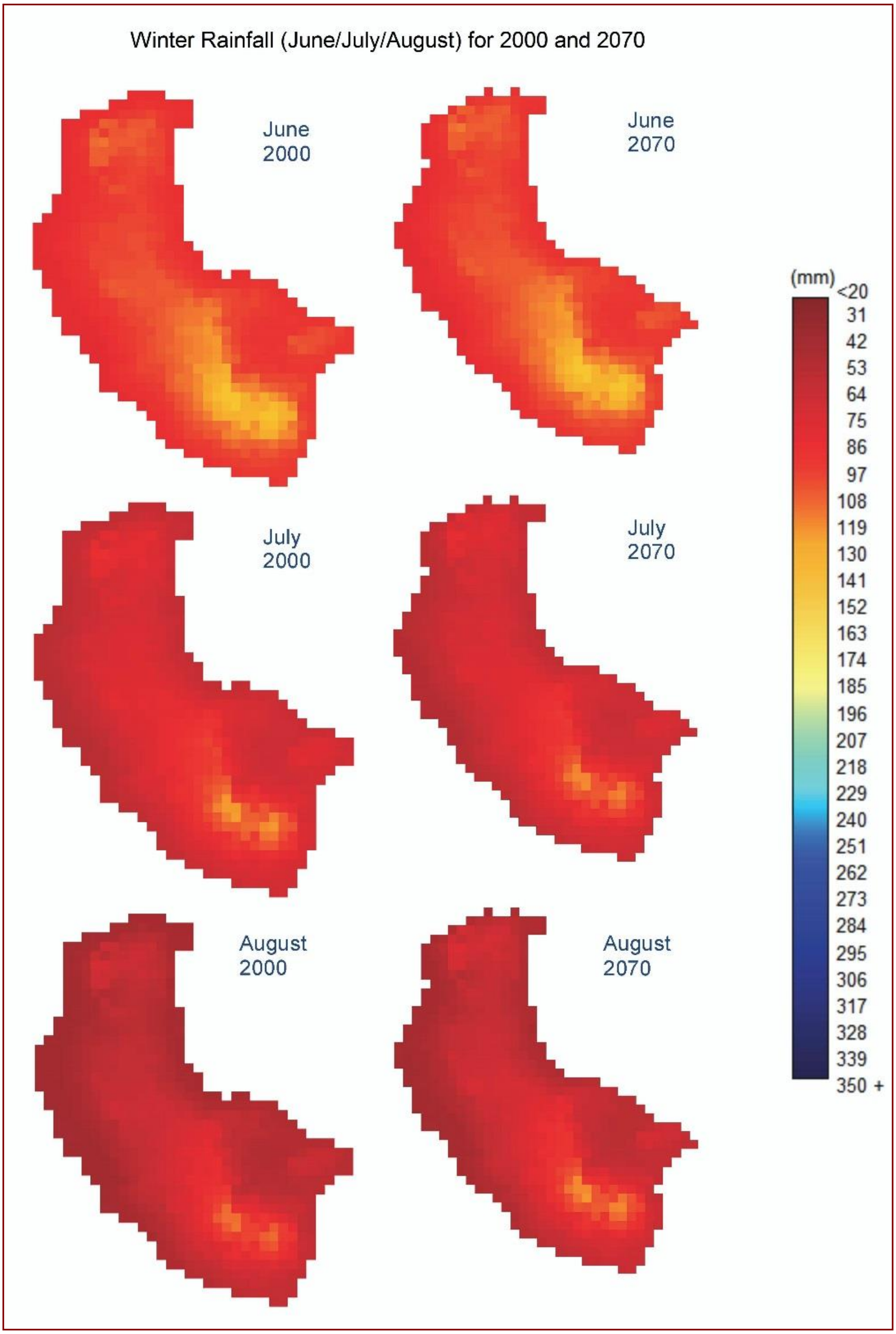

Figure 16. Mean monthly rainfall (mm) for Tanna for summer months for current climate and projected for 2070.

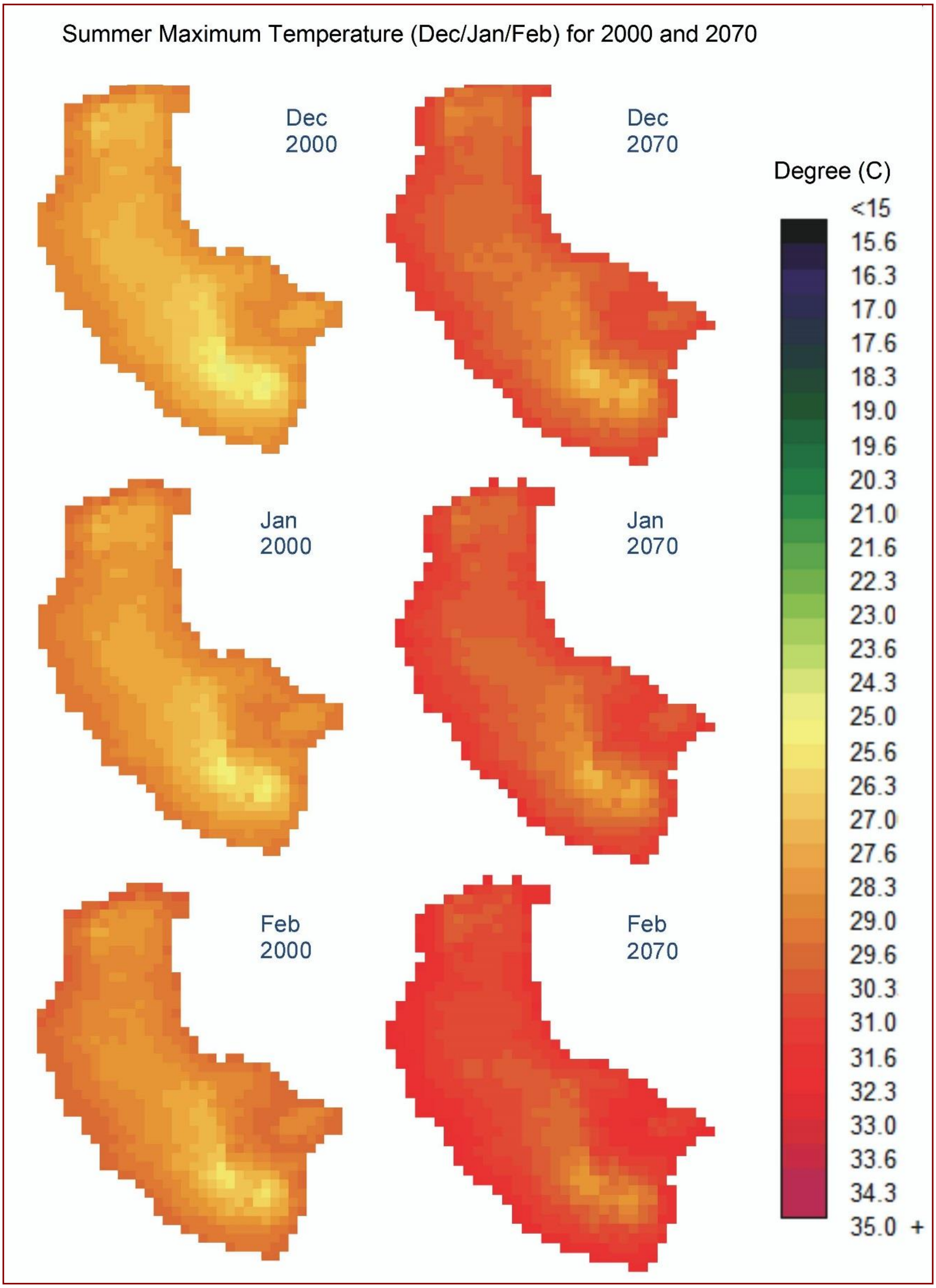

Figure 17. Mean monthly max. temperature for Tanna for summer months for current climate and projected for 2070

5 Environmental change pressures

While climate change presents serious threats to Vanuatu communities and ecosystems, it is important to consider these pressures in the context of ongoing environmental changes and the drivers of these changes. This section focuses on the environmental changes that can be observed on Tanna through vegetation mapping and brings this together with United Nations and Vanuatu Statistics Office data on current and projected populations. The section concludes with a discussion of the pressures and drivers on subsistence farming, which is leading to the conversion of tropical forest to subsistence farming; currently the main anthropogenic pressure on Tanna's ecosystems.

5.1 Population change

The Vanuatu National Statistics Office has been recording population data through a national census every decade between 1967 and the most recent mini census in 2016. Over this time, Vanuatu's population has grown from 77,710 to 272,459 (Table 15). We were able to obtain data on Tanna's population from the 1999, 2009 and 2016 Census (Table 15[12]).

A major driver of environmental change is population growth as this leads to increasing demand for food, water, other resources and services, which can place unsustainable pressures on ecosystems. The projected increases in Vanuatu and Tanna's population are given in Table 15, which shows that Tanna's population is estimated to more than double by 2070.

5.2 Land use change

The current dominant subsistence farming system in Vanuatu and Tanna operates at the local community (tribal) level and comprises three main components: (a) shifting cultivation mainly of taro but also peanuts, kava, yam and sweet potato; (b) perennial plantation cultivated system and cash crops; and (c) aboriculture including secondary regrowth forest, planted trees and *kastom* trees. While built on traditional gardening practices that used 'shifting cultivation', it is now more accurately described as a hybrid farming system (see Blanco et al. 2013; and Figure 21).

It is well documented (Hoffman 2013) that a major threat to the sustainability of subsistence farming is decreasing fallow periods due to increased food demand from high population densities and shortage of arable land. As discussed by Hoffman, fallow can only sustain soil fertility if the land is given sufficient time to add organic matter and soil nutrients. Traditionally, subsistence gardening lands were allowed to fallow for 5-7 years to improve degraded soil. However, increasing population and demand for cash crops over the last two decades has resulted in the fallow period being reduced to 2-3 years and in some cases to only a year.

Table 15: Current and projected population for Vanuatu and Tanna

Year	1967*	1979*	1989*	1999*	2009*	2016*	2030^	2050^	2070^
Vanuatu	77,710	111,251	142,419	186,678	234,023	272,459	354,337	475,657	580,185
Tanna				25,755	28,734	32,280			78,778

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[12] Sources: * Vanuatu National Census; ^medium estimate of 1.4% annual growth rate from UN World Population Prospects (2015).

Figure 19 maps the ecosystems that have been converted to subsistence gardening between 2011 and 2016. This map was produced by comparing the 2011 ecosystem map for Tanna (Schwetter 2012) with the 2016 map (Figure 8). Hatched areas on the map were a land cover type other than subsistence farming in 2016. Non-hatched areas were subsistence farming in 2016. The areas mapped as 'grassland' and 'tropical' forest were converted to subsistence farming between 2011 and 2016. Table 16 shows the area of ecosystems that have been replaced by subsistence gardening between 2011 and 2016.

When comparing the 2011 and 2016 ecosystem maps, it needs to be recognised that there may be some discrepancies between the methodologies used, as we were unable to source the methods used in Schwetter (2012) as only the GIS data layer was available from the Vanuatu Forestry Department. While there may be some discrepancies between methods, the two maps provide the only available evidence of overall trends in land use and land cover change. In addition, maps represent just two points in time for what is in reality a dynamic landscape.

Table 16. Ecosystems converted to subsistence gardening between 2011 and 2016

Ecosystem Type	Area km^2
Tropical Forest - Low	44.03
Tropical Forest - Thicket	21.17
Tropical Forest - Medium	7.75
Grassland	5.33
Built-up	1.12
Plantation cropping	0.99
Tropical Forest - Shrubs	0.21
Bare soil	0.15

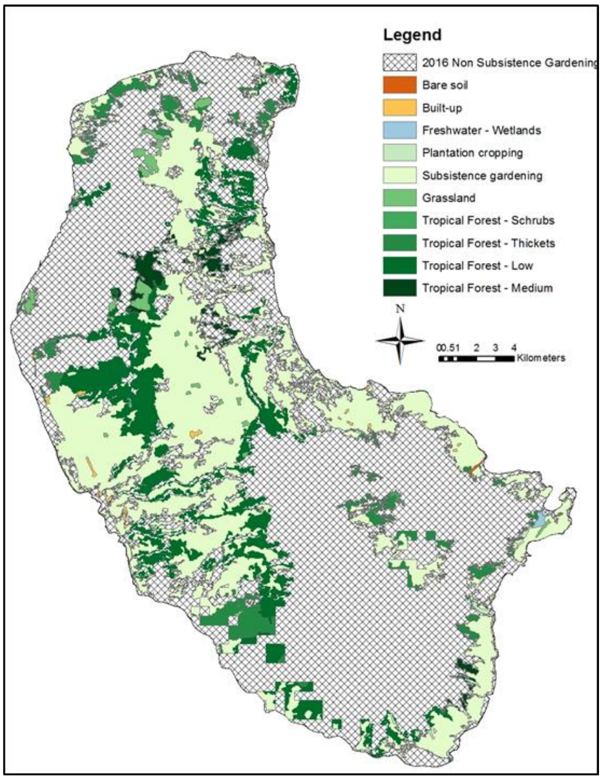


Figure 18. Loss of ecosystems from expansion of subsistence farming

For Tanna, the area of subsistence garden per person is stable between 2011 and 2016 at 0.74 ha^{-1} per person in 2011 and 0.72 ha^{-1} per person in 2016. If this relationship continues, the total area of subsistence garden required to service the medium range projection of Tanna's population in 2070 will be 56,900 ha^{-1} which is more than the total area of Tanna at approximately 56,000 ha^{-1}.

Table 17. Projecting Tanna Island land use change

	2011	2016	2070
Subsistence gardening ha^{-1}	21,900	23,400	56,900
Population	29,731	32,280	78,778
ha^{-1} per person	0.74	0.72	0.72

5.3 Understanding the drivers of land use change

We mapped the pressures on the sustainability of Tanna's subsistence farming systems using four indicators.

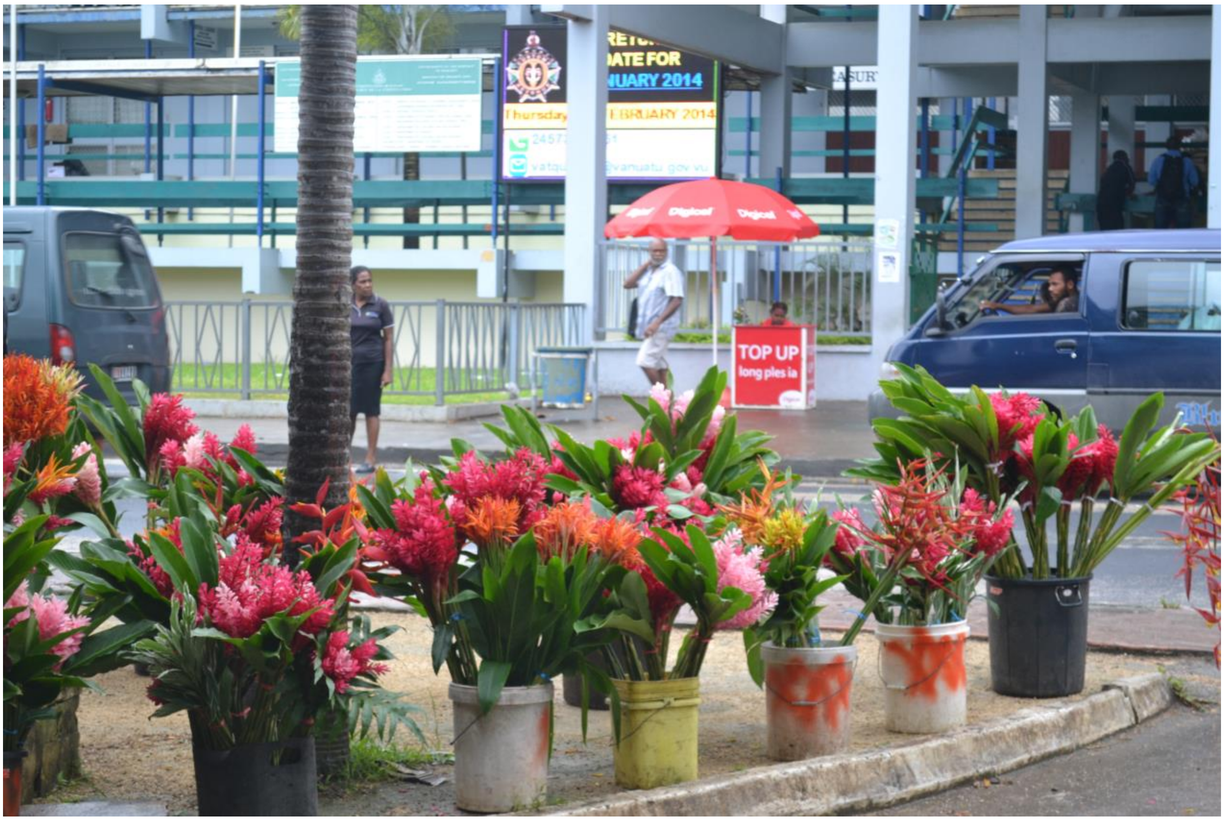
B. *Population growth* – this indicator shows the average annual population change between 1999 and 2009 where Low indicates a population decrease, Medium < 1.3%, High 1.3 - 3.5% and Extreme >3.5% with a maximum value of 13%.

C. *Declining productivity* - shows the average annual rate of subsistence gardening area growth between 2011 and 2016 with Low indicating no growth, Medium >6%, High 6 - 30% and Extreme >30%.

D. *Production pressure* – this is the area of subsistence garden (m^2) per person with Low > 10,861m^2 per person, Medium 6,792 - 10,861 m^2 per person, High 3,984 - 6,792 m^2 per person and Extreme <3,984 m^2 per person.

E. *Climate pressure* - this shows the land that retains a thermal regime suitable for the commercial production of taro by 2070.

We also generated a heat map showing an integrated index (A) of pressure on the sustainability of the subsistence farming system being the arithmetic sum of indicators (B)-(E), masked to exclude areas that are not currently subsistence farming (Figure 20).



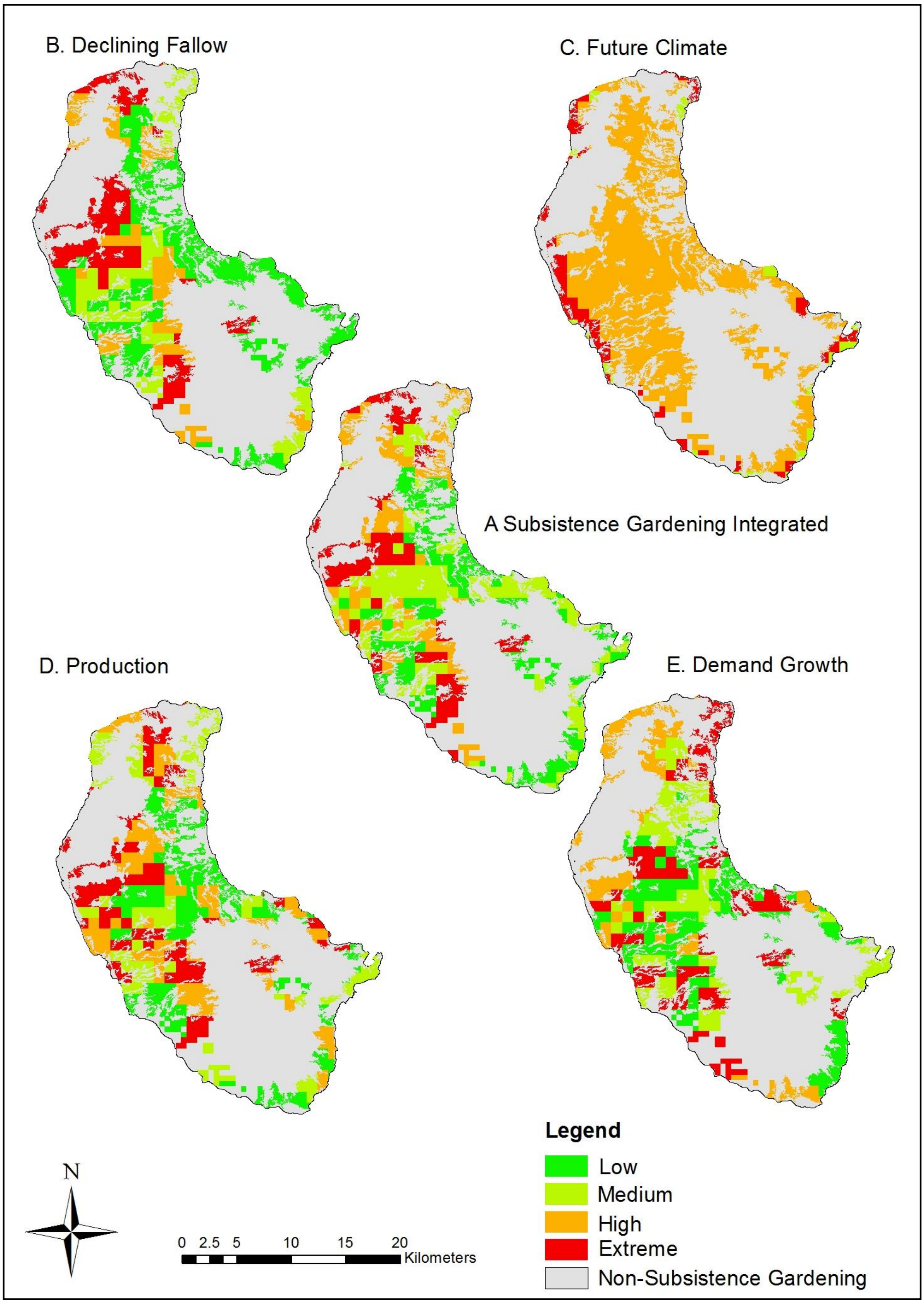


Figure 19. Four indicators of pressure on the sustainability of Tanna's subsistence farming systems in four categories of pressure

The pressure on Tanna's subsistence farming systems from population increase is accentuated by the relatively small area of high quality arable land.

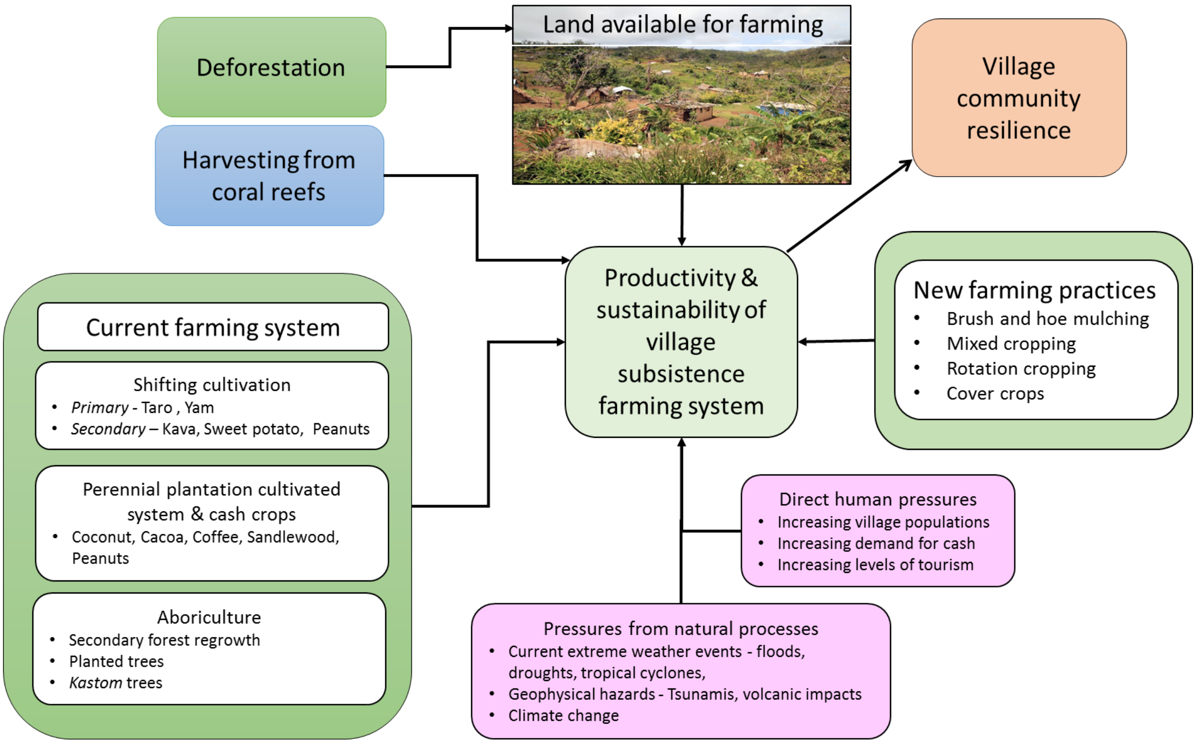


Figure 20. Influence diagram for the subsistence farming socio-ecological system in Tanna (adapted from Blanco et al. 2013)

The available data show that the population increased from 25,755 in 1999 to 32,280 in 2016. There is also empirical evidence that there has been an increase in the area of cropped versus fallow land (i.e. natural forest regrowth), pointing to a marked decrease in fallow times compared with traditional practices.

Information gained from the community interviews highlighted the fact that some communities were experiencing declining taro production, a decrease in soil fertility, competition between growing food for cash and subsistence food, along with increasing cultivation intensification and a loss of tree cover.

Some communities also reported clearing of previously unused natural forest for taro production as a response to increasing food demand and declining soil productivity. This appears to be a systemic problem across the island, though the east central coast and southern end of island are under relatively less pressure compared to the north, west and uplands.

Projected climate change impacts are of concern because rising temperatures will push the optimal thermal envelope for commercial production of taro to higher elevations to the south – areas currently under *kastom* forest.

The northern end of the island is currently drier and the future climate may lead to increased seasonal droughting, even if annual rainfall increases.

As suggested in Figure 20, food production for a community can be increased by expanding the land available for farming, but this will come at the expense of ecosystem types, such as *kastom* forest, or result in over-harvesting of fish from the fringing coral reef ecosystems. To avoid such impacts on forest and reef ecosystems, modified farming systems and practices are needed that can improve soil fertility and sustain high levels of food production. New farming practices, such as mulching or rotation cropping using nitrogen fixing crops, could be introduced to increase the productivity of existing areas of farmed land. Vanuatu subsistence farming must also be resilient to current and future climate-related risks.

5.4 Other threats to ecosystem services

In addition to the major threat to ecosystem integrity posed by encroachment from subsistence farming, the ongoing flow of ecosystem services is threatened by an array of climate change and development threats (Table 18). These threats were identified based on consultations with communities on Tanna and from the climate change analysis in Chapter 4.

Table 18. Threats to Tanna Ecosystem Services

	Climate change threats							**Development threats**					
	Temperature	**Sea temperature**	**Sea Level**	**Rainfall Variability**	**Rainfall total**	**Ocean Acidification**	**Tropical cyclone**	**Population pressure**	**Pollution pressure**	**Tourism pressure**	**Kastom decline**	**Invasive species**	**Western development**
Coastal													
Provisioning		x	x		x	x	x	x	x	x	x		x
Habitat		x	x		x	x	x	x	x	x	x		x
Eco-tourism & local recreation							x	x	x	x	x		x
Kastom		x	x		x	x	x	x	x	x	x		x
Tropical forest													
Provisioning	x			x	x		x	x		x	x	x	x
Habitat	x			x	x		x	x		x	x	x	x
Eco-tourism & local recreation							x	x		x	x		x
Kastom	x			x	x		x	x		x	x		x

Table 19. Indicators for Ecosystem-based Adaptation

EBA Strategies	Indicators
Establishment of diverse agricultural systems, where using indigenous knowledge of specific crop and livestock varieties, maintaining genetic diversity of crops and livestock, and conserving diverse agricultural landscapes secures food provision in changing local climatic conditions	• Area of farming land per person • Household income diversity • Community poverty levels • Food sources • Nutrition/malnutrition rates • Forest conversion and clearing rates
Establishing and effectively managing protected area systems to ensure the continued delivery of ecosystem services that increase resilience to climate change	• Area of land or sea under conservation agreements • Coral reef condition • Tropical forest condition • Reforestation activities • Invasive species management activities • Forest clearing rates
Sustainable water management where river basins, aquifers, flood plains and their associated vegetation provide water storage and flood regulation	• Water use efficiency • River basin flows • Water quality • Environmental health • Number of wells
Disaster-risk reduction where restoration of coastal habitats such as mangroves can be a particularly effective measure against storm-surges and coastal erosion	• Damage costs • Shoreline position • Exposure of assets and infrastructure
Sustainable management of grasslands and rangelands to enhance pastoral livelihoods	• Proportion of invasive plant species • Invasive species management activities • Livestock rates – herd densities

5.5 Options and strategies for restoring ecosystem health

Ecosystem-based Adaptation is an emerging field which has developed from the Ecosystem-based Approach developed under the Convention on Biological Diversity (CBD 2000).

The report of the 2nd Ad Hoc Technical Advisory group on Biodiversity and Climate Change (CBD 2009) noted that ecosystem-based adaptation is 'the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people to adapt to the adverse effects of climate change; uses the range of opportunities for the sustainable management, conservation, and restoration of ecosystems to provide services that enable people to adapt to the impacts of climate change; aims to maintain and increase the resilience and reduce the vulnerability of ecosystems and people in the face of the adverse effects of climate change; and is most appropriately integrated into broader adaptation and development strategies.'

The report lists means of implementing ecosystem-based adaptation, which we used to identify potential indicators in Table 19.

Monitoring and evaluation Indicators support the effective implementation of EbA (Rizvi et al. 2012).

Table 19 provides a candidate set of ecosystem-based adaptation indicators relevant for EbA implementation strategies. Further research is needed, however to identify the optimum set of indicators for monitoring specific EbA projects on Tanna.

6 Risk assessment

6.1 Introduction & approach

In the preceding sections we assessed the principle ecosystems of Vanuatu, their condition, the associated ecosystem service benefits that flow to the local communities who make use of them for their sustainable livelihoods and which contribute to their resilience, and the main threats to ecosystem condition and community resilience from anthropogenic and environmental pressures. We identified key factors that illustrate how local communities interact with their ecosystems and reviewed governance-related factors. Here we bring together these threads to provide a more holistic understanding of the risks to the condition of two key ecosystems, the ecosystem services they provide and in turn community resilience. These risk assessments inform the development of EbA options for Tanna, which are documented in a separate PEPACC report.

In the following sections we present risk assessments for Tanna's two dominant ecosystem types – *Fringing Coral Reefs* and *Kastom Forest*s – in terms of risks to community resilience as the result of the loss of ecosystem services due to environmental degradation. In addition to the impacts on ecosystem condition from over-use, we also consider future climate change impacts.

For our risk assessment, we followed the first four components of the risk assessment procedure as defined by the ISO31000-2009 international standard on risk management: (1) risk context; (2) risk identification; (3) risk analysis; and (4) risk evaluation. The fifth component of this ISO standard – risk treatment – is the focus of a separate PEBACC report on EbA options for Tanna.

6.1.1 Risk context

Human pressures, and other threats, including climate change, can degrade the condition of ecosystems, reducing the quantity and quality of ecosystem services, and presenting risks to the resilience of those local communities that depend upon a sustainable flow of these benefits. Pressure and threats influence ecosystem functioning through various interactions and pathways that can be most usefully understood through drawing socio-ecological system diagrams, based upon our conceptual frameworks illustrated in Figures 2, 3 and 4. Here, each socio-ecological system is represented as an influence diagram, whereby boxes represent key components of the system, such as a human institution or decision-making process, a biophysical object, or a flow of information, energy of resources of some kind. The arrows joining the boxes indicate the direction of influence between the system components.

6.1.2 Risk identification

For each of the two socio-ecological systems, we identify and map the risks using indicators, highlight major impacts, and consider community vulnerabilities. The results are summarised in a table comprising five columns which detail:

- the specified hazard;
- the indicator used to measure the hazard;
- the metric used to map the indicator;
- impacts to the condition of the ecosystem arising if the hazard is not addressed;
- factors that influence the community's vulnerability to the loss of ecosystem services, considered at a community level in terms of sensitivity and coping capacity, i.e. how dependent is the community on the ecosystem service

benefits and what alternative sources or substitutes are readily available; and
- how the socio-ecological system is geographically exposed to the hazard. Exposure can also be considered in the temporal dimension, including seasonal changes and projections of future climatic conditions.

6.1.3 Risk analysis

For each of the two ecosystems we map four risk indicators. The spatial unit of analysis varied, depending on the risk and the indicator being either (i) raster grids; (ii) water catchments derived from a 30 m resolution digital elevation model; (iii) census enumeration areas, which are closely aligned with currently available data on community boundaries; or (iv) coastal units defined by geomorphological type.

Each indicator is mapped using four categories of risk: Low – Medium – High – Extreme. The thresholds for each of the four categories were defined by quantiles of the indicators' values. It is also important to note that the ratings for each category are relative to areas on Tanna and cannot be used for comparison with other locations in Vanuatu.

We also combine for each ecosystem the four risk indicators using a GIS map calculator to produce a 'heat map' showing areas where there is a geographic concentration of risks. These integrated maps, however, can mask as much as they reveal and there is often more diagnostic value in examining each risk separately in order to identity the most appropriate adaptation options.

Further details on the methods used to map the indicators are provided in Appendix C.

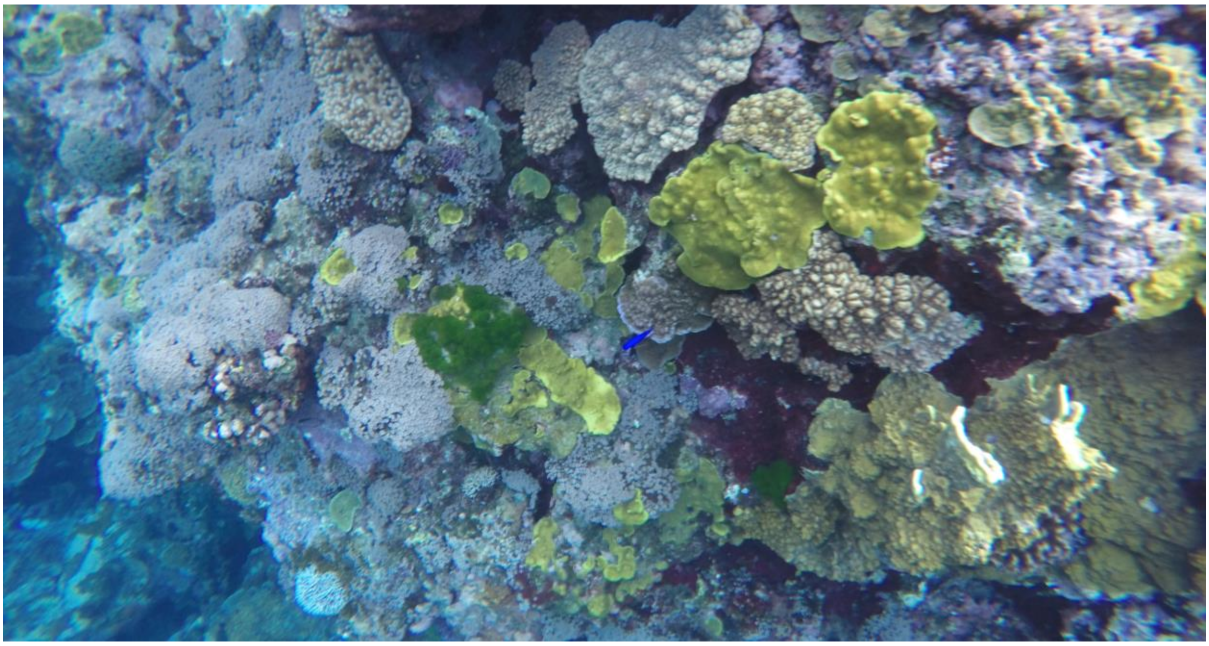
6.1.4 Risk evaluation

We then provide for each socio-ecological system a brief discussion of the risks and the locations where EBA interventions are most warranted on the basis of these analyses.

6.2 Coral reef socio-ecological system

6.2.1 Risk context

Coral reefs are a highly studied ecosystem and a great deal is known about their ecological functioning and the impacts of climate change, along with direct human pressures, which are



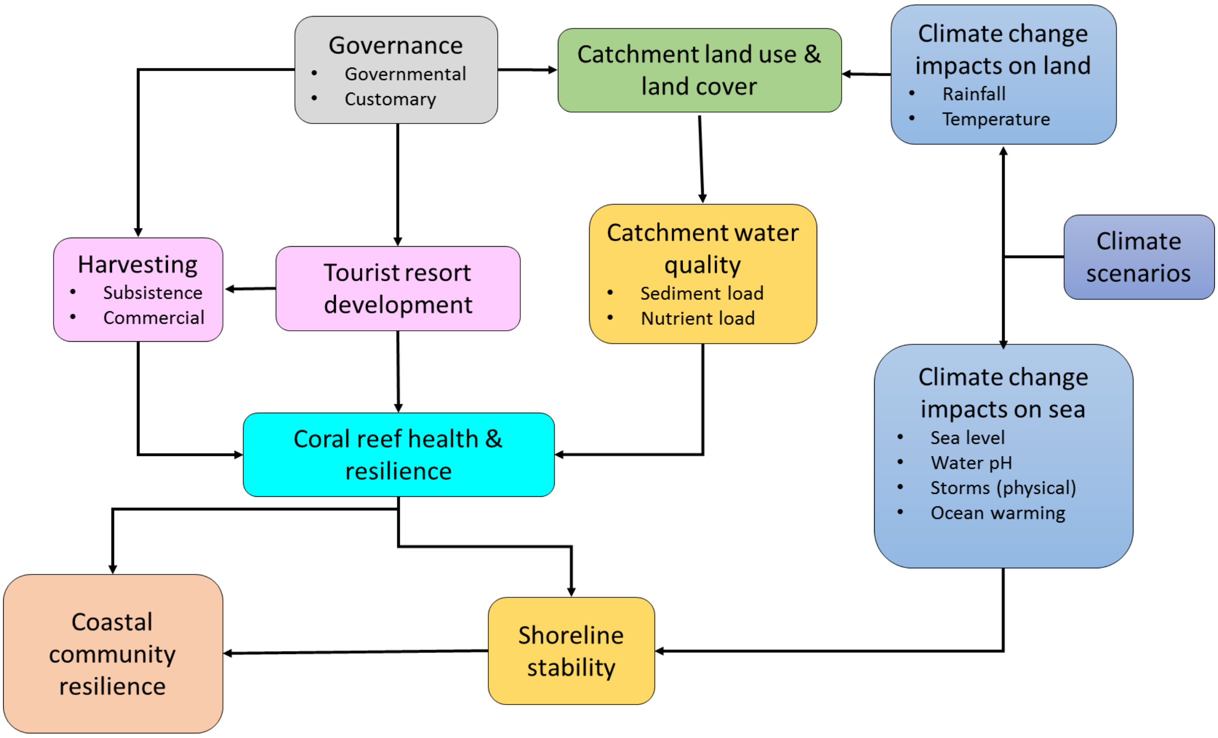
represented in the socio-ecological system diagram in Figure 23.

Direct human impacts include over-harvesting of fish, which as well as depleting fish stocks has the flow-on impact of reducing herbivory, resulting in an increase in algal growth.

Indirect human impacts include poor land use management in coastal flowing catchments, resulting in an increase in sediment and nutrient loads into stream and groundwater discharge: the sediment can smother the coral, while the nutrients can increase algal growth relative to coral.

Both cause turbidity, shutting out sunlight. Tourist resort development in the coastal zone can involve multiple direct and indirect impacts on a reef, including direct physical damage, increase in nutrient loads in water discharge, and increasing demand for fish harvesting. Carbon pollution and climate change impacts include rising sea levels, increasing temperature extremes, and ocean acidification. Reef management can be implemented through both formal government policy and customary natural resource management.

Figure 21. Factors, influences and pressures on the coral reef socio-ecological system for Tanna



6.2.2 Risk identification

Table 20. Summary of risk identification for the fringing coral reef socio-ecological system for Tanna

Hazard	**Hazard Indicator**	**Mapping**	**Impacts**	**Vulnerability**	**Exposure**
Increase in nutrients entering coastal waters	Water quality from adjacent catchment	Catchment population density	Algal blooms and reduced sunlight Crown of thorns starfish population increases and kills coral	Lack of alternative food supply Competition from growing tourist demand for seafood Lack of formal or breakdown in customary reef management Customary connection to place	Location of reef relative to densely populated catchments
Over harvesting of grazing fish	Population pressure on the reef	Area of reef per person from the local area	Algal growth covers and kills corals		Communities with the lowest area of reef per person are most exposed
Erosion damage during storm events	Proportion of community lands prone to erosion	Area of unstable shoreline as a proportion of community lands	Loss of assets, loss of land which increases pressure on remaining land		Communities with the largest proportion of lands in areas of shoreline stability are most exposed
Ocean Acidification	Ph level of water	There are no currently available data to show variation around around Tanna	Caused breakdown of the coral structures		All Tanna
Sea-level rise	Sea surface height	There are currently no available data to map variation around Tanna	Reduces UV radiation		Depth of the reef
Capital works	Projection of future demand for tourism developments	Tourism development potential Whitegrass Volcano Port Resolution	Tourism development damages coral reef or alters the coastal system		Location relative to tourism development

6.2.3 Risk analysis

The risk indicators for the fringing coral reef socio-ecological system are mapped in Figure 24.

(B) *Poor water quality* based on the indicator the population per km^2 of water catchment where Low 0 - 8, Medium 8.1 - 30.7, High 30.8 - 61.7 and Extreme >61.8 with maximum densities of 1,081. The water catchments were calculated from a 30 m resolution digital elevation model using the TerrSet GIS.

(C) *Shoreline instability* indicator was calculated as the proportion of land adjacent to unstable shoreline where Low = 0%, Medium < 1%, High 2% - 4% and Extreme ≳ 5% with a maximum value of 45%.

(D) *Harvesting pressure* indicator is the area of reef (m^2) per person where Low indicates areas where there is no reef, Medium>4,839 m^2 of reef per person, High 1,445 – 4,892 m^2 and Extreme < 1,444 m^2;

(E) *Tourism development pressure* identifies areas as extreme that are in close proximity to a tourism asset; airport, volcano or safe harbour.

We also generated a heat map showing an integrated coastal risk index (A) based on the arithmetic sum of indicators (B) - (E) masked to exclude non-coastal zone areas.

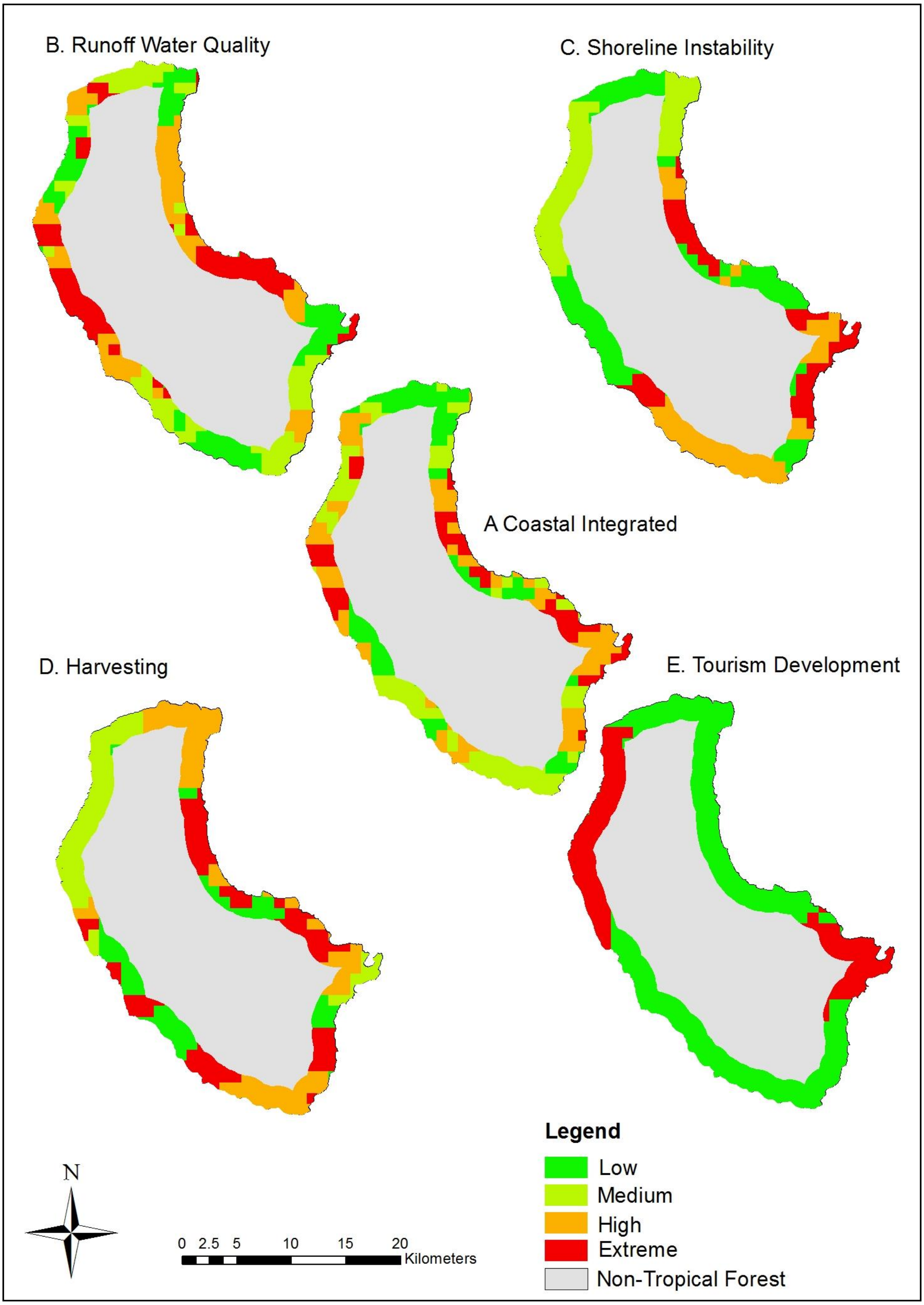


Figure 22. Fringing coral reef analysis showing four risk indicators mapped in four categories of low to extreme

6.2.5 Risk evaluation

When interpreting Figure 22 it is important to note here that there is a mix of spatial units employed for this analysis, with water catchments being used for indicator B and census enumeration areas for indicators C - E. Port Resolution has extreme levels of risk from poor water quality, shoreline instability, and tourist development, and high levels from harvesting pressure. Poor water quality (B) was modelled as a function of population density per unit of water catchment on the basis that there is no waste-water treatment on Tanna and in addition higher densities lead to more intensive land use, both of which add nutrients and sediment into the coral reef ecosystem.

Shoreline stability was based on four geomorphological types: (i) beach with no reef; (ii) beach with reef; (iii) relic coral cliff; and (iv) soft cliffs. The unstable types are are (i) and (iv). Port Resolution is one of three extreme risk shoreline locations on Tanna.

Harvesting pressure reflects the population density relative to the area of fringing coral reef, i.e. higher risk results from more people harvesting from a small area of reef. In addition to reducing the availability of this food source, fish harvesting also exposes the reef by removing grazing fish that regulate macro algae, which would otherwise smother the coral.

The main locations of tourist pressure are those areas of tourist development close to the airport, the volcano and safe harbour. Therefore, the two hot spots on Tanna are the White Grass coastline and Port Resolution. White Grass is the principal tourist accommodation location with new high-end resorts under development.

Unfortunately, the available data for climate change impacts on the coral reef ecosystem, including sea-level rise and ocean acidification, are inadequate to differentiate spatially and thus to map. It is clear, however, when future climate change projections are taken into account, of all the coastal locations considered, the one requiring most immediate intervention is Port Resolution.

We can also note that the current and future climate change maps for Tanna (Figures 14-18) show the south-east of the island being consistently the wetter part of the island, pointing to increased run off into Port Resolution and, depending on its catchment's land use, the potential for increased runoff and reef impacts.

The Port Resolution community has expressed concern at recent and dramatic erosion to the harbour's cliffs and the depletion of fringing reef fish stocks.

6.3 Tropical *kastom* forest socio-ecological system

6.3.1 Risk context

There remain significant areas of tropical forest in Vanuatu that are managed as *kastom* forest and are not used for commercial logging or mining, nor are they used by the customary owners for subsistence farming. Their use is restricted to *kastom* practices and harvesting of some non-timber forest products. The floristic composition and structure of the forest vegetation therefore largely reflect natural ecological processes. However, these *kastom* forests are under increasing pressures from multiple threats, including expansion of subsistence farming, commercial logging, forest loss and fragmentation as a result of the construction of capital works such as roads.

Climate change brings both direct and indirect threats. For example, climatic conditions may change, favouring species that are novel to the ecosystem and, at the extreme end of potential impacts, major shifts in fire regimes could occur. Also of concern is the potential for global warming to render lower elevations less suitable for growing certain crops, leading to increased pressure to clear cloud forest that occupies higher elevation landscapes which retain favourable temperature regimes. The degree to which these stresses result in deforestation and degradation will depend on whether governance arrangements, both governmental and customary, can be strengthened and conservation management regimes established and enforced.

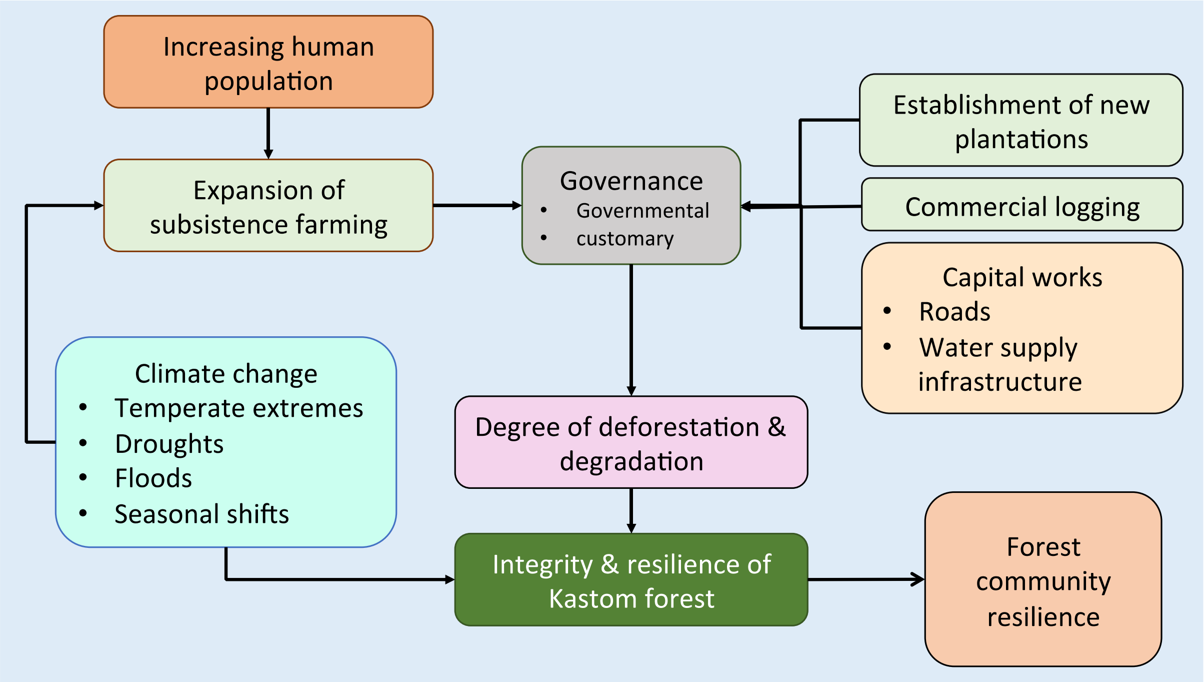


Figure 23. Influence diagram of the *kastom* forest socio-ecological system

6.3.2 Risk identification

Table 21. Summary of risk identification for the Kastom forest socio-ecological system

Hazard	Hazard Indicator	Mapping	Impacts	Vulnerability	Exposure
Competition from other land uses	Population growth	Average annual population growth rate between 1999 and 2009	Deforestation and forest degradation, including forest fragmentation	Lack of formal or breakdown in customary forest management Customary connection to place	Communities with fastest growing population
Clearing	Rates of forest clearing	Average annual forest loss between 2011 and 2016			Communities with the most rapid forest clearing rates
Over-harvesting of forest products	Area of forest per person	area of forest m^2 per person			Communities with the smallest area of forest per person
Commercial timber extraction	Accessibility to roads	Areas intersected by a road			Areas with easy access to road transport
Shift to drier rainfall regimes	Projected change in total annual rainfall		Climate no longer supports current forest structure (e.g. declining rainfall leads to more open forest canopy) Characteristic forest species composition alters due of species loss or arrival of new species		Projections of future climatic monthly mean values do not suggest that Tanna will experience a drying climatic regime. However, the models are not yet able to forecast shifts in ENSO and cyclonic patterns.

6.3.3 Risk analysis

The risk indicators for the *kastom* forest socio-ecological system are mapped in Figure 26.

(B) *Climate driven land use pressure* - This indicator maps the potential expansion of subsistence farming as the result of projected climate change. The Extreme category represents land that remains within the climate envelope for commercial taro growing at 2070. The High category is land currently in the envelope but outside the envelope in 2070; Medium is currently outside the climate envelope.

(C) *Forest clearing* - shows the average annual forest loss between 2011 and 2016 with Low indicating no loss of forest, Medium <3%, High 3 - 6.5% and Extreme >6.5%.

(D) *Harvesting pressure* - is the area of forest per person with Low > 11,030 m^2 per person, Medium 1,954 - 11,030 m^2 per person, High 66 - 1,954 m^2 per person and Extreme < 66 m^2 per person; and

(E) *Forest access* - shows remoteness from access which is a weighted distance based on two categories of roads. Locations near higher grade roads are more accessible by trucks and thus more exposed to commercial timber extraction and other development activities.

We also generate a heat map showing an integrated *kastom* forest risk index (A) based on the arithmetic sum of indicators (B)-(E) masked to exclude non-forest areas.

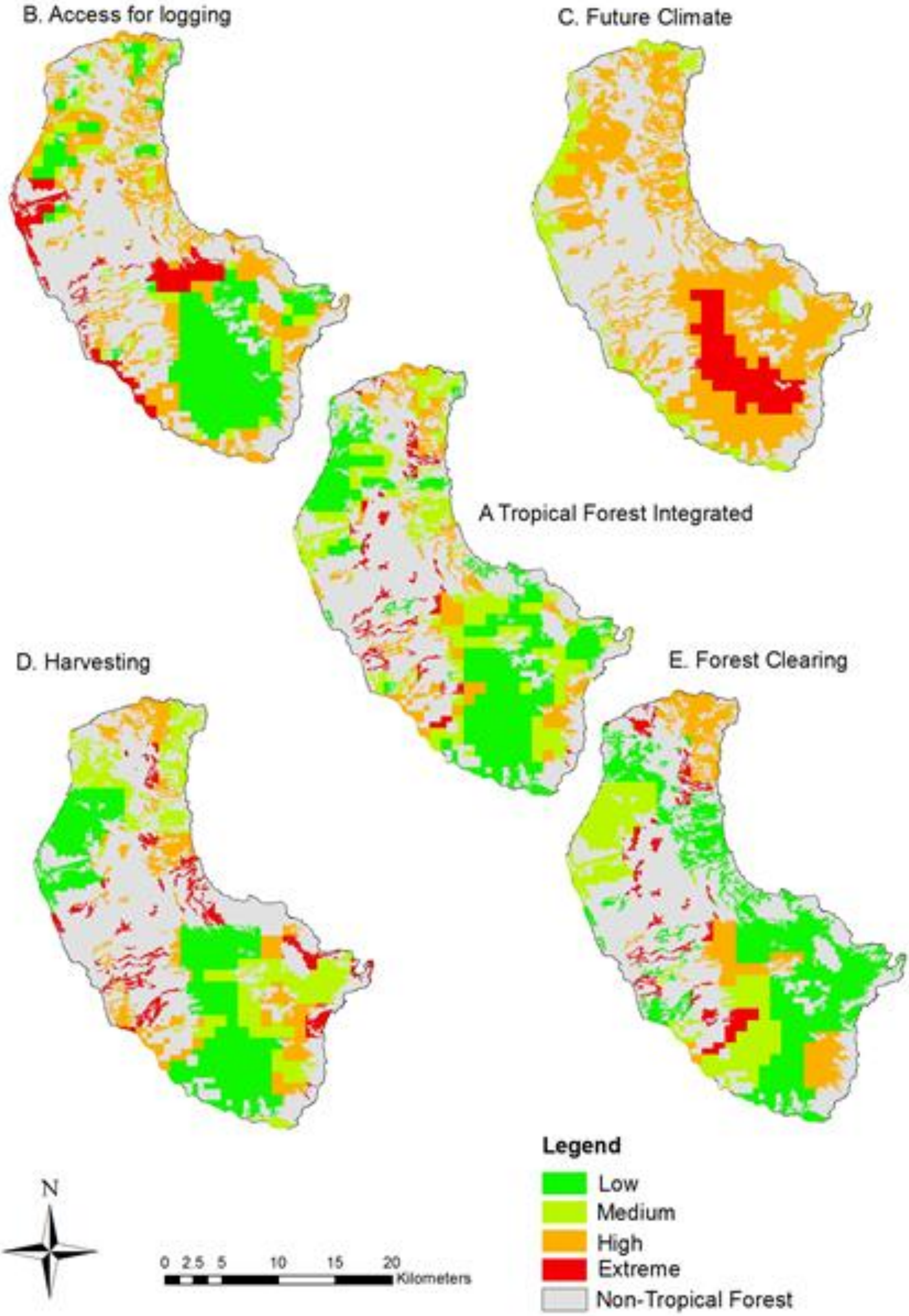


Figure 24. *Kastom* forest socio-ecological system risk assessment mapped in four categories (low to extreme)

6.3.4 Risk evaluation

There are three extensive areas of relatively intact tropical forest landscapes left on Tanna but smaller patches of primary forest remain across the island (Figure 8). The most ecologically intact forest remaining on Tanna is an upland cloud forest with a distinctive biodiversity. This cloud forest functions as a *kastom* forest and the local community have expressed concern about the growing threats to its condition. The road through the forest, connecting Lenekel to the Volcano and Port Resolution, therefore brings both opportunities and threats: opportunities in terms of enhancing the community's ability to engage in eco-tourism and increasing access to markets; and threats in terms of exposure to activities that can lead to deforestation and degradation, including access to logging and encroachment from subsistence farming.

The future climate change analysis points to rising temperatures and increasing rainfall (Figures 16-20) which also presents mixed blessings for Tanna communities. More rain up to a point is better than less rain, but whether these rainfall changes are beneficial or not will depend on whether they are accompanied by an increase in extreme weather events resulting in more intense flooding and drought. What is more certain is that temperatures will inexorably rise with the downscaled projections, indicating that much of the island's thermal envelope will be above the optimum threshold for commercial taro production. While this threshold is not a barrier to small-scale subsistence farming per se, it does indicate that the optimum land for growing taro will shift up and south, such that by 2070 it is coincidental with the current distribution of the cloud forest. We can anticipate, therefore, that the *kastom* cloud forest will come under increasing pressure in the future from expansion of subsistence farming.

It is also important to note that intact forest ecosystems, due to their characteristic biodiversity and their dense canopies and vegetation layers, are more resilient to climatic extremes as they buffer micro-climatic conditions and have greater natural adaptive capacity (Shukla et al. 1990). The *kastom* cloud forest warrants species consideration as it provides a rare opportunity to avoid loss of biodiversity and other ecosystem services, including its *kastom* values, by acting now to protect its high level of condition from threatening processes.

6.4 Scenario analysis

The extent to which the risks identified above are manifest on Tanna will be influenced by two key external factors. The first is the impact of climate change, the severity of which will depend on the international community meeting its obligations to reduce GHG emissions and limit global warming to well below two degrees above pre-industrial levels, as per the Paris Agreement. We considered two possibilities: either global climate action succeeds or it fails. The second external factor relates to the efficacy of governance at regional and national levels and the subsequent availability of funds for adaptation, conservation and sustainable development in Tanna. The two possibilities we considered were: either good governance is implemented and adequate funding is available, or they are not. Together, these factors can be represented by two axes, generating four scenarios that Tanna could be facing in the coming decades (Figure 26).

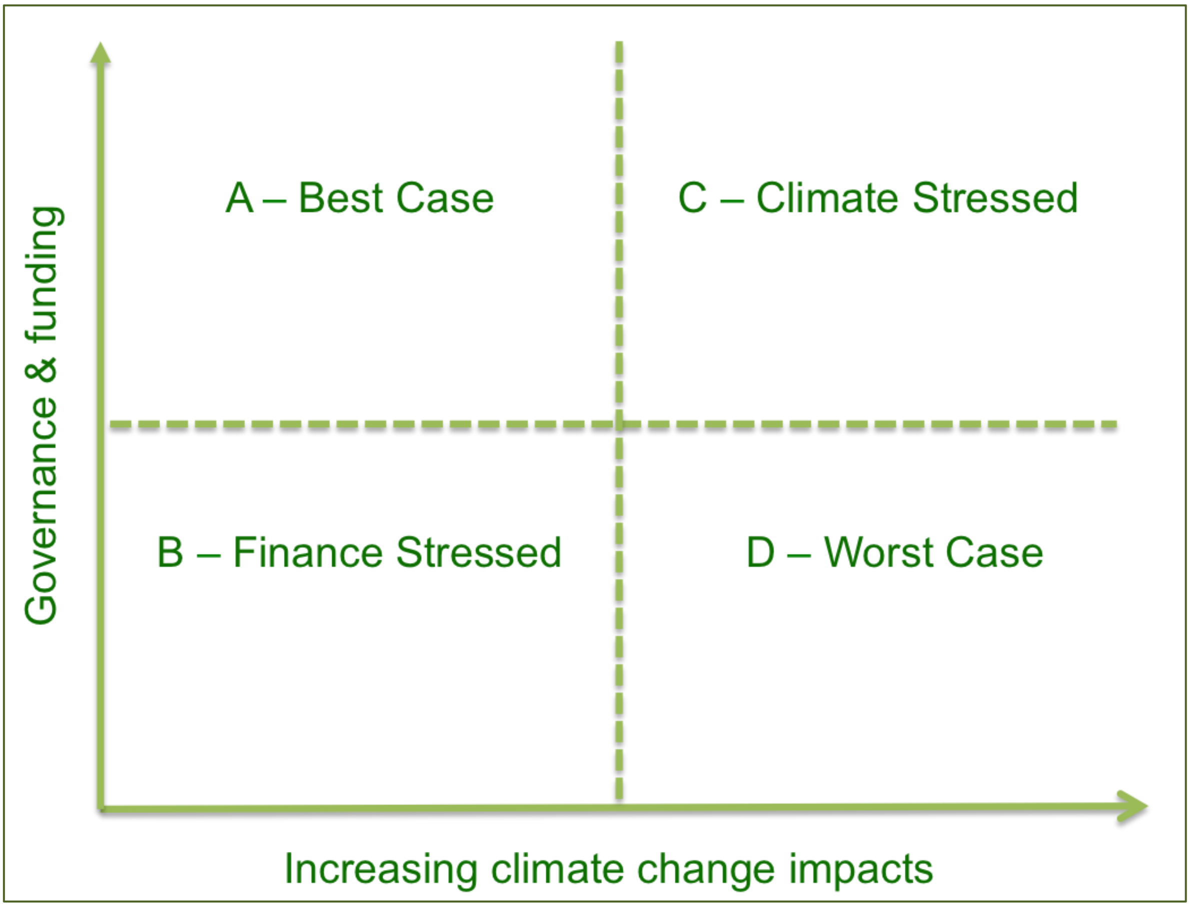


Figure 25. Scenarios of climate change and environment for Tanna

Scenario A - Best case

Under this scenario the international community meets its Paris Agreement commitments, global climate action succeeds in limiting global warming to well below two degrees and the promised funds for adaptation are forthcoming. Furthermore, under this scenario, progress continues to be made in advancing good governance at regional and national levels, which ensures that resources and funding are available to support adaptation project implementation on Tanna.

Scenario B - Finance stressed

Under this scenario global climate action succeeds in keeping global warming to well below two degrees and adequate funds for adaptation are made available to developing countries. However, this scenario also envisages that, unfortunately, governance issues emerge at the regional and national level which restrict access to international funds and their flow to on-ground implementation works for Tanna.

Scenario C - Climate stressed

Here, global climate action fails due to key state parties ignoring mitigation commitments and emissions continue at a level that sends global warming above the two degree target, perhaps more in line with RCP 8.5 projections (Figures 16-20). Fortunately however, other state parties make sufficient funds available to enable adaptation to climate change for developing countries. Also under this scenario, progress continues to be made in advancing good governance at regional and national levels, which helps ensure that the necessary funds flow to Tanna for implementing adaptation projects.

Scenario D - Worst case

Where global climate action fails, there is inadequate funding available for adaptation in developing countries and governance issues at the national and regional scales emerge and persist. The condition of ecosystems continues to be degraded, the flow of ecosystem services to communities is reduced and community resilience declines.

These scenarios have implications for the risks that have been identified to community resilience and the condition of the coral reef and *kastom* forest ecosystems on Tanna. Each scenario presents circumstances that can exacerbate or ameliorate the identified risks and provide either barriers or opportunities for EbA. A summary of some of the major implications is given in Table 22.

Table 22. Implications of scenarios for ecosystems and communities

Scenario	Implications for Ecosystem Services	Implications for Community Resilience
A - Best Case	Future climate change pressures are limited but existing environmental change pressures such as land use change and inappropriate development remain. New risks to ecosystems emerge as a result of large scale adaptation and development projects that often preference capital works over ecosystem services. Governance and institutional initiatives are critical to maintaining ecosystem condition in the face of development pressures.	Community resilience improves but with challenges for maintaining *kastom* and connections to ecosystems. Access to water, food, health and education services improves.
B – Finance Stressed	Future climate change pressures are limited but existing environmental change pressures such as land use change remain. This is increasingly significant as government services are limited due to reduced availability of funding and communities. Low cost and appropriate technology strategies are necessary to respond within the current institutional capacity constraints. EbA becomes an essential intervention under this scenario.	Access to water, food, health and education services decreases. As populations grow, overharvesting and overuse pressures continue to degrade ecosystem condition leading to a reduction of community resilience.

C – Climate Stressed	New climate pressures emerge such as bushfire and invasive species. These new pressures compound the existing environmental change pressures on ecosystems. Funding for capital works adaptation projects creates new risks to ecosystems. Governance and institutional initiatives are critical to maintaining ecosystem condition in the face of development pressures.	Access to health and education services improves but water and food security decrease. Capital works and technology based solutions drive a shift away from *Kastom* practices.
D – Worst Case	Ecosystems are under extreme pressure from climate and environmental change along with overharvesting and overuse. With limited funding available, the condition of ecosystems is eroded from new threats such as invasive species and the onset of bush fires. Community-based EbA projects are the only choice but there are serious and real limits to the capacity of ecosystems to promote community resilience that cannot be ignored.	Access to water, food, health and education services decreases. As populations grow, overharvesting and overuse pressures continue to degrade ecosystem condition, leading to a reduction of community resilience.

6.5 Summary and conclusions

We have identified a set of pressures that generate risks to the condition of Tanna's ecosystems and the continued flow of their ecosystem service benefits.

The increasing population of local communities that are primarily dependent on subsistence farming and harvesting of marine life are leading in many locations to declining crop productivity, particularly of taro, and over-harvesting of reefs. There is also increasing pressure for communities to grow cash crops at the expense of food for their community's consumption.

Previously unfarmed forest land is now suffering increased risk of deforestation and degradation from encroachment of subsistence farming, plantations, and capital intensive infrastructure, including roads. There is also ongoing pressure from logging for commercial/industrial roundwood and wood fuel, which on Tanna has been accelerated by the presence of portable sawmills post TC Pam.

A rapidly changing climate is bringing about an apparent increase in the intensity of tropical cyclones, an increase in their frequency during El Niño events, and an increase in the length and intensity of the dry season. Given the topography of Tanna with significant uplands and mountains, higher temperatures will increasingly be experienced at higher altitudes.

Increasing threats to the ecological integrity of coral reef ecosystems from heat stress as a consequence of global warming resulting in coral bleaching are emerging. The health of coral reef systems impacts on community resilience, such that any increase in bleaching or reduction in ecological integrity will reduce food security and nutrition for coastal communities.

While the possible impacts of rising sea levels on coastal processes are difficult to discern due to seasonal and year-to-year variability in sea levels, when combined with the erosion occurring due to capital works, tourist resort development and sand mining, among others things, the stability of sections of the coastline are under stress and threatened.

The four scenarios established above and used to analyse risks to ecosystems and community resilience have highlighted the importance of EbA given the uncertain external environment. We found that EbA strategies are appropriate to improve community resilience, regardless of changes to external circumstances and despite serious limits under the worst case scenario. Correspondingly, if the best case scenario eventuates, new risks could arise, such as inappropriate capital works that cause ecosystem loss and degradation.

While there is evidence of effective *kastom* natural resource management, these practices are under serious pressure from social change, inappropriate developments and insufficient formal institutional support and funding. EbA solutions provide a means of maintaining *kastom* connections to ecosystems while incorporating the conservation science needed in response to emerging environmental pressures, including climate change.

Our review of the formal governance and institutional arrangements for ecosystems in Vanuatu revealed that there is an array of policies that recognise the role of EbA and its contributions to community resilience. Translating this supportive policy environment into on-ground action is limited by the resources and capacity available at the provincial and local community level.

In order to promote successful EbA on Tanna, projects must simultaneously address - institutional capacity, land use change pressures and conservation. Institutional capacity-building is needed that better connects formal planning with *kastom*-based land and sea ecosystem management. Land use change pressures on forest ecosystems need to be addressed through projects that increase the sustainability of the subsistence farming system. Greater use should be made of formal community conservation areas to ensure conservation and sustainable management of forest and reef ecosystems.

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Appendices

Appendix A. Ecosystem assessment methodology

National terrestrial ecosystem assessment

The national level assessment of ecosystems drew on the Vanuatu Forestry Department vegetation maps developed in 2012 (Schwetter 2012). These maps were provided to the project as a .shp file by the SPREP project manager. While a number of attempts were made to contact the Vanuatu Forestry Department, at the time of the completion of this report the project team has been unable to source metadata or methodology for the 2012 Vanuatu vegetation maps.

There are two components to the ecosystem assessment: ecosystem type and extent maps; and ecosystem condition maps. For the national assessment, these maps were produced by province for each of Vanuatu's five provinces. The two components both required a classification scheme. While there are numerous possible classifications available for ecosystem types, the project adopted a classification that was consistent with that used within the ecosystem service valuation literature (de Groot et al. 2012) to ensure that there was consistency with that aspect of the project. For ecosystem condition, the project adopted the VAST framework, which was modified for application to the Vanuatu context.

The .shp file containing the Vanuatu Forestry Department vegetation maps comprised polygons, which continuously covered Vanuatu's entire terrestrial environment. The classifications for each of the polygons comprised vegetation types, conditions and land use based descriptors all within a single category. The data from these categories have been used as the basis for the terrestrial component of mapping outputs for ecosystem type and extent, and for ecosystem condition. Table 16 describes the connection between the 2012 Vanuatu vegetation maps as an input and the project's ecosystem assessment outputs.

Table 23. Use of vegetation map classification by ESRAM outputs

Vanuatu vegetation map	ESRAM type and extent	ESRAM condition
Medium height forest (> 20m), mostly closed canopy	Tropical forest - medium	Intact
Medium height forest (> 20m), open canopy, degraded or logged over	Tropical forest - medium	Modified
Low forest (< 20m), mostly closed canopy	Tropical forest - low	Intact
Low forest (< 20m), open canopy, degraded or logged over	Tropical forest - low	Modified
Forest plantation	Plantation cropping	Replaced by crops
Thickets (3-8m), dense structure	Tropical forest - thickets	Intact
Thickets (3-8m), open structure	Tropical forest - thickets	Modified

Scrubs (< 3m)	Tropical forest - schrubs	Intact
Mangroves and marshes	Coastal - mangroves	Intact
Grassland, no trees (including cattle farms)	Grassland	Modified
Grassland, with scattered trees and woody shrubs	Grassland	Intact
Cultivated area, mosaic of annual crops, gardening and fallows	Subsistence gardening	Transformed
Cultivated area, plantations, i.e. coconut plantations or crop area dominated by coconut	Plantation cropping	Replaced by crops
Bare soil, rocky outcrops, other naturally unvegetated area (volcanic areas)	Bare soil	Naturally Bare
Built-up and settlement area, villages and infrastructure (i.e. airstrips)	Built-up	Removed
Swamps	Fresh water wetlands	Intact
Waterbodies	Fresh water waterbodies	Intact

National coastal ecosystem assessment

In addition to the terrestrial ecosystems the classification approach of de Groot et al. (2012) includes three coastal ecosystems – mangroves, seagrass and coral reef. For the ecosystem types and extent maps only one of these three types, 'mangroves' was identified within the Vanuatu vegetation map used for the terrestrial ecosystem assessment. The other two categories drew on regional mapping by the United Nations Environment Program. Table 17 provides details of the dataset used to assess type and extent for each of the coastal ecosystems.

Table 24. Sources for coastal ecosystem type and extent

Ecosystem type	**Data source**
Coastal – Mangroves	2012 Vanuatu Vegetation Map, Vanuatu Forestry Department
Coastal – Seagrass	2005 Global Distribution of Seagrass UNEP World Conservation Monitoring Centre - Marine metadata catalogue[1]
Coastal – Coral Reef	2010 Global Distribution of Coral Reefs UNEP World Conservation Monitoring Centre - Marine metadata catalogue[2]

[1] UNEP-WCMC, Short FT (2005). Global Distribution of seagrasses (version 3). Second update to the data layer used in Green and Short (2003). Cambridge (UK): UNEP World Conservation Monitoring Centre. URL: http://data.unepwcmc.org/datasets/7. Other cited reference(s): Green EP, Short FT (2003). World Atlas of Seagrasses. Prepared by UNEP World Conservation Monitoring Centre. Berkeley (California, USA): University of California. 332 pp. URL: https://archive.org/details/worldatlasofseag03gree.

[2] IMaRS-USF (Institute for Marine Remote Sensing-University of South Florida) (2005). Millennium Coral Reef Mapping Project. Unvalidated maps. These maps are unendorsed by IRD, but were further interpreted by UNEP World Conservation Monitoring Centre. Cambridge (UK): UNEP World Conservation Monitoring Centre IMaRS-USF, IRD (*Institut de Recherche pour le Developpement*) (2005). Millennium Coral Reef Mapping Project. Validated maps. Cambridge (UK): UNEP World Conservation Monitoring Centre Spalding MD, Ravilious C, Green EP (2001). World Atlas of Coral Reefs. Berkeley (California, USA): The University of California Press. 436 pp. UNEP-WCMC, WorldFish Centre, WRI, TNC (2010). Global distribution of warmwater coral reefs, compiled from multiple sources (listed in "Coral_Source.mdb"), and including IMaRS-USF and IRD (2005), IMaRS-USF (2005) and Spalding et al. (2001). Cambridge (UK): UNEP World Conservation Monitoring Centre. URL: http://data.unep-wcmc.org/datasets/13.

The mapping of ecosystem condition was conducted for coral reefs and drew on the established relationship between population density and coral reef condition as discussed in the methodology section of the report. Condition was unable to be mapped for mangroves and seagrass due to a lack of available data or well-established basis for condition assessment at a national scale.

The assessment of coral reef condition drew on two datasets:

- 2010 Global Distribution of Coral Reefs; and
- 2009 Vanuatu Census (Households).

To establish the relationship between an area of coral reef and population density, GIS analysis was used based on the steps listed below.

1. The input datasets above were imported to Arcmap.
2. A buffer zone was created 1km landward of the shoreline for all of Vanuatu.
3. Households outside the coastal buffer zone were discarded from the population density calculations.
4. A 10 km^2 fishnet (regularly spaced grid) was created over Vanuatu.
5. Population density or number of residents per/km^2 was calculated for each grid cell.
6. A frequency histogram of population density was prepared (Figure 25). There is a spread of population densities from zero to greater than 100 and these group approximately evenly into the three categories of population density.
7. Categories of population density were assigned based on frequency across three categories Low (0-10); Medium (11-50); High (>50).
8. Condition was allocated to the reef within a given grid area based on the population density category as described in Table 18.

Table 25. Coral reef condition assessment classification

Population density category	Coral reef condition
Low	Intact
Medium	Modified
High	Transformed

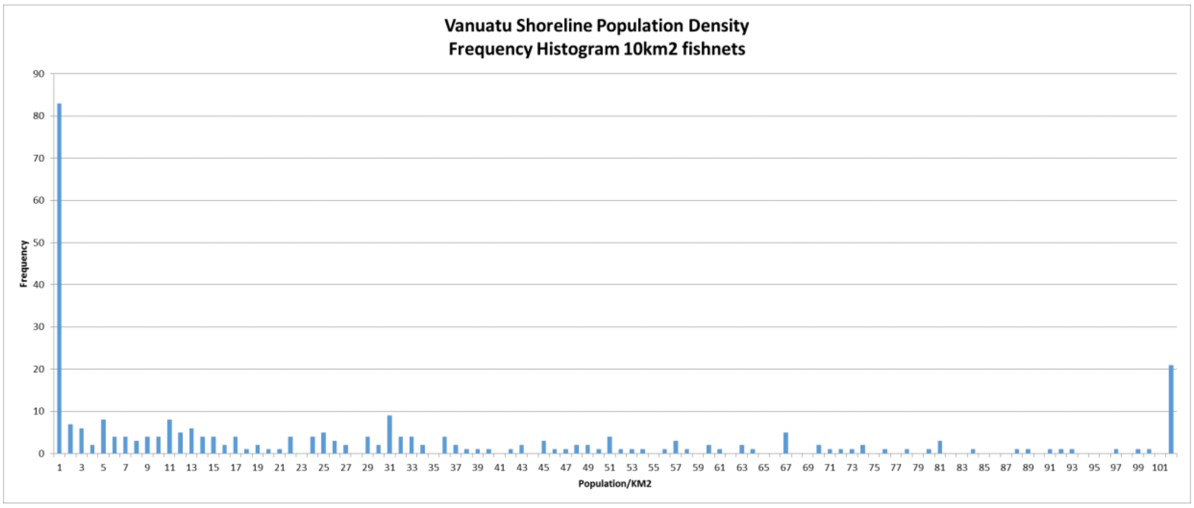

Figure 26. Vanuatu shoreline population density

Tanna ecosystem assessment

The mapping of Tanna's ecosystems adopted a consistent classification approach to that used for the national ecosystem assessment and the ecosystem valuation. The mapping, however, drew on different datasets and methods to improve the resolution of the national level maps. The following process was used for the type and extent maps for terrestrial ecosystems.

1. A combination of field visits to Tanna and review of satellite imagery was used to compile a dataset of ecosystem types for more than 100 sites across the island representative of different ecosystems.
2. Rapideye multispectral satellite imagery was used within the TerrSet application to segment polygons across Tanna based on homogeneity of the spectral pattern providing more than 1,000 polygons for the island.
3. For the areas of Tanna where the volcano smoke or cloud obscured the rapideye image, a fishnet was created with grid cells of 500m^2 creating approximately a further 1,000 polygons.
4. The rapideye segments and the fishnet were combined into a single continuous layer of polygons covering the entire terrestrial area of Tanna;.
5. Where a field site fell within a polygon, that polygon was classified as the ecosystem recorded by the field site;
6. The remaining unclassified polygons were imported to Google Earth and overlayed on high resolution satellite imagery of Tanna;
7. The project team member who had conducted the field site assessments went through each of the unclassified polygons and allocated an ecosystem type based on knowledge of the Island and the Google earth Satellite Image; and
8. Coral reef extent drew on the 2010 Global Coral Reef Distribution map from the national assessment.

Note that, based on extensive field surveys, the other coastal ecosystems were found in very small areas on the Island and were not included in the mapping.

Appendix B. Description of ministry responsibilities

The Ministry for Climate Change Adaptation, Meteorology, Geo-Hazards, Environment, Energy and Disaster Management hosts the National Advisory Board on Climate Change and Disaster Risk Reduction (NAB) and the Vanuatu Meteorological and Geo-hazards Department (VMGD) with the aim of coordinating and managing all Vanuatu's climate change adaptation and disaster risk reduction projects. The Vanuatu Climate Change and Disaster Risk Reduction Policy 2016-2030, aims to further strengthen a coordinated and participatory approach to adaptation and disaster risk reduction in the country.

The Ministry of Lands and Natural Resources (https://mol.gov.vu/index.php/en/) oversees the functions of the Department of Lands, the Department of Water, Geology and Mines and also hosts the Office of the Valuer General. The Ministry of Trade, Tourism, Commerce and Industry coordinates functions performed by the Department of Trade, Industry and Commerce, the National Tourism Development Office and the Food Technology Centre. It also maintains a close working relationship with the Vanuatu Tourism Office, the Vanuatu Chamber of Commerce and Industry, the Vanuatu Investment Promotion Authority and the Vanuatu Commodities Marketing Board.

The Ministry of Infrastructure and Public Works Utilities has a number of departments, including the Public Works Department, the Civil Aviation Authority and the Ports and Marine Department, and the Meteorological Service Department. The ministry is a key player in infrastructure planning and in the implementation of associated decisions.

The Ministry of Agriculture, Livestock, Forestry, Fisheries and Biosecurity (MALFFB) oversees the following departments: Department of Agriculture and Rural Development, Department of Forests, Fisheries Department, Livestock Department, and Biosecurity Department. The MALFB has a critical role in terms of the control of invasive species and also broader planning for agriculture and related sectoral livelihoods.

The Ministry of Internal Affairs has responsibility for the Corporate Services Division (CSD), the Department of Local Authorities (DLA), National Disaster Management (NDMO), the Vanuatu Police Force (VPF), the Department of Immigration, the Department of Labour and Employment Services (DoL), the Electoral Office, the Passport Office and Civil Status. The DLA in particular is involved in negotiations regarding the implementation of provincial-level plans and the linkages between national-level and provincial-level plans and strategies.

The *Prime Minister's Office* is the highest body of national level planning in Vanuatu. The Prime Minister's Office recently released the National Sustainable Development Plan for Vanuatu, which maps out desired development goals for 2016-2030 in the Vanuatu cultural context. Overall the Prime Minister's Office has six major objectives: (1) to provide high level policy, planning and administrative support to the Prime Minister, the Council of Ministers (COM), the Central Agencies Committee (CAC) and the Development Committee of Officials (DCO); (2) effective monitoring and evaluation of government policies and programs; (3) effective alignment of development partners resources with government policy priorities; (4) to provide quality language services to the Government and to raise awareness of the use of official languages; (5) to efficiently and professionally administer the Citizenship Act; and (6) to provide strategic policy advice and coordination to constitutional and statutory bodies under the Prime Minister's portfolio.

The Ministry of Justice and Community Services oversees the Department of Women's Affairs, the Department of Correctional Services, the Disability Desk, the Child Desk Office, the Supreme Court, the Magistrates Court, the Public Prosecutor's Office, the Public Solicitors Office, *Malvatumauri* Council of Chiefs, the Customary Land Management Office, the Vanuatu Law Commission, the Ombudsman's Office and the State Prosecution Department. Of particular importance in terms of the dual governance structure is *Malvatumauri* (National Council of Chiefs).

The main aim of *Malvatumauri* is to safeguard *kastom*, including culture and languages, and to support *kastom* practices. It also functions as the main representative body for customary chiefs in Vanuatu as it includes *kastom* chiefs that sit on island councils of chiefs.

Appendix C. Pressure and risk mapping methods

The appendix describes the methods used to produce the risk maps included within the risk assessment section of the report.

Mapping pressures on the sustainability of Tanna's subsistence farming systems

The Subsistence Farming System is defined as the area of land which is currently used for subsistence farming.

Declining fallow pressure

This map shows four levels of historical expansion of the subsistence farming system within community land. The greater the rate of expansion, the lower the potential fallow period, resulting in higher pressure on soil.

The map was developed as follows:

1 – The boundaries of the Vanuatu 1999 Census Enumeration areas were overlayed on the 2016 and 2011 Tanna Island Vegetation maps so that the area of subsistence garden at 2011 and 2016 for each enumeration area could be identified.

2 – The average annual change in area of subsistence garden between 2011 and 2016 was calculated for each enumeration area providing a rate of expansion

3 – The raw scores were separated into quantiles, the enumeration areas with the largest annual Increase were allocated a 4 or extreme risk, next 3 or high, followed by 2 or medium and finally 1 or low.

Future climate pressure

This map shows three levels of pressure on the subsistence system as a result of current and future projected climate. The levels are differentiated based on the climate envelope for commercial taro production (average annual TMAX between 21ºC and 27 ºC) applied to Tanna's current and 2070 projected climate.

The map was developed as follows:

1 – Tanna's current climate and 2070 annual TMAX was plotted using data from worldclim as described earlier within the report;

2 – Area where the current TMAX is outside the climate envelope for commercial taro production was allocated a 4 or extreme;

3 – Area currently within the climate envelope but outside the climate envelope in 2070 was allocated a 3 or high;

4 – Area within the commercial Taro climate envelope at 2070 was allocated a 2 or medium

Production Pressure

This map shows four levels of harvesting pressure on subsistence garden based on the area of subsistence garden per person from the local community. The area of subsistence garden per person from the local community gives an indication of harvesting pressure an area is subject to, such that the smaller the area of subsistence garden per person the greater the pressure.

The map was developed as follows:

1 – Boundaries of the Vanuatu 1999 Census Enumeration areas were overlayed on the 2016 Tanna Island Vegetation Map so that the area of subsistence garden for each enumeration area could be identified;

2 - Area of subsistence garden for each enumeration area was divided by the population of the enumeration area to provide the area of subsistence garden per person;

3 - The raw scores were separated into quantiles, the enumeration areas with the smallest area per person allocated a 4 or extreme risk, next 3 or high, followed by 2 or medium and finally 1 or low.

Demand growth pressure

This map shows four levels of demand growth for the Subsistence Farming System within community land based on changing population. The greater the rate of population growth the greater the potential pressure on soil and the rest of the system.

The map was developed as follows

1 – The Vanuatu 1999 and 2009 census was used as the basis for identifying population change at the community level using the Vanuatu 1999 Census Enumeration Areas.

2 - The Average Annual Change in population between 1999 and 2009 was calculated for each enumeration area providing a rate of population growth

3 - The raw scores were separated into quantiles, the enumeration areas with the largest annual increase were allocated a 4 or extreme risk, next 3 or high followed by 2 or medium and finally 1 or low.

Integrated subsistence farming pressure Index

This map shows four levels of risks across the subsistence system of Tanna Island based on the integration of each of the previous coastal system maps.

The map was developed as follows:

1 – Tanna Island subsistence zone was defined as the area of land covered by subsistence gardening at 2016;

2 – Subsistence zone was separated into 1km x 1km grids creating a subsistence zone grid;

3 – Subsistence zone grid was overlayed on each of the fallow, climate, production and demand layers to extract the risk level for each layer;

4 – Subsistence system Integrated risk level for each 1km grid =Fallow + Harvesting + Climate + Demand; and

5 - Raw scores were separated into quantiles, with the highest numbers allocated a 4 or extreme risk, next 3 or high, followed by 2 or medium and finally 1 or low.

Mapping coral reef socio-ecological system risks

The coastal reef system is defined as the extent of the inshore coral reefs and the area 5 km landward of the shoreline. This system is described by four maps and one integrated map.

Reef harvesting

This map shows four levels of harvesting pressure on coral reefs based on the area of reef per person from the local community. The area of reef per person from the local community gives an indication of harvesting pressure an area is subject to, such that the smaller the area of reef per person the greater the pressure.

The map was developed as follows:

1 – Boundaries of the Vanuatu 1999 Census Enumeration areas were projected seaward to allow the inshore coral reef polygon from the 2010 UNEP to be subdivided into each enumeration area;

2 – Area of reef for each enumeration area was divided by the population of the enumeration area to provide the area of reef per person; and

3 – Raw scores were separated into quantiles, the enumeration areas with the smallest area per person allocated a 4 or extreme risk, next 3 or high followed by 2 or medium and finally 1 or low.

Shoreline instability

This map shows four levels of shoreline instability hazards to coastal communities based on the proportion of a community's land within an area of shoreline instability. The greater the proportion of a communities land within an area of shoreline instability the greater the hazard.

The map was developed as follows:

1 – Shore zone of Tanna Island was defined as the area of land 200 m landward from the shoreline;

2 – Shore zone was classified based on four classes; beach no reef, beach with reef, soft cliffs, hard cliffs;

3 – Four shoreline classes are categorised into 2 stability types – stable or unstable;

4 – Shorezone was segmented by enumeration areas from the 1999 Vanuatu Census;

5 – Proportion of each enumeration area that is within unstable category of the shorezone was calculated for each enumeration area; and

6 – Raw scores were separated into quantiles, the enumeration areas with the greatest proportion were allocated a 4 or extreme risk, next 3 or high, followed by 2 or medium and finally 1 or low.

Tourism development

This map shows two levels of potential intensification of tourism development based on input from local stakeholders. The map depicts two primary areas which comprise the enumeration areas in close proximity to the Mount Yasur Volcano and the Whitegrass Airport. These are the two areas where there is most intense level of current development and based on construction activities already under way these are the areas where future development is most likely to occur.

Runoff water quality

This map shows four levels of runoff water quality based on the population density for Tanna Island's catchments. The greater the population density, the lower the run-off water quality entering the coastal environment.

The map was developed as follows:

1 – 2011 ASTER GDEMV2 was used to identify Tanna Island's catchments using the TerrSet watershed analysis toolkit;

2 – 2009 Vanuatu Census Household GIS layer was used to identify the population within each catchment;

3 – Population density for each catchment was calculated;

4 - Raw scores were separated into quantiles, the catchments with the greatest population density were allocated a 4 or extreme risk, next 3 or high, followed by 2 or medium and finally 1 or low.

Coastal integrated

This map shows four levels of coastal risks across the coastal zone of Tanna Island based on the integration of each of the previous coastal system maps.

The map was developed as follows:

1 – Tanna Island coastal zone was defined as the island within 5kms of the shoreline;

2 – Coastal zone was separated into 1 km x 1 km grids creating a coastal zone grid;

3 – Coastal zone grid was overlayed on each of the reef, shoreline, tourism and runoff layers to extract the risk level for each layer;

4 – Coastal integrated risk level for each 1 km grid = reef + shoreline + tourism + runoff; and

5 - Raw scores were separated into quantiles, with the highest numbers allocated a 4 or extreme risk, next 3 or high, followed by 2 or medium and finally 1 or low.

Mapping tropical *kastom* forest socio-ecological system risks

The *kastom* forest system is defined as the area of land which includes tropical forest, shrubs and thicket. This system is described by four maps and one integrated map

Access for logging

The map shows four levels of access to Tanna Islands tropical forest for potential logging activity based on the proximity to and quality of the nearest road. Areas of forest closest to good quality roads are easy for loggers to access and under greater deforestation pressure.

The map was developed as follows:

1 – Tanna’s roads (based on the Vanuatu Governments Roads GIS Layer) were classified as either; 1 irregular maintenance with high likelihood of access restrictions or 2 regular maintenance with limited likelihood of access restrictions;

2 – Tropical forest was separated into 1 kmx1 km grid cells;

3 – 1km grids were overlayed on the Tanna road layer to identify both the distance and the type of the nearest road;

4 – Distances to the road were then classified into quantiles from 1-4, with 1 being the cells with greatest distance from a road and 4 being the cells which were closest to or contained a road;

5 – Raw access index was the result of multiplying the road distance score with the road type score; and

6 - Raw scores were separated into quantiles, the highest scores were allocated a 4 or extreme risk, next 3 or high, followed by 2 or medium and finally 1 or low.

Forest harvesting

This map shows four levels of harvesting pressure on tropical forest based on the area of tropical forest per person from the local community. The area of tropical forest per person from the local community gives an indication of harvesting pressure an area is subject to such that the smaller the area of tropical forest per person the greater the pressure.

The map was developed as follows:

1 – Boundaries of the Vanuatu 1999 Census Enumeration areas were overlayed on the 2016 Tanna Island Vegetation Map so that the area of tropical Forest for each enumeration area could be identified;

2 - Area of tropical forest for each enumeration area was divided by the population of the enumeration area to provide the area of tropical forest per person; and

3 - Raw scores were separated into quantiles, the enumeration areas with the smallest area per person allocated a 4 or extreme risk, next 3 or high, followed by 2 or medium and finally 1 or low.

Forest clearing

This map shows four levels of historical clearing of tropical forest within community land. The greater the rate of historical clearing the higher the pressure on remaining forests.

The map was developed as follows:

1 – The boundaries of the Vanuatu 1999 Census Enumeration areas were overlayed on the 2016 and 2011 Tanna Island Vegetation Maps so that the area of tropical forest at 2011 and 2016 for each enumeration area could be identified;

2 – Average annual change in area of tropical forest between 2011 and 2016 was calculated for each enumeration area, providing a rate of historical clearing where negative or regeneration where positive; and

3 – Raw scores were separated into quantiles, the enumeration areas with the largest annual decrease allocated a 4 or extreme risk, next 3 or high, followed by 2 or medium and finally 1 or low.

Future climate

This map shows three levels of pressure on tropical forest as a result of current and future projected climate. The levels are differentiated based on the climate envelope for commercial taro production (Average Annual TMAX between 21ºC and 27 ºC) applied to Tanna's current and 2070 projected climate.

The map was developed as follows:

1 – Tanna's current climate and 2070 Annual TMAX was plotted using data from worldclim as described earlier within the report;

2 – Area where the current TMAX is outside the climate envelope for commercial tarro production was allocated a 2 or medium;

3 – Area currently within the climate envelope but outside the climate envelope in 2070 was allocated a 3 or high; and

4 – Area within the commercial Taro climate envelope at 2070 was allocated a 4 or extreme.

Tropical forest Integrated risk index

This map shows four levels of risks across the tropical forest of Tanna Island based on the integration of each of the previous coastal system maps.

The map was developed as follows:

1 – Tanna Island tropical forest was defined as the area of land covered by tropical forest at 2016;

2 – Tropical forest zone was separated into 1 km x 1 km grids creating a tropical forest zone grid

3 – Tropical forest grid was overlayed on each of the access, harvesting, clearing and climate layers to extract the risk level for each layer;

4 – Tropical forest integrated risk level for each 1 km grid = access + harvesting + clearing + climate; and

5 – Raw scores were separated into quantiles, with the highest numbers allocated a 4 or extreme risk, next 3 or high, followed by 2 or medium and finally 1 or low.

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