

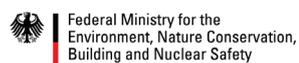
PORT VILA

V A N U A T U

Ecosystems, Climate Change and Development Scenarios



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SPREP Library Cataloguing-in-Publication Data

Blaschke, Paul M ... [et al.]

Port Vila. Ecosystems, Climate Change and Development Scenarios, Vanuatu. Apia, Samoa: SPREP, 2017.

96 p. 29 cm.

ISBN: 978-982-04-0739-8 (print)

978-982-04-0740-4 (ecopy)

1. Ecosystem management – Port Vila (Vanuatu)
 2. Nature conservation – Port Vila (Vanuatu).
 3. Port Vila (Vanuatu) – Social conditions
 4. Port Vila (Vanuatu) – Economic conditions
- I. Blaschke, Paul M. II. Zari, Maibritt Pedersen. III. Archie, Kelli M. IV. Jackson, Bethanna. V. Komugabe-Dixon, Aimée. VI. Livesey, Chris. VII. Loubser, Dave. VIII. Gual, Carles Martinez-Almoyna. IX. Maxwell, Deb. X. Rastandeh, Amin. XI. Renwick, James. XII. Weaver, Sean. XIII. Pacific Regional Environment Programme (SPREP). XIV. Title

333.7 959 5

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Port Vila Ecosystems, Climate Change and Development Scenarios

Report prepared by Victoria University of Wellington for the Pacific Ecosystem-based Adaptation to Climate Change (PEBACC) Programme of the Secretariat of the Pacific Regional Environment Programme (SPREP).

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Acknowledgements

Our thanks go to the following people for their helpful assistance at various stages of the project:

In Port Vila:

- Staff from several government departments and the Port Vila Municipal Council, especially from the Department of Climate Change and the Department of Environment Protection and Conservation.
- Vivian Fischer and Amy Yang who helped with organising the Port Vila workshop on June 13 2017.
- All of the people who attended that workshop, spoke with us on our visits, and provided information – your information, insight and support was invaluable. In particular we wish to thank Vanessa Organo and Christina Shaw.

In Wellington and Suva:

- Emma Fisher and Cheryl Johansen for considerable logistic support, Mohammad Namdar and Alicia Taylor for digitising soils data, Wren Green for helpful information, Herman Timmermans, PEBACC project manager, for many helpful comments and support.

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Executive Summary

Introduction

Port Vila is the capital and largest city of the Melanesian island nation of Vanuatu, and is situated on the southern coast of Efate, the third largest island in Vanuatu. Metropolitan Port Vila is where more than a quarter of Vanuatu's total population live. In 2016 the population of the city was approximately 75 000 and current growth rates are as high as 8% per annum. Population growth in Port Vila is much higher than in other provinces and the city is attracting internal migrants from all other islands in Vanuatu. Most new internal migrants reside in outer urban or peri-urban settlements where they do not generally have formal access to housing or land for growing food.

Tropical Cyclone Pam (TC Pam) in March 2015 was one of the most severe cyclones in living memory, causing at least 16 fatalities and more than US\$360 million worth of damage. Efate was one of the worst affected islands by TC Pam because of the infrastructure and population concentration in Port Vila. Vanuatu's experience of TC Pam, followed immediately by a severe El Niño-Southern Oscillation drought which caused widespread food shortages, highlighted the vulnerability of Vanuatu to natural hazards and other risk factors.

The Pacific Ecosystem-based Adaptation to Climate Change (PEBACC) Project responds to these vulnerability challenges. The five-year Project (implemented by the Secretariat of the Pacific Regional Environment Programme (SPREP)) explores and promotes Ecosystem-based Adaptation (EbA) options for adapting to climate change in the Pacific region. EbA is the practice of strengthening ecosystems to increase people's ability to adapt to the impacts of climate change. It draws upon knowledge of ecosystem services and is based on the premise that if ecosystems are protected, remediated, or regenerated, this leads to healthier ecosystems, more ecosystem services, and therefore greater human wellbeing and resilience to the impacts of climate change.

The current study continues the PEBACC project in Vanuatu. It builds on an earlier PEBACC study that undertook a baseline ecosystem and socio-economic resilience analysis and mapping appraisal of the Port Vila Metropolitan area. The methodology approach adopted provided for mainly desk-top review work, supplemented by four key workshops (including one in Port Vila), interviews with Port Vila stakeholders, and brief field inspection in Port Vila.

Section 2 Mapping and assessing Port Vila's ecosystems

Mapping of land and coastal cover types (a composite of ecosystem and land use types) was conducted at two different scales to construct a robust platform for spatial analysis and decision making. The combined Port Vila catchments (200km²) were selected as the full study area in which to examine the current status of all urban, peri-urban, rural and coastal cover types. Greater detail on built-up land cover classes was provided for the administrative Greater Port Vila area (Municipality of Port Vila plus surrounding areas within Shefa Province; total area 24 km²).

Terrestrial ecosystems

Over half (55.8%) of the total area of the Port Vila catchments is still forested, with approximately equal amounts of more intact, high-density forest and modified, low-density

forest. The next largest category of land cover is grassland (28.4%) of which the biggest portion is pasture or grassland, while 10.6% is actively gardened areas ('bush gardens'). Built-up areas comprise 11% of the total Port Vila catchments, almost all of low density urban development, and much of the suburban area containing active home gardens. Most of the land mapped as rural built-up areas or other types of informal settlement areas is also low density. Mapped coastal marine areas (mangrove, seagrass and reef ecosystems) comprised 4% of the total catchments area.

The assessment of terrestrial ecosystem condition shows dynamic changes occurring within already modified ecosystems, rather than a process of unidirectional change or degradation. In steep mid and upper catchment areas, significant natural mass movement erosion has been taking place as result of recurrent tropical cyclones.

Coastal ecosystems

Coastal ecosystems condition assessment analysis and maps clearly show the high spatial variability of reef condition, related not only to nearby population density but also to factors such as accessibility, exposure to natural disturbances, predator outbreaks, tidal influence, condition of adjacent coastal habitat, and position in relation to river and point source discharges. Observations from divers indicate low fish abundance on all reefs, in particular of piscivores (snappers and groupers) and large herbivores (parrotfish). Some Port Vila coral reefs have shown resilience to disturbances. However increasing pressures may compromise the ability of Port Vila's reefs to recover.

Information on key native plant and animal species in the Port Vila catchment area and environs is summarised in a table compiling information on threat status, distribution and reasons for threat. Many key species are used by Port Vila residents for various ecosystem services.

Section 3 Impacts of climate change and human activities on Port Vila's ecosystems and people

This section focusses on the impacts of current ecosystem processes, climate change and human activities on those ecosystems and habitats, drawing on analysis of existing data and literature, and the results of team and community workshops. Functional linkages between Port Vila ecosystems and the community benefits of having healthy ecosystems are made through an ecosystem services conceptual framework. Ecosystem services benefitting residents of Port Vila are summarised.

Threats to ecosystem services in Port Vila

The causes of ecosystem degradation can be split into two main categories in the Port Vila context: activities of people living in Port Vila (such as overharvesting, pollution, and rapid unplanned urbanisation), and climate change (impacts include changes to rain and weather patterns). Other causes of ecosystem degradation may be due to natural disturbance and are largely outside the scope of this report, but can interact with local human or climate change driven pressures. Major causes of ecosystem degradation in terrestrial, freshwater, coastal and marine ecosystems in Port Vila context are summarised. The impacts of land use activities and current harvesting regimes on the ecological integrity and functional biology of Port Vila ecosystems are also reviewed.

Harvesting pressures arise from fishing, harvest of reef animals such as sea cucumbers, tree harvest (often for cooking fuel), and various agricultural practices both from commercial farming and subsistence gardening in home gardens in built-up areas and larger bush gardens in peri-urban areas. Currently most farming activities occur at low intensity. Urban and peri-urban agriculture could play an expanded role in increasing Port Vila's resilience in the face of natural disasters, changing climate, food supply pressures caused by continued internal migration, or increased prices of imported grains. A successful expansion of urban and peri-urban agriculture could provide additional and more affordable food supply, and additional employment. Tourism is a very important part of the national and Port Vila economy and a major employer. It is also a strong driver of ecosystem service demand in some areas (particularly in terms of food, water, and energy provision), and a leading user of building services and materials. Resort development in and around Port Vila, often situated on coastal land, has been responsible for the destruction of some mangrove and coastal forest habitat.

Industrial activity in Vanuatu is heavily concentrated in Port Vila and a number of potentially polluting point sources were identified, particularly located in the lower Tagabe catchment, but the actual level of pollution is poorly known. Sand mining for construction sand, particularly on Mele Beach, occurs widely and may be a cause of beach erosion. Infrastructure in Port Vila is under significant pressure, and this could lead to a decline in environmental quality and ecosystem service provision. Inadequate water and sewerage supply, roading, and waste management are seen as key infrastructure deficiencies.

Water, nitrogen and phosphorus

Flows of water, sediment and nutrients in the Port Vila catchments were modelled and mapped using the Land Utilisation and Capability Indicator (LUCI) land management decision support tool and ecosystem process modelling framework. Results from modelling water flows show flow-accumulating catchment areas offering very little mitigation against flooding, primarily located in the built-up areas of the catchments, as well as areas of pasture and subsistence gardening. High flood concentration areas tend to be found in lowland areas of the catchments, close to waterways, and there are opportunities to make modifications in the landscape to reduce flood risk. Modelling of nitrogen and phosphorus flows showed that pastoral areas generated the largest amount of nitrogen. The major rivers and streams draining these areas into Mele Bay likely have the highest levels of nitrogen. Pastoral areas were also a significant source of phosphorus, but areas of active subsistence gardening generated the largest amount of phosphorus. Areas of land which are vulnerable to severe soil erosion and which can be readily connected to nearby waterways by overland flow are identified in LUCI. Areas most vulnerable to erosion occur in steeper areas of the catchment around cliff faces and valley walls of the highlands, but sediment and erosion rates vary considerably, often coinciding with large rainfall events, resulting in pulses of sediment going into waterways. The analysis identified terrestrial areas and land uses which can be targeted to reduce the adverse impacts of accumulating water flows, sediment delivery and nutrients.

Climate change impacts

Port Vila has a tropical climate which is influenced by the Trade Winds. There is considerable interannual variability in precipitation as the location and intensity of the South Pacific Convergence Zone are influenced by El Niño-Southern Oscillation activity. Vanuatu is often

affected by tropical cyclones. Consistent with global trends, temperatures in the Port Vila area have risen on the order of 1°C in the past 40 years while precipitation has shown no significant trends in recent decades. Sea levels in the western Tropical Pacific have risen at around 4-5mm/year over the past 20 years, faster than the global mean rate of 3.3mm/year.

The future magnitude of climate change impacts for Port Vila will depend strongly on how global greenhouse gas emissions reduction policy and technology develop. Future temperature rise in the Port Vila region is expected to be somewhat slower than the global average rate, but all future scenarios show temperatures rising significantly above what has been observed in recent decades. Even with moderate warming scenarios, the occurrence of extreme events increases rapidly.

Precipitation change is on average expected to be small through the rest of the 21st century, but variability is expected to increase. Sea level rise in the region of Vanuatu is projected to continue at a rate slightly greater than the global average. Absorption of carbon dioxide by the oceans makes ocean water more acidic and reduces the availability of calcium carbonate in the water column, interfering with coral growth and shell formation. Reef health may become marginal by 2030, if significant global emissions reductions are not achieved.

The impacts of the changes described in this section on the ecological and human systems of Port Vila, and the ability of these systems to adapt, depend heavily on which greenhouse gas emissions pathway is followed. The pattern of expected changes suggests that the major impacts will fall into the broad categories of flooding and coastal / marine processes. Insufficient drainage systems and degraded watersheds (especially on river margins) compromise Port Vila's ability to cope with flooding under average conditions. Any increase in rainfall or storm surges will exacerbate this issue, and standing water resulting from poor drainage systems has implications for local human health. Ocean warming increases the risk of coral bleaching events and Crown of Thorns outbreaks, which could have significant impacts on both Vanuatu's tourism economy and the provision of traditional seafood.

Section 4 Future development scenarios

Likely future Port Vila scenarios to 2030 based on alternative development pathways were developed, in order to evaluate and prioritise the initial EbA project ideas for Port Vila, to try to predict how each project might work in different possible futures. The most important variables when devising possible future scenarios for the Port Vila context are rate of population growth, rate and nature of economic development and magnitude of climate change impacts. Three future scenarios for Port Vila were developed to show a range of possible futures under high climate change impacts: a high impacts scenario, a business as usual scenario and a low impact sustainable development scenario.

1 Introduction

Port Vila is the capital and largest city of the Melanesian island nation of Vanuatu, and is situated on the southern coast of Efate, the third largest island in Vanuatu.

Tropical Cyclone Pam (TC Pam) in March 2015 was one of the most severe cyclones in living memory, causing at least 16 fatalities and more than US\$360 million worth of damage. Efate was one of the worst affected islands by TC Pam because of the infrastructure and population concentration in Port Vila. Vanuatu's experience of TC Pam, followed immediately by a severe El Niño-Southern Oscillation drought which caused widespread food shortages, highlighted the vulnerability of Vanuatu to natural hazards and other risk factors.

This report was commissioned by the Pacific Ecosystem-based Adaptation to Climate Change Project (PEBACC) – an International Climate Initiative (IKI) project implemented by SPREP in conjunction with the Government of Vanuatu. The project advocates ecosystem-based adaptation (EbA) as a cost-effective and appropriate response to climate change in Pacific island countries. As with most climate change adaptation work, the effective use of EbA requires a strong planning foundation. Critical is a good understanding of the ecosystems (spatial distribution, condition, trends, etc.) and how they contribute to the social and economic resilience of communities. It also requires an appreciation of the anthropogenic drivers of ecosystem degradation and an understanding of projected changes in climate variables and how these will impact on linked social and ecological systems. Scenario planning allows for identifying desired development pathways and serves to ensure that selected EbA actions are appropriate towards achieving sustainable development outcomes.

This report complements an earlier study conducted by RMIT University (McEvoy et al. 2016) that focused on mapping the social use of Port Vila's ecosystems by the residents of the city. It concentrated more on the demand side of the ecosystem-services equation. The current report focusses on the supply side by mapping and assessing the condition of the ecosystems that provide these vital services. It goes further to map and assess the impacts of climate change and human activities on Port Vila's ecosystems and people. The report concludes by presenting three scenarios of possible future development pathways and describes the actions that would be needed to achieve sustainable development outcomes for the city in the context of climate change.

2 Mapping and Assessing Port Vila's Ecosystems

2.1 Port Vila urban area

The geography and demographics of the Port Vila urban area are described in McEvoy et al. (2016). The authors show boundaries for different areas of the Port Vila 'entity', from the central Port Vila Municipal Council area, to a larger bordering 'Greater Port Vila' urban area, and a still larger 'Metropolitan Port Vila Region', i.e. the full extent of the modern 'urban catchment'. In the current study, which is based around ecosystem processes, the preferred method has been to analyse and show the largest entity as a physical catchment bounded by river catchment boundaries rather than McEvoy et al.'s more administratively based

Metropolitan Port Vila area (Figure 2.1). The total size of the Port Vila catchments shown in Figure 2.1 is 20,100 ha, about 22% of the area of Efate Island.

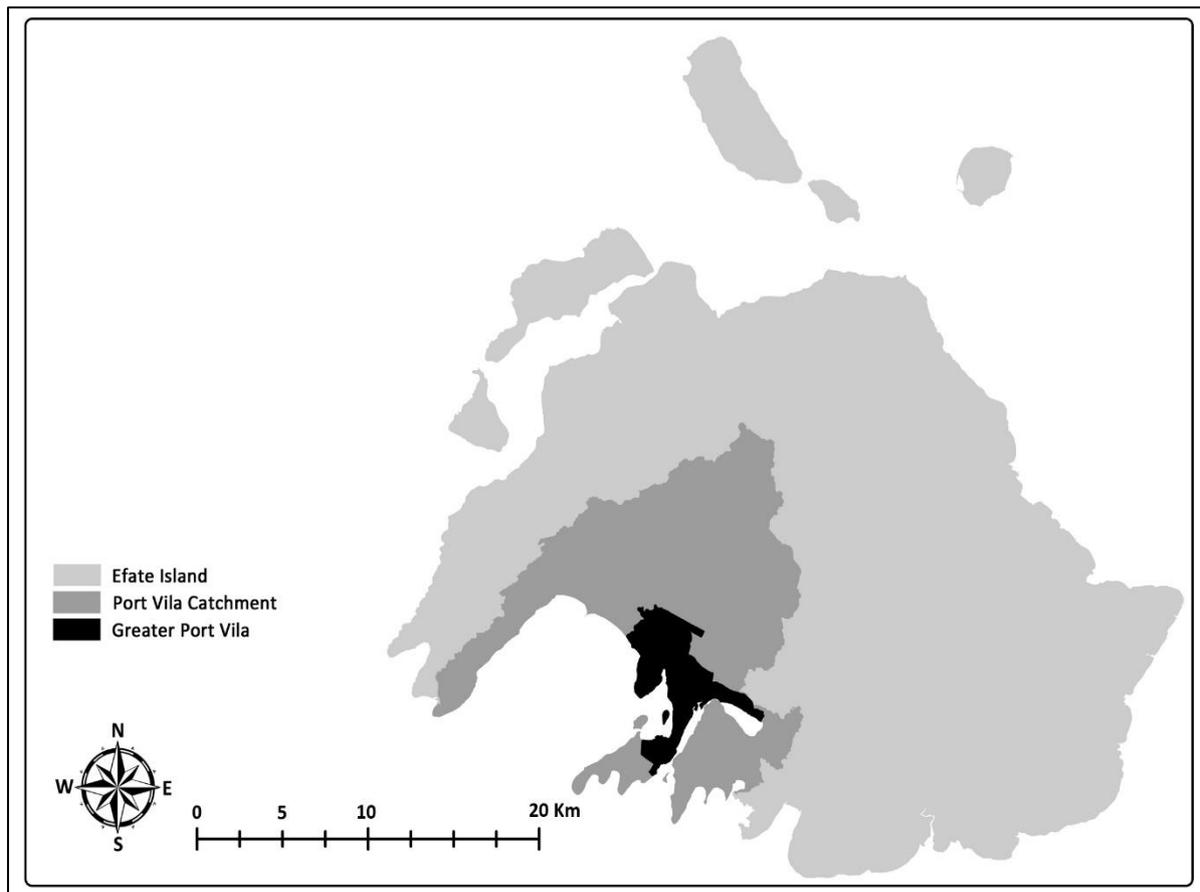


Figure 2.1 Position of Greater Port Vila within Efate, Vanuatu

The population of the Metropolitan Port Vila region was given from 2016 ‘Mini-Census’ (post-TC Pam) at 74,775¹, about 27% of the total population of Vanuatu. The population in 2009 was estimated by McEvoy et al. (2016) as 62,678. It is significant that the population of Metropolitan Port Vila in both 2009 and 2016 is around 50% greater than that of the Port Vila Municipal Council area, indicating the extent of Port Vila’s growth outside its designated municipal boundary. McEvoy et al. (2016) quoted annual population growth rates between 1999 and 2009 for different parts of the metro region, ranging from 4.8% to 7.75%. These are likely to be some of the highest population growth rates in Pacific island countries, and very high population growth rates even compared to other rapidly developing countries (cf. United Nations 2008; 2014). For example, the population of Honiara (Solomon Islands) in 2009 was 64,609, with an average growth rate over the previous 10 years of 2.7% (BMT WBM 2016).

¹ See:

https://vnso.gov.vu/images/PublicDocuments/Census/2016/2016_Mini_Census_Main_Report_Vol_1.pdf. This total population comprises Port Vila Municipal Council (50,995) and Mele (4,711) Ifira (1,186), Pango (2,326), Erakor (8,918) and Eratap (6,640) area councils. The boundaries of these council areas do not completely coincide with the boundaries of the Port Vila catchments shown in Figure 2.1, nor with the Metropolitan Port Vila area described by McEvoy et al. (2016) and in this report.

McEvoy et al. (2016) comment on population growth in the context of urbanisation pressures as people migrate from other parts of Vanuatu to Port Vila. They state:

‘These findings...demonstrate an accelerating trend in urbanisation across Vanuatu, particularly in and around the capital Port Vila.... It can be reasonably argued that the rapid urbanisation processes currently being experienced by Port Vila are likely to continue for the foreseeable future (if not accelerate as environmental ‘push’ factors in regional / rural / island areas are worsened by climate change). This will mean escalating stress on the integrity of ecosystems relied on by the communities of Port Vila.’

2.2 Methods for mapping of Port Vila Ecosystems

2.2.1 GIS-based ecosystem mapping

Due to the importance of scale in landscape ecology research (q.v. O'Neill et al. 1998; Forman 1995), ecosystem mapping was conducted at two different scales to construct a robust and reliable platform for spatial analysis and decision making on potential ecosystem-based responses to the current climate change-induced challenges in Port Vila.

2.2.1.1 Catchment scale

The combined Port Vila catchments were selected as the full study area to examine the current status of ecosystems in terms of the extent and spatial arrangement of land cover type classes. 2016 satellite imagery with a 5 m resolution was utilised as a basis to map the study area. Ecosystem mapping was conducted using Geographic Information System techniques in the Arc Map v.10.2.2 and v.10.4.1 environments. In order to increase the accuracy of ecosystem mapping, the observable objects and colours on the satellite imagery were checked constantly during the process of ecosystem mapping using available sources of spatial information including Google Map and Google Earth. In addition, local information about the current status of land cover types was gathered from a limited number of experts who had already undertaken field research in the study area. Reconnaissance field inspection over parts of four days was also undertaken from roads in the lower parts of the Port Vila catchments to provide a more realistic picture of the current status of patches of vegetation, particularly in areas where land cover was not identifiable by remote sensing techniques. This process was performed in order to facilitate the process of land cover classification as accurately as possible.

GIS-based ecosystem mapping was developed through iteratively creating and revising six versions to ultimately create the final version of the Port Vila catchment land and coastal cover map (Figure 2.3).

2.2.1.2 Urban scale

Due to the importance of addressing urban ecosystems in relation to human activities in the built environment, particularly in an era of climate change (q.v. Pedersen Zari 2012), the area within Greater Port Vila was mapped at a more detailed scale to build up a platform for spatial analysis of land cover patterns in relation to land use activities. This was mapped with a greater emphasis on built up land cover types than for mapping the Port Vila catchments, as a basis to distinguish different, and sometimes overlapping types of urban, rural, and informal built-up areas across the catchment (Figures 2.4 and 2.5).



Figure 2.2 Urban Port Vila

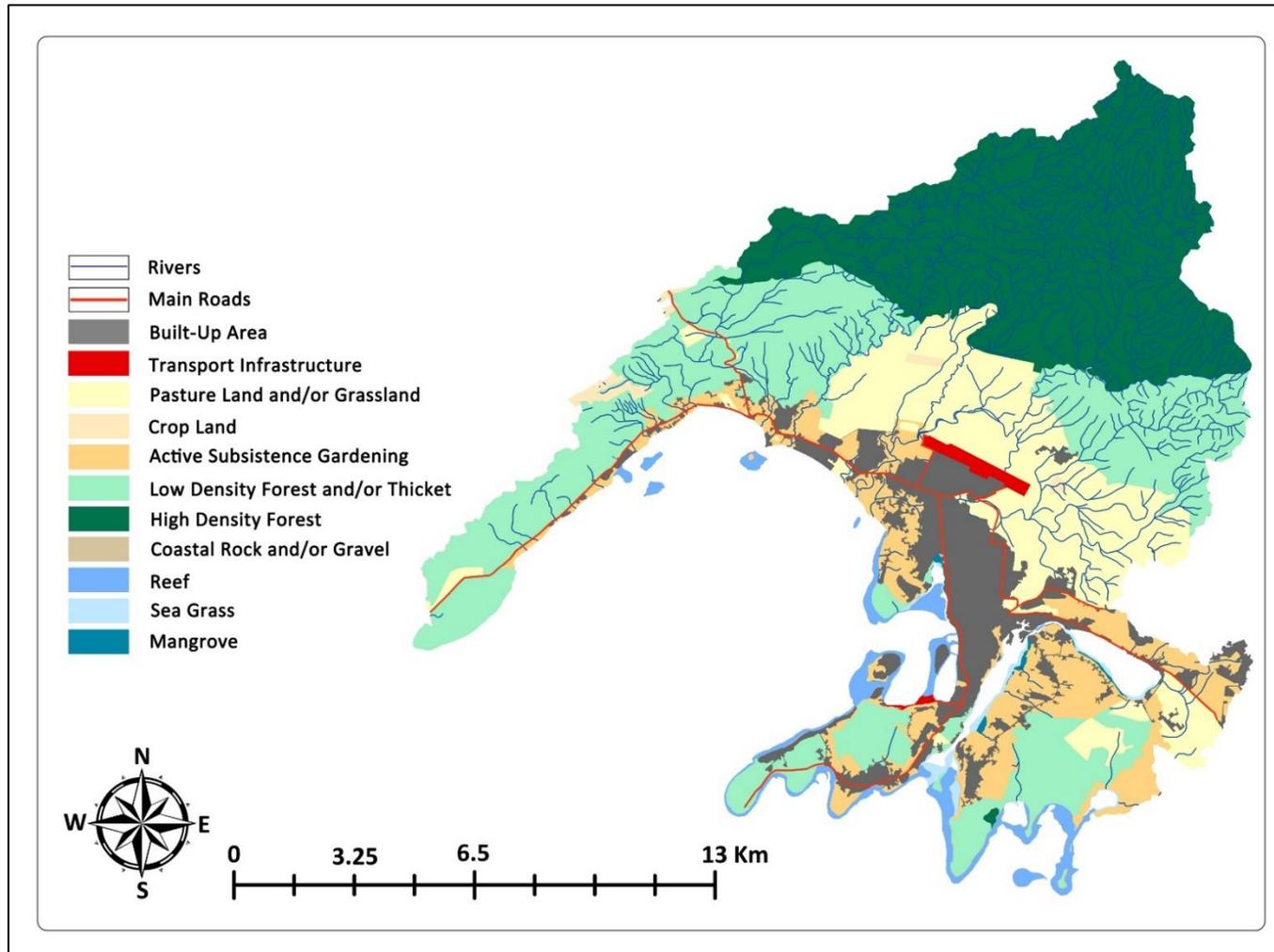


Figure 2.3 Port Vila catchments land and coastal cover map (catchment scale)

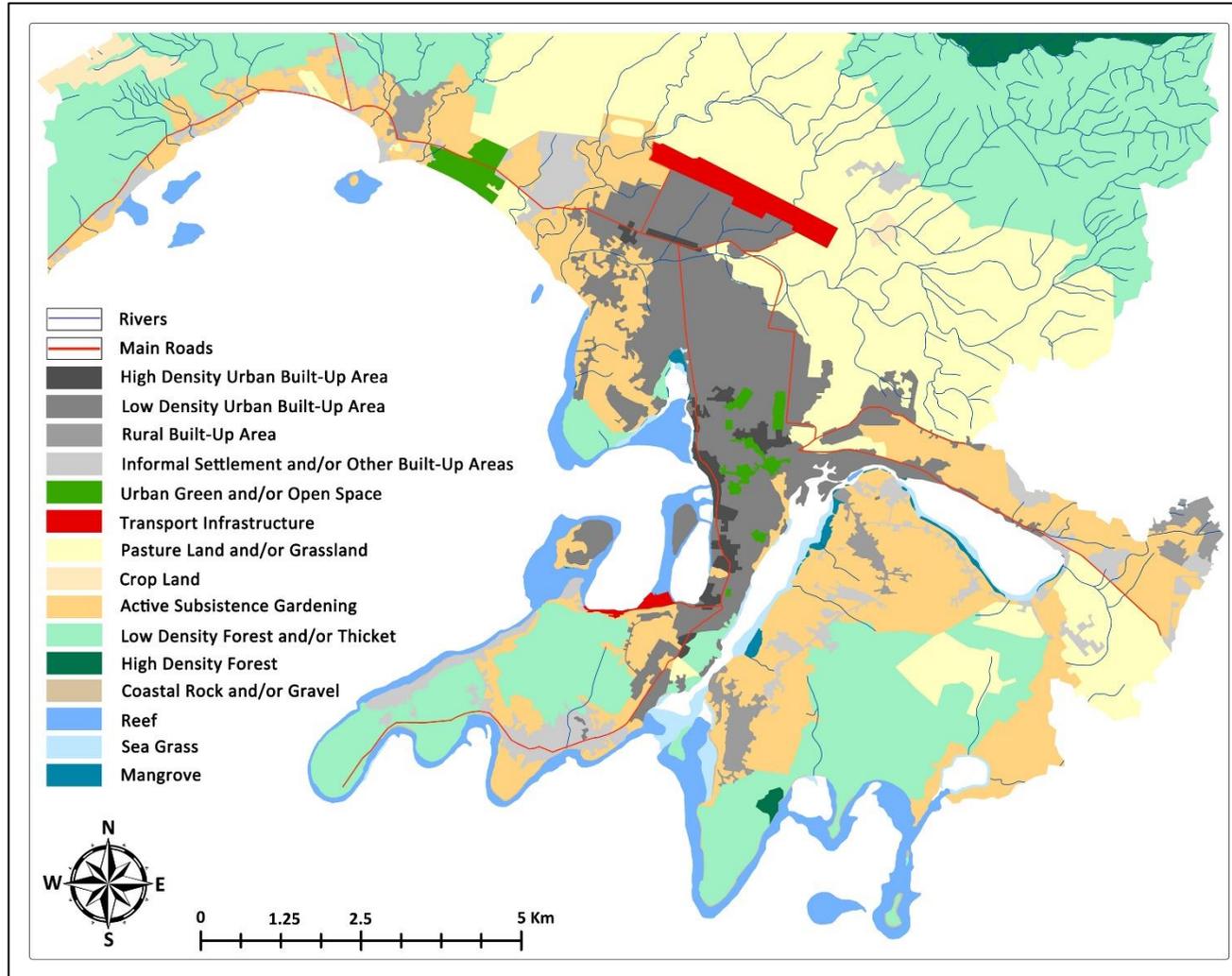


Figure 2.4 Metropolitan Port Vila land and coastal cover map at urban scale

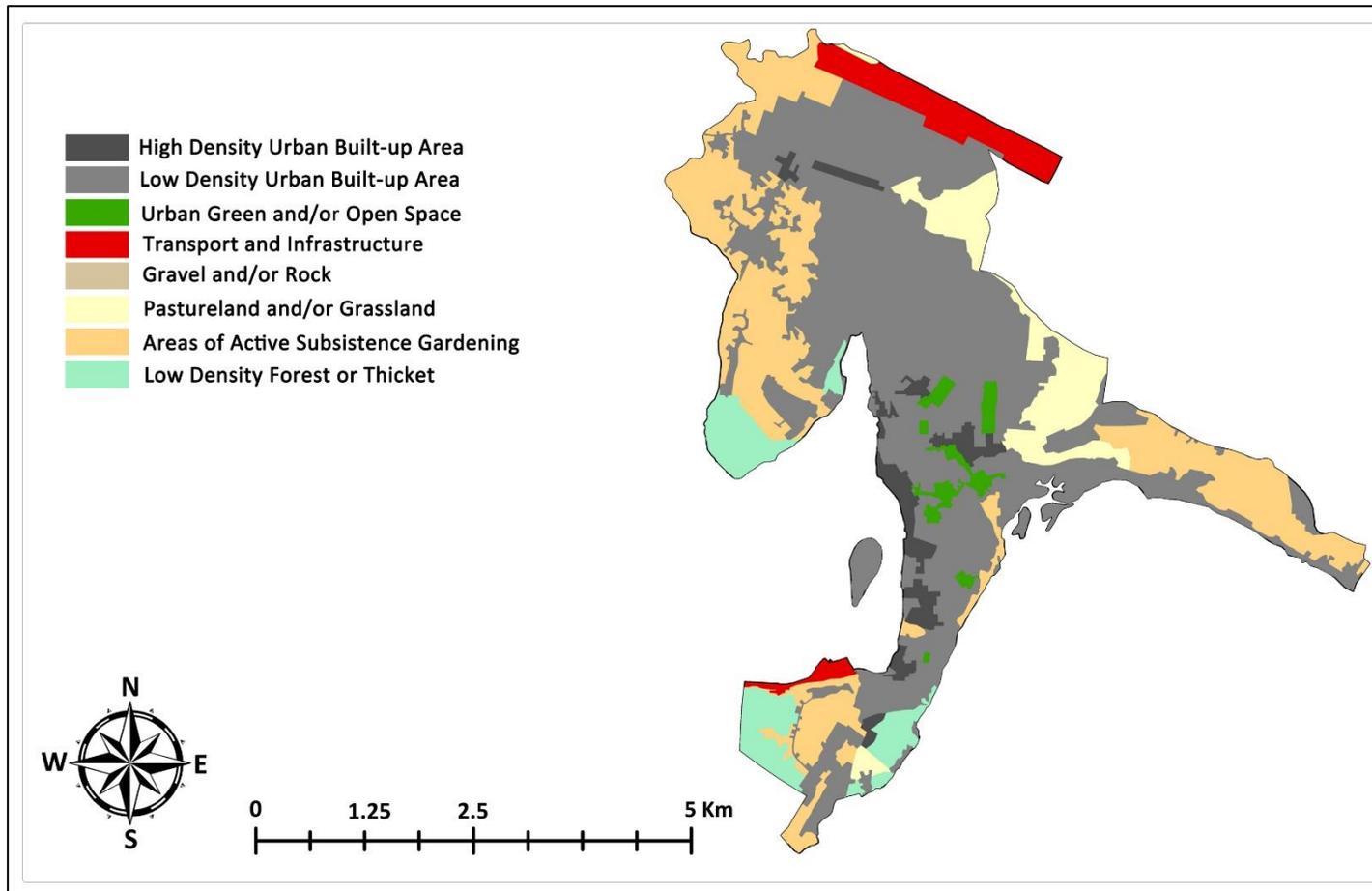


Figure 2.5 Greater Port Vila land cover map (urban scale)

2.2.2 Land use and coastal cover types

The mapping units developed for the initial mapping were a composite of ecosystem types, such as forests, and land use types, such as built-up areas. These were called ‘land cover types’, for terrestrial zones. The land cover types were in fact broadly consistent with units called ‘vegetation types’ in the Vanuatu Vegetation Map 2012 (Schwetter 2012) and ‘ecosystem types’ in the ESRAM mapping at multiple scales in Vanuatu (Mackey et al. 2017). Cover units were developed for coastal marine as well as terrestrial zones in the wider Port Vila catchment area. More detailed land cover types for built-up areas were developed, primarily for mapping at more detailed scale for the Greater Port Vila area.

The final land and coastal classification units developed and mapped for the catchment scale are shown in Table 2.1. Table 2.2 shows classifications for the urban scale.

Table 2.1 Port Vila land and coastal cover type classification: catchment scale

	1. Built-up areas: All urban and rural areas with clustered housing/building (all densities), including home gardens and urban parks /green areas
	2. Infrastructure and transportation zone
	3. River and riparian zone: not mapped separately from rivers network
	4. Terrestrial coastal (beach) zone: sand and gravel cover
	5. Agricultural land
	5.1 Pasture land and grassland including coconut trees over pasture and degraded pasture land with >50% grass cover
	5.2 Crop Land including horticulture and tree plantations (other than coconut)
	5.3 Areas of active subsistence gardening (away from built-up areas; ‘bush gardens’)
	6. Water bodies: not mapped in Port Vila catchments
	6.1 Lake
	6.2 Swamp/wetland (not riparian)
	7. Forest
	7.1 High density forest (tree canopy >75% total canopy cover)
	7.2 Low density forest (tree canopy 40–75% total canopy cover) and thickets
	7.2.1 Lowland low density forest (tree canopy 40–75% total canopy cover—human disturbed forest for older bush gardens)
	7.2.1 Thickets, scrub or fern (tree canopy <40% canopy cover and grass <50% canopy cover)
	8. Marine coastal zone
	8.1 Coastal mangroves
	8.2 Coastal seagrass
	8.3 Coastal nearshore reef areas

Table 2.2 Port Vila land and coastal cover type classification: urban scale

	<p>1. Built-up areas: All urban and rural areas with clustered housing/building (all densities), including home gardens and urban parks /green areas.</p> <p>1.1. High density – Urban (estimated >50% impervious surfaces)</p> <p>1.2. Low density – Urban (including associated home gardens; estimated <50% impervious surfaces)</p> <p>1.3. Rural area / Village (including traditional/domestic gardening)</p> <p>1.4. Informal settlement</p> <p>1.5. Other residential zone (e.g. patches of residential buildings outside the urban area and accommodation infrastructures for tourism-related activities)</p> <p>1.6. Urban parkland and open space (e.g. formally-designed park and playgrounds)</p>
	
	
	
	
	
	
	
	
	
	
	2. Infrastructure
	3. Transportation
	4. River and riparian zone
	5. Coastal zone
	6. Agricultural land
	6.1 Pasture land and grassland including coconut trees over pasture and degraded pasture land with >50% grass cover
	6.2 Crop Land including horticulture and tree plantations (other than coconut)
	6.3 Areas of active subsistence gardening (away from built-up areas; ‘bush gardens’)
	7. Water bodies
	7.1 Lake
	7.2 Swamp/wetland (not riparian)
	8. Forest
	8.1 High density forest
	8.2 Low density forest
	8.3 Thickets and continuous scrub and fern
	9. Coastal mangroves
	10. Coastal seagrass
	11. Coastal nearshore reef areas

2.2.3 Coastal ecosystems mapping assessment

The Point Intercept Transect (PIT) method was used to coordinate a rapid assessment by divers of the benthic community of selected reefs around Port Vila. A diver laid a 100 m fibreglass tape measure and securely attached it to prevent excessive movement. A second diver swam along a transect line and recorded the type of reef category directly below the transect line at specific points along the transect. Four sites were selected according to significance to local communities and to the tourism industry, and accessibility and proximity to terrestrial pollutants (Table 2.3). Four 20 m transects (separated by 5 m) were taken in Pango Cove and Twin Bommies; three 20 m transects (separated by 5 m) were taken in Blacksands and the Port Vila Harbour (Table 2.3). The benthic type was recorded every 50 cm. Substrate category was recorded consistently with Reef Check categories (Table 2.9).

Table 2.3 Coastal survey sites

Date surveyed	Site	Depth (m)	Water visibility (m)	Temp (°C)	Hard coral % at site	Habitat type/Zone	# of transects	Location
4/05/17	Blacksands	8–10	2–3	27	18	Reef slope	3	17° 42'45.83" S, 168° 17'15.61" E
4/05/17	Twin Bommies	10–13	20	27	64	Reef slope	4	17° 45'40.40" S, 168° 16'40.06" E
5/05/17	Pango Cove	10–13	10–15	26	31	Reef slope	4	17° 46'10.96" S, 168° 15'47.24" E
5/05/17	Harbour	9–11	5–10	26	15	Patch reefs, sandy bottom	3	17° 44'10.92" S, 168° 18'33.52" E

2.3 Land use cover extent

Figures 1.3–1.5 show maps of the Land and Coastal Cover Types mapped at the catchment and urban scales. Tables 2.4 and 2.5 show the extent of these cover types. Because of the limitations of cover type recognition from the available imagery (see Appendix 1) and lack of opportunity for systematic ground-truthing, some land cover units could not be consistently differentiated over the whole mapping area. For example, low-density forests and vine thickets, although structurally quite different, were very closely interwoven in the field and therefore could not be consistently differentiated over the whole catchment at the scale of mapping, and were therefore mapped as a complex. Similarly, riparian areas, although of considerable interest as the focus of environmental pressures and potential areas of ecosystem-based adaptation, could not be consistently distinguished over the whole of their length, even for major rivers. Therefore, riparian areas were not mapped independently of the stream network.

Results of the spatial analysis (Tables 2.4 and 2.5) show that well over half (55.8%) of the total area of the Port Vila catchments is still forested, with roughly equal amounts of more intact or high-density forest and modified or low-density forest. The next largest category of land cover is grassland (28.4%) of which the biggest portion was pasture or grassland (not all of it actively grazed), while 2,130 ha (10.6%) is actively gardened areas ('bush gardens'). Within built-up areas (11% of the total Port Vila catchments), almost all this area was regarded as low-density urban (estimated less than 50% of area impervious), and much of the suburban area containing active home gardens. Most of the land mapped as rural built up areas or other types of informal settlement areas were also low density.

Table 2.4 Land cover classes/subclasses present in the study area

Class	Subclass	ESRAM condition*	Area (ha)	%
Built-up areas			2,202	11.0
	<i>1.1. High density urban built-up area</i>	<i>Removed</i>	102	
	<i>1.2. Low density urban built-up area</i>	<i>Transformed</i>	1,289	
	<i>1.3. Rural built-up area</i>	<i>Transformed</i>	181	
	<i>1.4. Informal settlement or other built-up areas</i>	<i>Transformed</i>	524	
	<i>1.5. Urban green and/or open space</i>	<i>Replaced</i>	106	
Infrastructure and transportation zone			115	0.6
	<i>2.1. Transport and infrastructure</i>	<i>Removed</i>	115	
River and riparian zone		<i>Intact</i>	N/A	
Terrestrial coastal zone		<i>Intact</i>	17	
	<i>4.1. Gravel and/or rock</i>	<i>Intact</i>	17	
Agricultural land			5,719	28.4
	<i>5.1. Pastureland and/or grassland</i>	<i>Replaced</i>	3,451	
	<i>5.2. Crop land</i>	<i>Replaced</i>	138	
	<i>5.3. Areas of active subsistence gardening</i>	<i>Highly modified</i>	2,130	
Water bodies			N/A	
	<i>6.1. Lake</i>	<i>Intact</i>	<i>N/A</i>	
	<i>6.2. Swamp and/or wetland</i>	<i>Intact</i>	<i>N/A</i>	
Forest			11,217	55.8
	<i>7.1. High density forest</i>	<i>Intact</i>	5,519	
	<i>7.2. Low density forest or thicket</i>	<i>Modified/replaced</i>	5,698	
Marine coastal zone			831	4.1
	<i>8.1. Coastal mangrove</i>	<i>Intact</i>	34	
	<i>8.2. Coastal seagrass</i>	<i>Intact</i>	142	
	<i>8.3. Coastal nearshore reef areas</i>	<i>Intact</i>	655	
Total area			20,101	100

*See Table 6.1 for an explanation of this column

Table 2.5 Land cover classes/subclasses present in the Greater Port Vila

Class	Subclass	Area (ha)	%
Built-up areas		1,435	59.4
	<i>High density urban built-up area</i>	102	4.2
	<i>Low density urban built-up area</i>	1,289	53.3
	<i>Urban green and/or open space</i>	44	1.8
Infrastructure and transportation zone		115	4.8
	<i>Transport and infrastructure</i>	115	
River and riparian zone		N/A	
Terrestrial coastal zone		0.3	0
	<i>Gravel and/or rock</i>	0.3	
Agricultural land		729	30.2
	<i>Pastureland and/or grassland</i>	172	7.1
	<i>Areas of active subsistence gardening</i>	557	23.0
Water bodies		N/A	
	<i>Lake</i>	N/A	
	<i>Swamp and/or wetland</i>	N/A	
Forest		138	5.7
	<i>Low density forest or thicket</i>	138	
Total		2,417	100

It is notable that in a city of around 100,000 residents, only 102 hectares (0.5%) are mapped as high-density built up area. We know from census information that some of the city wards and settlements have a very high population density (e.g. Mele and Blacksands; McEvoy et al. 2016). The high-density term in the land cover classification refers, therefore, to density of buildings rather than population density. The Port Vila metropolitan area, at both the catchment and urban scale, is overall quite heavily forested, or at least wooded, as indicated by the visual impression of leafiness of most of the city.

2.4 Land use cover condition

Port Vila is situated in one of the world's rarest tropical wilderness areas with a high rate of endemism (Mittermeier et al. 1998; Cincotta et al. 2000). Despite this, ecosystem degradation and land cover transformation resulting from human activities have had widespread impacts on the 'intactness' of the natural ecosystems over time. Thus, the spatial assessment of Port Vila's ecosystems, including degradation factors, was necessary to provide an ecological picture of the study area at the present time. This was conducted not only to develop a deeper understanding of the current ecological situation but also to assist decision makers to contribute to the process of ecosystem-based adaptation to the local impacts of climate change and other human impacts.

Table 2.6 Categories of urban terrestrial vegetation condition / transformation

(Modified from Mackey et al., 2017; Table 2)

Category	I	II	III	IV	Va	Vb	VI
Description / condition (rural)	Intact, largely unmodified	Modified	Highly modified	Transformed	Replaced by crops	Replaced by invasives	Removed
Example	Primary forest	Commercially logged native forest	Trad. subsistence farming (bush gardens)		Coconut plantations	Lantana infestation	Airport
Description (urban)	Intact & largely unmodified	Modified	Highly modified	Transformed Replaced by leafy areas	Replaced by crops	Replaced by grass / urban green space	Removed
Examples (urban)	Primary forest (largely absent from urban or peri-urban area)	Low-density Forest remnant (peri-urban)	Traditional subsistence farming (home & bush gardens) – sparse buildings (mainly peri-urban)	Low-density suburban & peri-urban area (<50% impervious), incl. some garden areas (urban)	Market gardens, horticulture (peri-urban)	Park, sports field, grassland (urban and peri-urban)	Airport, street, commercial precinct, high density urban (>50% impervious) (urban)
Urban scale land cover unit	6.1	6.2	5.3	1.2-1.5	5.2	5.1, 1.6	1.1, 2

2.4.1 Terrestrial

The assessment of terrestrial ecosystem condition was based on mapped land cover types. Mackey et al. 2017 assessed ‘intactness’ of ecosystem types in Vanuatu which were in fact composites of ecosystem types and land cover types. We have modified this approach for the Port Vila urban context as shown in the remainder of the table, by considering the land cover units mapped for the Port Vila urban area at the ‘urban’ scale (Table 2.6).

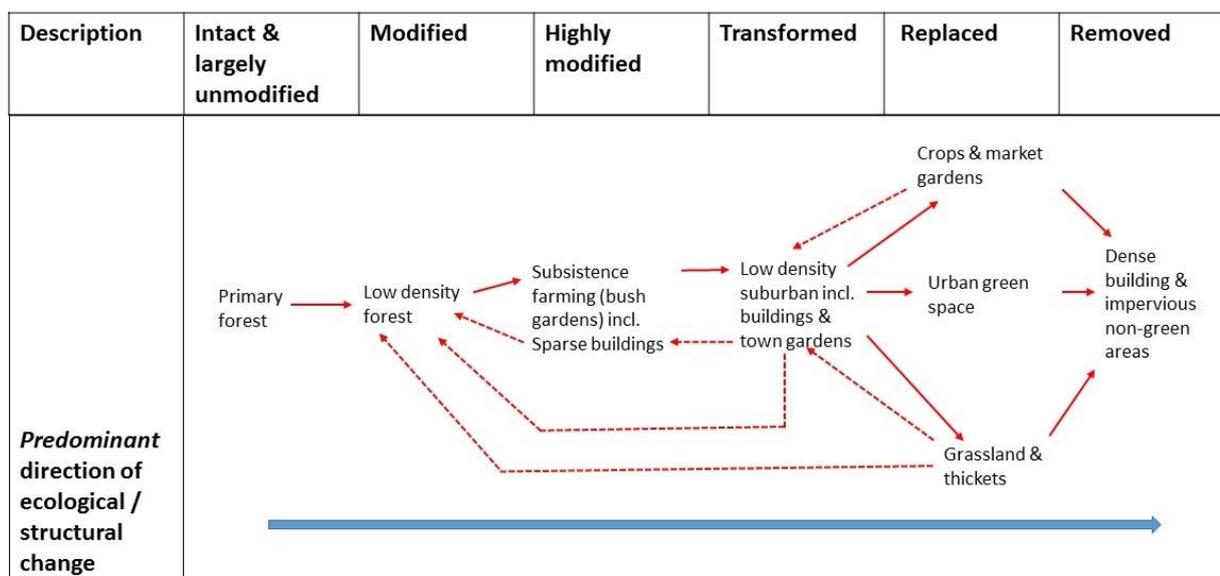


Figure 2.6 Predominant directions of ecological and structural changes in urban terrestrial land cover units

We have also considered the direction of ecological change or degradation of the land cover units (Figure 2.6). The column ‘ESRAM condition’ in Table 2.4 refers to the category of ecological change shown in Table 2.6, applied to each land cover type.

The arrows in Figure 2.6 crudely represent ecological processes such as the loss of trees and forest structure. They could represent changes that may happen in the future as well as past and current changes. As long as key ecosystem functions are not critically compromised and certain thresholds not crossed (such as key species becoming locally extinct, or gap size becoming too large in relation to forest tract size), forest degradation through loss of forest canopy cover and structure does not necessarily represent ‘deforestation’ nor is it necessarily a threat to future EbA (Fox et al. 2000; Finegan and Nasi 2004; Chazdon et al. 2009). However, population density-related deforestation due to shifting agriculture reported for Papua New Guinea (Shearman et al. 2009) does raise concerns for metropolitan Port Vila given the known and likely future population increase there. More specific research on forest cover trends and degradation processes over the whole of Efate is needed to increase understanding of this critical aspect of EbA planning.



Figure 2.7 Upper catchment forest, Port Vila

When the land cover units are remapped using the transformation categories shown in Table 2.6, the resulting map of ecosystem condition and land transformation is shown in Figure 2.8. This map shows that the degree of transformation generally increases towards the core of the Port Vila CBD, and that the forest in upper catchments is the largest area of intact ecosystems. However, there are some small areas of less modification and transformation relatively close to the Port Vila centre. The aerial analysis of the information mapped in Figure 2.8 is shown in Table 2.7.

Table 2.7 Port Vila’s ecosystem conditions based on ESRAM classification

ESRAM condition	Area (ha)	%
Intact	6,367	31.7
Modified/Replaced²	5,698	28.3
Highly modified	2,130	10.6
Replaced	3,695	18.4
Transformed	1,994	9.9
Removed	217	1.1
Total area	20,101	100

² This category is mainly modified forest but includes areas of thicket (replaced category) which occur in fine-scale mosaic with modified forest.

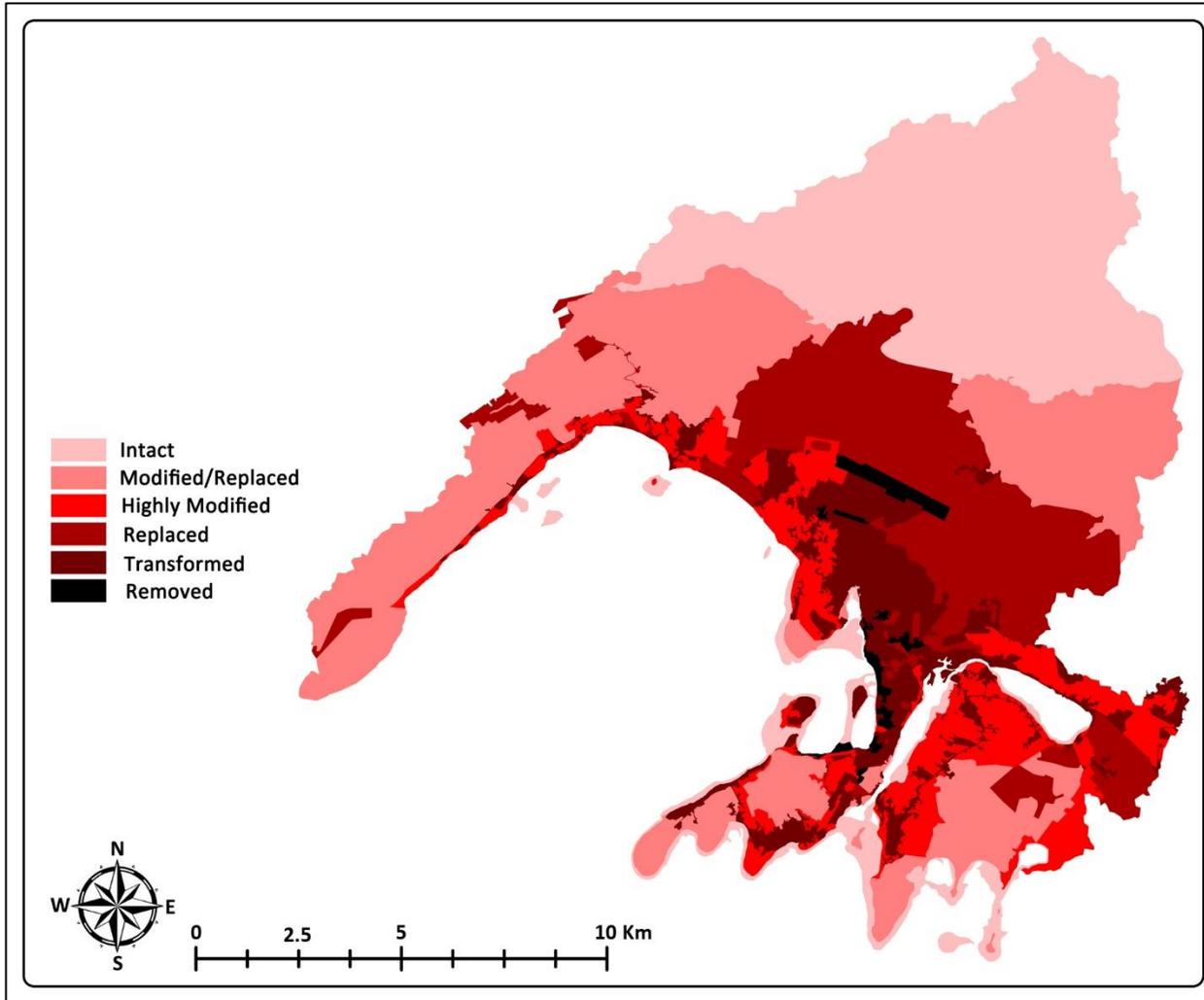


Figure 2.8 Map of ecosystem conditions and land transformation in Port Vila catchments

2.4.2 Coastal

Available results for coastal ecosystem services provision and demand are limited to coral reef habitats. Table 2.8 is derived from diving surveys to derive percent coral cover, personal communications from Port Vila workshop participants, divers, and other interested persons, and author's personal knowledge.



Figure 2.9 Vanuatu coral reef

2.4.2.1 Diver questionnaire

Four diving instructors from two recreational diving companies in Port Vila were interviewed. Three divers had been diving regularly in Port Vila for over twenty years, and the fourth for six months. All divers had extensive knowledge of coral and fish species in Port Vila, and an adequate to good understanding of reef ecosystems. The divers were asked questions regarding their perception of coral condition, fish and seagrass abundance, as well as trends and threats to the ecosystems they dive in. The divers were asked to rate reef condition as poor, medium or high for all dive sites. Sites with less than a quarter (25%) live coral cover were classified as poor. Sites with over 70% live coral cover were classified as high. For each reef, the diver ratings were compared, and where there was congruence with three or more perspectives, this rating was used.

Table 2.8 Comments on ecosystem services

Reef	% Hard Coral Cover*	Condition*	Provision	Demand
Blacksands	18	Poor	Landslip from 2003 earthquake increased sediment load in Tagabe River and smothered the reef. Very poor water quality. Poor visibility and light penetration reduces depth range of reef and photosynthetic lifeforms. Loss of top predators, piscivores, herbivores and invertebrate species from reef. Loss of other habitat: seagrass & mangroves. Decreased protection from cyclones and storm surges. Lot of flooding. This used to be a popular dive-spot, but no recreational dives since 2003.	Fishing has moved to other reefs, mainly Mele and Devil's Point. Increase in offshore fishing. Population increase has increased fishing pressure. Still a bit of recreational activity on the beach. Sand mining activities prevalent.
<i>Other comparable reefs: Malapoa</i>			Poor water quality due to oil leaks from ships, pollution from harbour, crown-of-thorns starfish (COTS). Loss of fish due to aquarium and shell trade	Fishing efforts have increased since the degradation of Blacksands
Mele (Emperor's Garden; landward reefs at Hideaway)			Emperor's Garden: Pollution (current carries plastics from Ifira to reef) Hideaway landward reef: Erosion from sand-mining has decimated the reef. Decreased protection from cyclones, storm surges. A lot of flooding. Increased sediment from Mele rivers	Fishing efforts increased. Use of mosquito nets to catch sardines. Recreation. Sand mining
Port Vila Harbour	15	Poor	Sedimentation from construction of Irifa point road and wharf. Seagrass smothered by sediment and sand during cyclone. Loss of seagrass habitat for dugong. Coral bommies decimated by TC Pam	Fishing, swimming, wreck diving (Tasman & Konanda)
<i>Other comparable reefs: Ifira Point, Vila, Konanda</i>			Reefs used as a dumpsite for rubbish, electronics, furniture. Anchor damage. Decrease in fish species. Decreased water quality	Konanda reef: used to train beginner divers.
Pango Cove Including nearby Reefs: Semle, Bougainvillea	31	Fair	COTS outbreak in 2010/2012 decimated reef. Reduction in fish. Increase in algal lifeforms. Top predators still present including whitetip reef sharks and yellowfin tuna at depth	Diving, swimming, fishing, aquarium and shell trade
<i>Other comparable reefs: Erakor, Eratap</i>			Exposed reef. COTS outbreak in 2012. Fish kills at Erakor due to high SST during 2016/2017 El Nino	Reefs are exposed and hard to access, therefore less fishing pressure. Not much diving, mainly snorkeling
Twin Bommies <i>Including nearby reefs: Kate's Corner, Vila 25, Konanda Wall</i>	64	Good	Remarkable resilience after COTS outbreak and TC Pam. Increased fish numbers over the past five years, including Yellowfin tuna. Clear waters, good recovery from TC Pam. Plenty of fast growing coral (<i>Acropora</i> sp.)	Easy access means increased fishing efforts from residents all around Vila. Popular dive sites and regular patrol for COTS. Tourism: many nearby coastal resorts
<i>Other comparable reefs: Pango Point, Mele (Devil's Point Rd)</i>			Good water quality, but decreasing due to coastal erosion from sand mining and coastal development. Biodiversity includes turtles, dugongs, sharks, reef invertebrates. Loss of seagrass	Popular diving sites. Recreation and increased fishing pressure from community members and other Port Vila residents

* Criteria for hard coral cover reef condition (Chou et al. 1994):

>75% cover = Excellent; <75% and >50% cover = Good; <50% and >25% cover = Fair; <25% and 0% cover = Poor.

Maps showing the condition of Port Vila reefs based on hard coral reef condition are shown in Figures 2.10–2.12. These maps clearly show the high spatial variability of reef condition with reefs closer to the coastal settlements being in poorer condition.

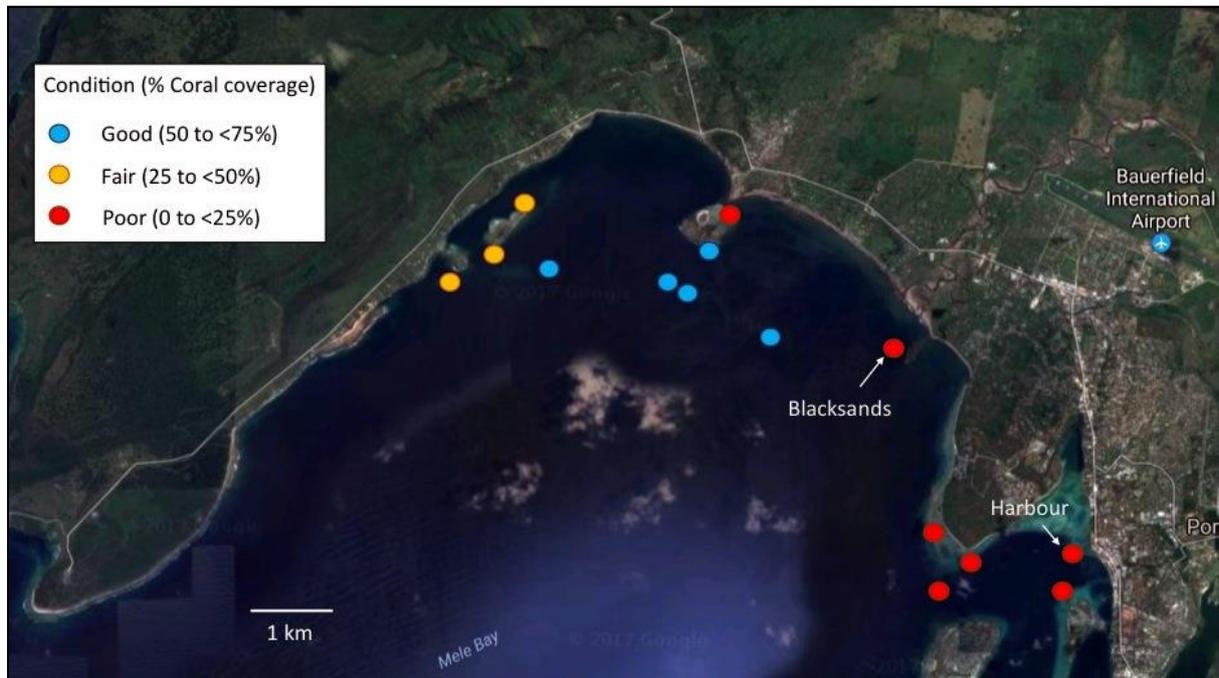


Figure 2.10 Reef condition at individual dive locations in Mele Bay and Port Vila Bay

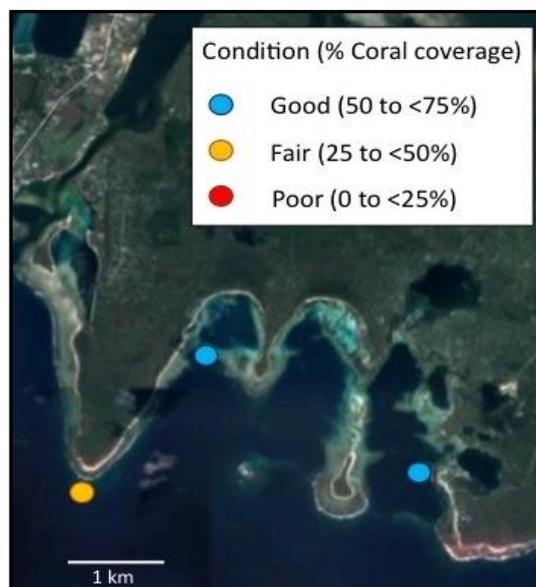


Figure 2.11 Reef condition at individual dive locations in Erakor and Eratap

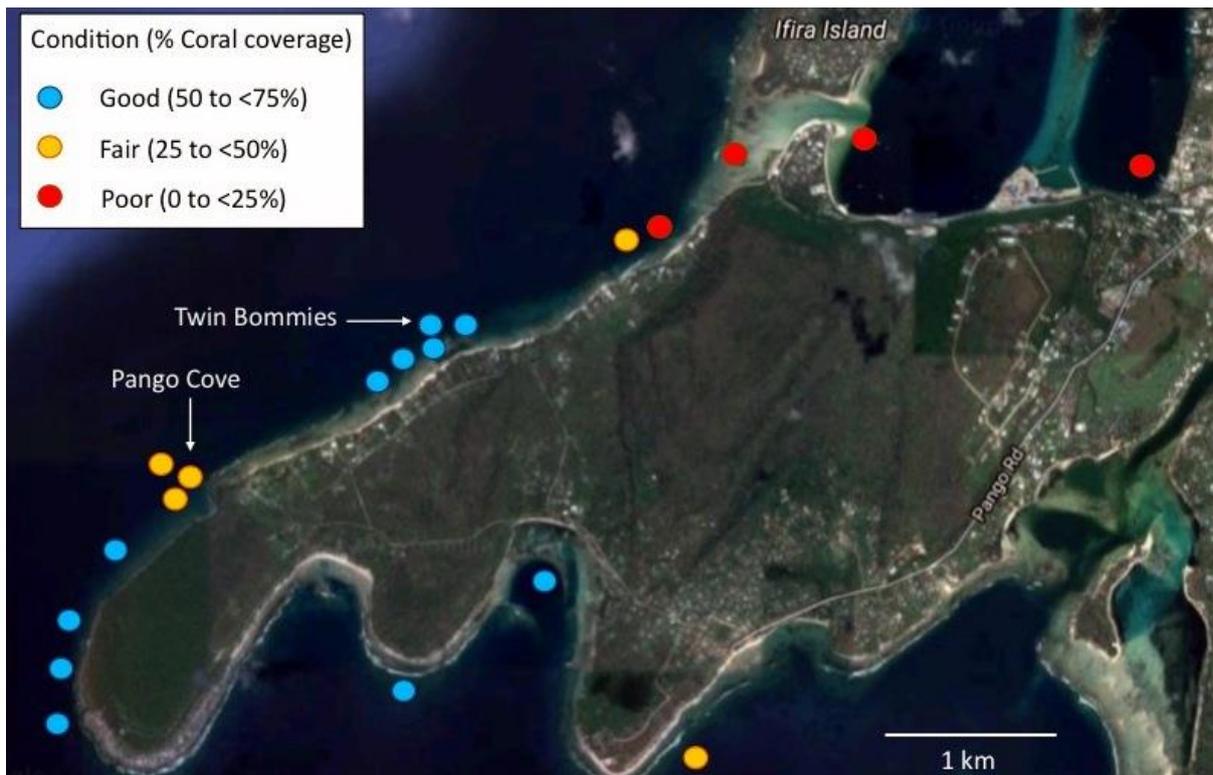


Figure 2.12 Reef condition at individual dive locations in Pango, Ifira and Port Vila Bay

2.4.2.2 Surveys of overall reef condition

Full results of direct observation and cover assessment are shown in Figures 2.13–2.17 and Table 2.9.

Table 2.9 Reef check codes for substrate categories

Code		Rationale
HC	Hard Coral	The major building component of the reef
SC	Soft Coral	Non-reef builder coral
SP	Sponge	Indicator of sewage pollution. Encrusting sponges directly compete with hard coral
NIA	Nutrient indicator algae	Indicator of nutrient pollution
RKC	Recently killed coral	Indicator of recent disturbance
RC	Rock (Including rock covered with turf and coralline algae)	Bare surface on which juvenile coral can settle
SI	Silt	Indicator of sedimentation
SD	Sand	
RB	Rubble	Indicator of storm or dynamite damage
OT	Other	Includes biota such as tunicates
Dead Coral*		Provides suitable substrate for settlement

*Dead coral is usually combined with the “Rock” category in Reef Check methods.

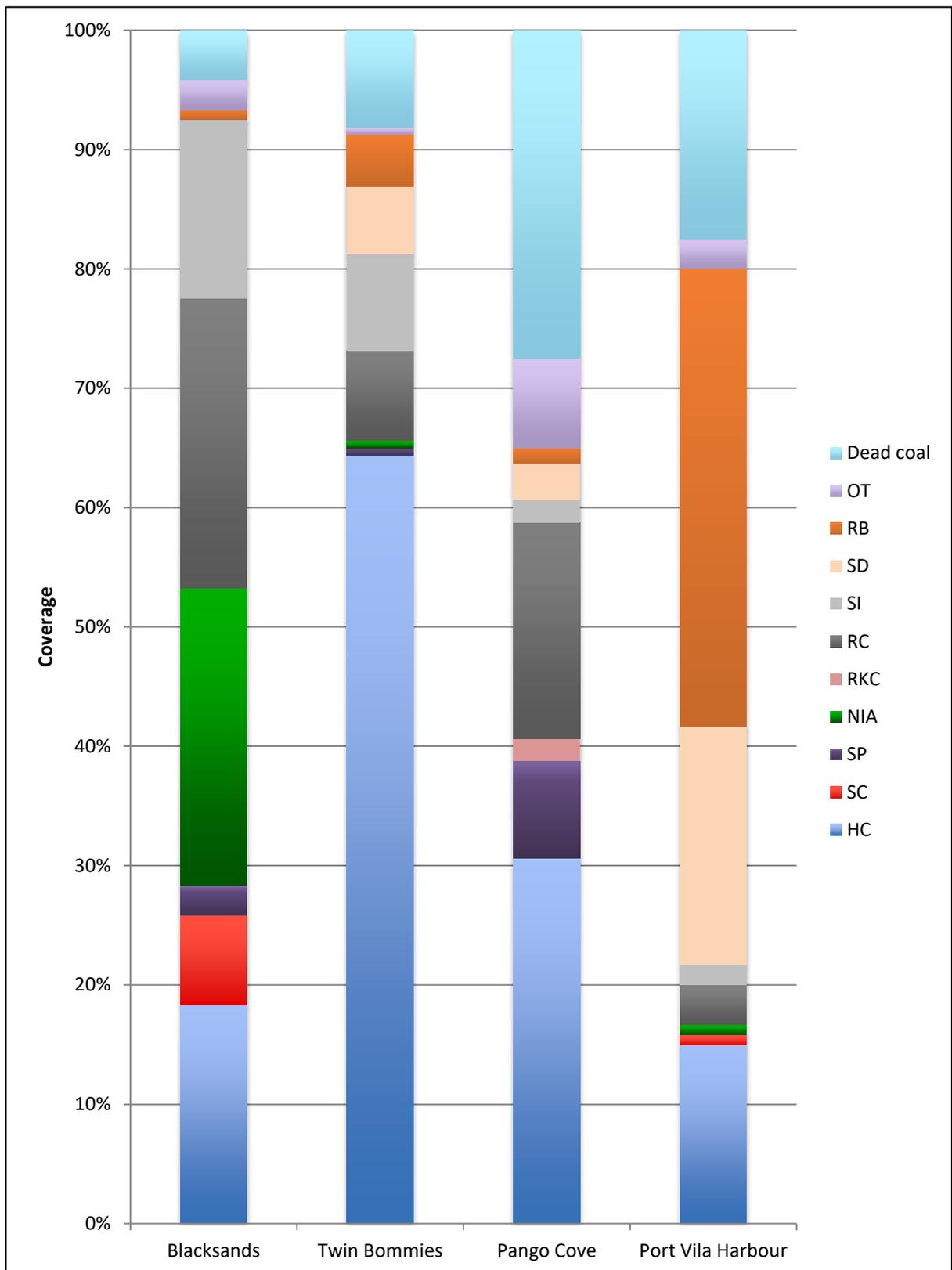


Figure 2.13 Benthic type and percentage cover for four Port Vila locations



Figure 2.14 Reef wall at Blacksands

The substrate is dominated by algae (25%), hard rock (24%) and silt (15%) reflective of very high nutrient conditions, increased sedimentation, loss of herbivores. Regime shift from coral-dominated to algal-dominated, including coralline and other calcareous algae. A few soft corals – zoanthids, toadstool coral/elephant ear (*Sarcophyton* sp.).



Figure 2.15 Reef at Twin Bommies

This site had the highest hard coral cover (64%) mainly composed of branching forms. The reef was destroyed by crown of thorns (COTS) outbreak 5 years ago and shows the capacity of reefs to recover given appropriate conditions.



Figure 2.16 Reef at Pango Cove

This site had the highest amount of dead coral (28%), reportedly due to recent COTS predation. There is high coralline and turf algae. Of the live corals, most are digitate and encrusting. Other biota (8%) include tunicates and halimeda.



Figure 2.17 Reef at Port Vila Harbour

The high percentage of sand (20%) is indicative of the reef type (coral bommies/patch reefs) whereby coral cover is low. Seagrass used to be present but majority of it has been covered by sand after TC Pam. Hard coral cover is still below optimum levels as evidenced by the high rubble levels (38%), mainly due to TC Pam. This reef type is quite vulnerable to storms and storm surges.

2.4.2.3 Discussion of reef health and threats

Port Vila coastline is characterised by extensive but narrow fringing reefs. The reefs around the Port Vila Harbour and Blacksands (Tagabe River mouth) have very low live coral cover of 15–18%. The remaining reefs around Port Vila have moderate to good live coral coverage (30–65%). This is similar to a previous survey that reported live coral cover between 30–40% at Pango (Pakoa, 2007), and 25–30% in Mele Bay (Raubani, 2009). Port Vila Bay sites have the highest percentage of rubble of all four sites surveyed. Seagrass beds in the harbour have been lost and degraded, mainly as a result of increased sediment input after recent cyclones.

The diver interviews reveal a low fish abundance on all reefs, in particular of piscivores (snappers and groupers) and large herbivores (parrotfish), although no quantitative measurements have been taken. The lack of data makes it hard to attribute these low abundances to any specific cause, although in the harbour and Blacksands one of the primary causes is likely to be land-based pollution (see Section 3.3.4).

Port Vila coral reefs have shown resilience to disturbances, especially on the north-western side of Pango peninsula (on reefs such as Twin Bommies) where there is good oceanic circulation.

Seagrass is prevalent in Fatumari Bay, Erakor lagoon, Nambatu lagoon and Eratap. However, detailed abundance or distribution data are not available. Diver interviews reveal that there used to be seagrass in Mele (near Teae River mouth) about 20 years ago, but this has been lost.

In summary, current key threats to the reef habitat on the Port Vila coastline include land-based pollution, the aquarium and shell trade (rife in the early 1990s and increasing again now), periodic crown of thorns starfish outbreaks, overfishing and natural hazards such as earthquakes, cyclones and tsunamis. It is anticipated that climate change will exacerbate some of these threats.

2.5 Conservation status of ecosystems and species

2.5.1 Habitats and ecosystem types

No systematic information is known concerning trends in the extent or condition of ecosystem types. The analysis of ecosystem condition based on ESRAM categories shows that 6,367 ha, a little over one third of the Port Vila catchments by area, is still substantially intact forest (Figure 2.7). As the island was almost entirely forested before human settlement, apart from small areas of coastal and riverine/riparian habitat, this proportion suggests that about two thirds of the catchment area has been modified or transformed by human disturbance. In the steep mid and upper catchment areas, mapped as 'intact forest', natural erosion and decline has been taking place as result of recurrent tropical cyclones. This can be clearly seen on Google images of the interior of Efate after TC Pam in March 2015 (Figure 2.18), showing multiple debris flows essentially bare of vegetation, which were still clearly visible in 2017 Google Earth imagery.

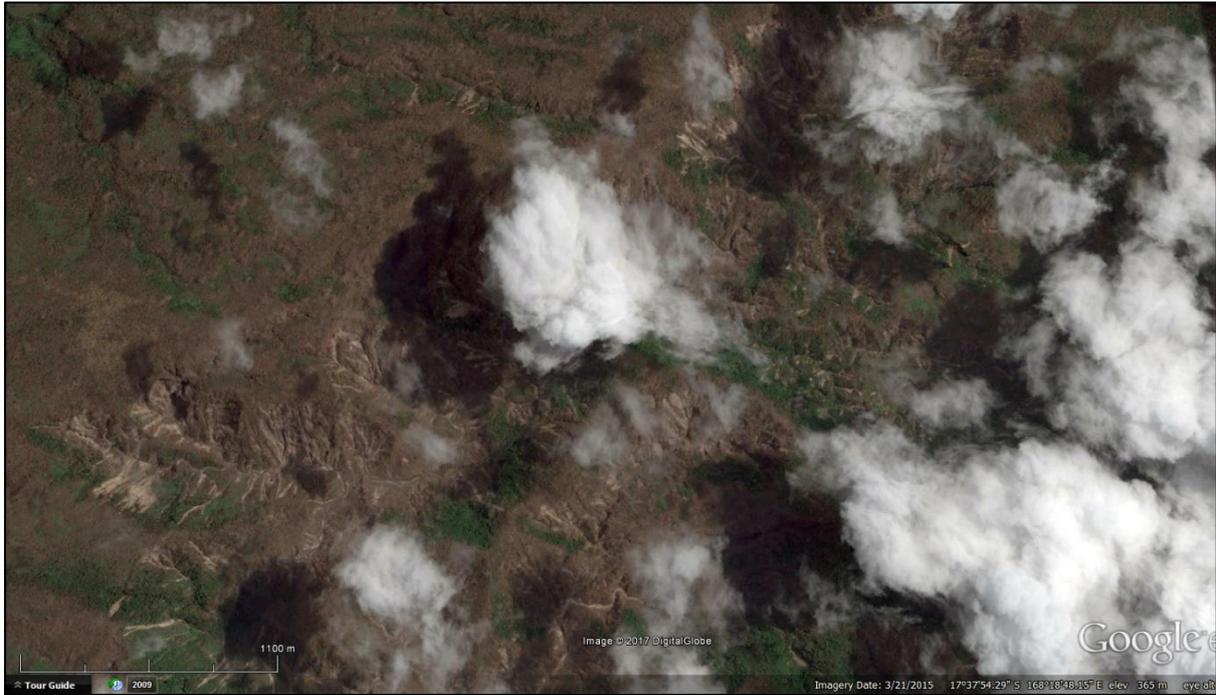


Figure 2.18 Aerial photo of multiple debris flows in upper Port Vila catchment following Tropical Cyclone Pam in March 2015 (Google Earth photo taken 26 March 2015)

In the coastal environment where development pressures have been acute, some natural habitat types have decreased in extent, notably coastal forest and mangrove ecosystems.

2.5.2 Species

Information on key native plant and animal species in the Port Vila catchment area and environs is summarised in Table 2.10. This compiles information on threat status, distribution and reasons for threat and/or critical species³. The table is drawn from published Vanuatu species surveys including the IUCN Red List, the Critical Ecosystems Partnership Fund (CEPF) Vanuatu Priority Species List; the SPREP Vanuatu State of Conservation Country Report for Vanuatu (SPREP 2013) and Country report to the Conference of Parties to the Convention on Biological Diversity (DEPC 2014b); the knowledge of the authors and personal communications from Port Vila informants and workshop participants.

³ 'Critical species' in this sense does not denote any particular threat level, but is loosely used to denote a species that is likely to be highly significant in delivering ecosystem services of some type.



Figure 2.19 Dugong

2.5.3 Biological indicators of ecosystem pressures

Table 2.11 shows potential indicator animal species for reef environments. Many of these species were discussed in McEvoy et al. (2016) as being species that were used by Port Vila residents for supply of ecosystem services. Here the species are listed that could be usefully monitored (in terms of presence in specified locations, or abundance), specifically those that indicate pressures on the Port Vila environment, as shown in columns 3–9. In practice, intensively monitoring of all these species would probably not be feasible.

Table 2.10 Vanuatu threatened and iconic species probably present in Port Vila metro area and catchments

Scientific name	Common name	Species-focused conservation action needed	Comments on Port Vila distribution	Critical species	Reason for selection as critical	Other information
<i>Dugong dugon</i>	Dugong	Control of overexploitation	Occasional in shallow coastal habitats	C	Largest and most iconic Vanuatu mammal. Traditionally hunted but also subject to hunting bans	http://www.dugongconservation.org/where-we-work/vanuatu/
<i>Emballonura semicaudata</i>	Polynesian sheath-tail bat	Control of overexploitation	Probably erroneous report from Vanuatu, based on one specimen only			
<i>Pteropus anetianus</i>	Vanuatu flying-fox	Control of overexploitation	Forested habitat	C	Listed as vulnerable on IUCN Red List	
<i>Tadarida bregullae</i>	Fijian mastiff bat	Control of overexploitation	Possibly in forested habitat			
<i>Notopterus macdonaldi</i>	Fijian blossom bat	Control of overexploitation ?	Reported from Efate. Vulnerable in Vanuatu but is not on CEPF priority list	C?	Likely to be vulnerable bat species on Efate	
<i>Erythrura regia</i>	Royal parrot finch	Control of overexploitation	Known in North Efate, golf course			
**Ducula pacifica	Pacific imperial pigeon	Control of habitat loss & species mortality	Shrubland, forest			https://mol.gov.vu/index.php/en/vanuatu-s-flora-and-fauna/206-what-species-are-endangered
<i>Megapodius layardi</i>	Vanuatu megapode	Control of overexploitation and habitat loss	Known in North Efate	C	Endemic to Vanuatu. Eggs were harvested traditionally	
<i>Caretta caretta</i>	Loggerhead turtle	Control of overexploitation	Occasional in shallow coastal habitats			Turtles (species not known) illegally caught around Mele and Devil's point
<i>Chelonia mydas</i>	Green turtle	Control of overexploitation	Shallow coastal habitats			
<i>Dermochelys coriacea</i>	Leatherback turtle	Control of overexploitation	One record in Port Vila. May be extinct in Efate			

<i>Eretmochelys imbricata</i>	Hawksbill turtle	Control of overexploitation				
<i>Carpoxylon macrospermum</i>	Carpoxylon palm	Population management	Planted around Port Vila			
<i>Intsia bijuga</i>	Mollucan ironwood	Control of overexploitation	Common around Port Vila. Mainly planted but probably also native			
Other fern species	Other fern species	Population management?	Further information at 'Secret Garden'			
Other plants species	Other plants species	Population management?	Further information at 'Secret Garden'			
<i>Cromileptes altivelis (Epinephelus altivelis)</i>	Humpback grouper	Control of overexploitation	Found in Pango, Mele reefs and Erakor lagoon and reefs	C	Harvested commercially and for subsistence. Top-level reef predator (keystone species)	https://mol.gov.vu/index.php/en/vanuatu-s-flora-and-fauna/206-what-species-are-endangered
**<i>Panulirus sp</i>	Lobsters	Control of overexploitation	Intertidal to subtidal rocky shores/reefs		Harvested for subsistence and commercially	https://mol.gov.vu/index.php/en/vanuatu-s-flora-and-fauna/206-what-species-are-endangered
<i>Birgus latro</i>	Coconut crab	Control of overexploitation and habitat loss	Distributed around Port Vila, e.g. Pango, Mele, Blacksands, Tagabe, Etas, Erakor. Live on land in underground burrows, caves and rock crevices		Harvested for subsistence. Feed on fallen Pandanus fruit and coconut palm. Complex lifecycle and slow growth rates make them even more vulnerable. Coastal development destroys habitat	Data Deficient species
<i>Tridacna gigas</i>	Giant clam	Control of overexploitation	Reef flats and lagoons. All but disappeared on Vila reefs	C	Food source. Important ecological function (increases reef complexity, water purification and nutrient cycling)	Actively reseeded by Fisheries Dept. around Efate, but not in Port Vila
<i>Turbo marmotarus</i>	Green snail	Control of overexploitation	Currently found in Pango & Mele reefs. Usually among the first to disappear on degraded reefs, e.g. Blacksands			Ecological and economic indicator species. Actively reseeded by Fisheries Dept. around Efate, but not in Port Vila

<i>Trochus niloticus</i>	Trochus shell	Control of overexploitation	Used to be common around Port Vila. Now currently occur in Pango & Mele. Usually among the first to disappear on degraded reefs, e.g. Blacksands			Ecological and economic indicator species. Actively reseeded by Fisheries Dept. around Efate, but not in Port Vila
9 species	Sea cucumber	Population management	Blackfish (<i>Actinopyga miliaris</i>) and sandfish (<i>Holothuria lessoni</i> , <i>H. scabra</i>) common around Pango and Erakor. Seagrass, lagoon and reef (intertidal to <200m) habitats	C	Harvested mainly for export to Asian markets. Key role in sediment filtration and nutrient cycling	5-yr moratorium on sea cucumber harvesting 2008–2013 by Fisheries Dept. Re-imposition being considered
<i>Charmosyna palmarum</i>	Green palm lorikeet		In the 1960s it disappeared from Efate, but were seen again on Efate in 1998 (Diamond 1975, Bregulla 1992, S. Birchenough and S. M. Evans verbally 1998)	C?	Endemic to Vanuatu and Solomon Islands	http://www.iucnredlist.org/details/22684661/0
<i>Triaenodon obesus</i>	White-tip reef shark	Control of overexploitation	Inshore, shallow water habitat	C	Important reef predator (key-stone species). Increased fishing pressure threatens species due to restricted habitat and depth range. Illegally caught in Mele and Pango. Fins and jaws sold	Include other reef sharks: grey reef and blacktip
<i>Galeocerdo cuvier</i>	Tiger shark		Medium to deep water habitats (epipelagic and deeper). Sighted around Blacksands reefs			Important predator
Various palm species	Various palm species					https://mol.gov.vu/index.php/en/vanuatu-s-flora-and-fauna/206-what-species-are-endangered
Various orchid species	Various orchid species					https://mol.gov.vu/index.php/en/vanuatu-s-flora-and-fauna/206-what-species-are-endangered

Non-threatened critical species						
Nine spp in Vanuatu	Seagrass	Population and habitat management		C	Habitat critical ecologically and for subsistence. Main coastal habitat for dugong	http://www.dugongconservation.org/where-we-work/vanuatu/
<i>Heritiera littoralis</i>, <i>Rhizophora stylosa</i>	Mangrove	Control of habitat loss	<i>H. littoralis</i> at landward boundary, <i>R. stylosa</i> extends further into intertidal zone	C	Habitat for subsistence foods including Caledonian crabs, oysters, mangrove shells. High quality timber (also harvested for food and medicine?)	
<i>Santalum austrocaledonicum</i>	Sandalwood			C	Valued for timber and as amenity large tree	
<i>Charonia tritonis</i>	Triton's trumpet shell	Control of over-exploitation and population management	Sighted at Pango. Shallow water reef habitat, and sandy substrate		Voracious predator. Preys on crown of thorns starfish. Economically important. Illegally harvested for its shell	https://mol.gov.vu/index.php/en/vanuatu-s-flora-and-fauna/206-what-species-are-endangered

** Species listed as Endangered on the Vanuatu Department of Environment website, but not 'threatened' on IUCN Red List.

*Vanuatu threatened species information from IUCN Red List and CEPF Vanuatu Priority Species List.

Note that CEPF list does not include Data Deficient species. Information on Port Vila distribution largely based on comments from Christina Shaw VESS (personal com.)

Table 2.11 Potential biological (species) indicators of Port Vila reef condition and pressure

Common Name	Scientific Name	Overfishing	Water quality/ Pollution	Coral damage	Coral-Algal phase shift	Predator-Prey Balance	Aquarium collection	Curio collection
FISH								
Butterflyfish, Batfish and Bannerfish	Chaetodontidae; ehippidae	X			X		X	
Sweetlips	Haemulidae	X			X		X	
Grouper	Serranidae	X						
Snapper	Lutjanidae	X						
Parrotfish	Scaridae	X			X			
Moray eel	Muraenidae	X					X	
Barrumundi cod	<i>Cromileptes altivelis</i>	X					X	
Humphead wrasse	<i>Cheilinus undulates</i>	X				X	X	
Bumphead parrotfish	<i>Bolbometopon muricatum</i>	X			X			
Rabbitfish	Siganidae	X			X			
INVERTEBRATES								
Banded cleaner shrimp	<i>Stenopus hispidus</i>						X	
Rock and slipper lobsters	<i>Panulirus sp.</i> ; Scyllaridae	X						
Crown of thorns starfish	<i>Acanthaster planci</i>		X	X		X		
Diadem urchin	<i>Diadema sp.</i> ; <i>Echinothrix sp.</i>		X					
Pencil urchin	<i>Heterocentrotus mammillatus</i>		X					X
Collector urchin	<i>Tripneustes sp.</i>		X					X
Edible sea cucumbers	Holothurians	X						
Giant clams	<i>Tridacna sp.</i> ; <i>Hippopus sp</i>	X						X
Triton shell	<i>Charonia tritonis</i>	X				X		X
Trochus	<i>Trochus niloticus</i>	X						X
Green snail	<i>Turbo marmoratus</i>	X						X
Snails	<i>Drupella spp.</i>			X		X		
Cowrie shell	<i>Cypraeidae spp.</i>							X
Turban shell	<i>Turbo petholatus, Turbo chrysostoma</i>							X

3 Impacts of climate change and human activities on Port Vila's ecosystems and people

3.1 Introduction

Section 2 of this report focussed on the current status of species ecosystems, habitats and species of Port Vila, examining types, spatial distribution, extent and condition. This section focusses on the impacts of current ecosystem processes, climate change and human activities on those ecosystems and habitats.

The initial sections of this chapter provide an ecosystem services context to the analysis, then focus on both the causes and the impacts of degradation of Port Vila's ecosystems and the services they provide. Firstly, the causes and impacts are examined in terrestrial, freshwater and coastal environments, focussing on specific impacts of various activities and land uses. The chapter then examines the impacts of water, sediment and nutrient flows, and the effects of climate change. The chapter concludes with a summary of the most significant climate change and degradation effects on the communities and people of Port Vila.

3.1.1 Methodology

Most of Section 3 was undertaken as a desk-top analysis of existing data and literature, drawing also on the results of team and Port Vila community workshops. However, for Section 3.3 a new analysis was made of flows of water, sediments and nutrients in Port Vila ecosystems, using available data and a team-devised methodology. This methodology is separately reported in Section 3.3.

3.1.2 Ecosystem services framework

Functional linkages between Port Vila ecosystems and the community benefits of having healthy ecosystems are made through an ecosystem services conceptual framework. Ecosystem services are the benefits that humans derive, either directly or indirectly from the functions of ecosystems (Costanza et al. 1997). They have been described as '*the aspects of ecosystems consumed and utilised to yield human well-being*' (Turner and Daily 2008). Ecosystem services are fundamental to basic human survival and human wellbeing (Figure 3.1) (MEA 2005a; TEEB in Local Policy, 2011). A focus on ecosystem services has been widely adopted among ecology and policy professionals (Carpenter et al. 2009) and was formalised by the United Nations' Millennium Ecosystem Assessment of ecosystems and human wellbeing (MEA 2005a; 2005b).

The more recent Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) Conceptual Framework provides a related model of interactions between nature and people, focussed on sustainability (Figure 3.2) (Diaz et al. 2015). This framework is useful for EbA because it shows clear linkages between both natural and anthropogenic drivers of impacts on nature and ecosystem services and links these to human wellbeing.

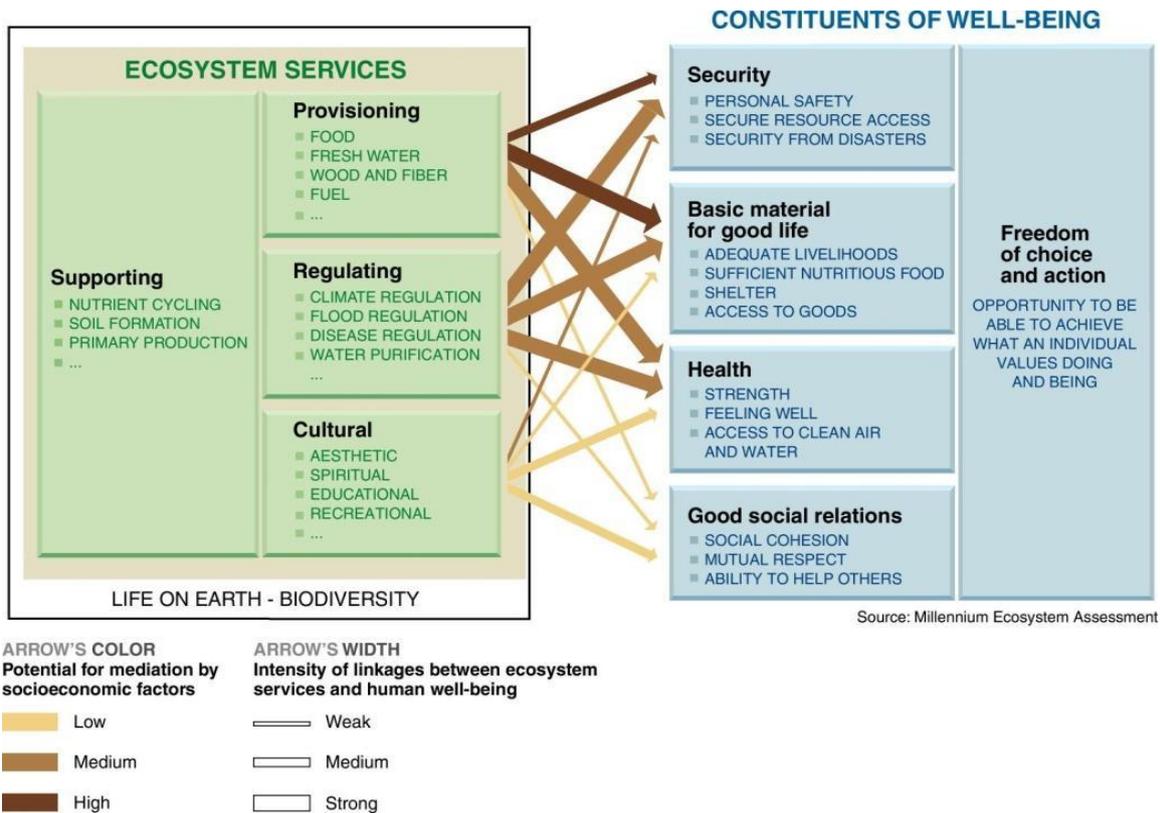


Figure 3.1 Relationships between ecosystem services and human wellbeing (source: MEA, 2005)

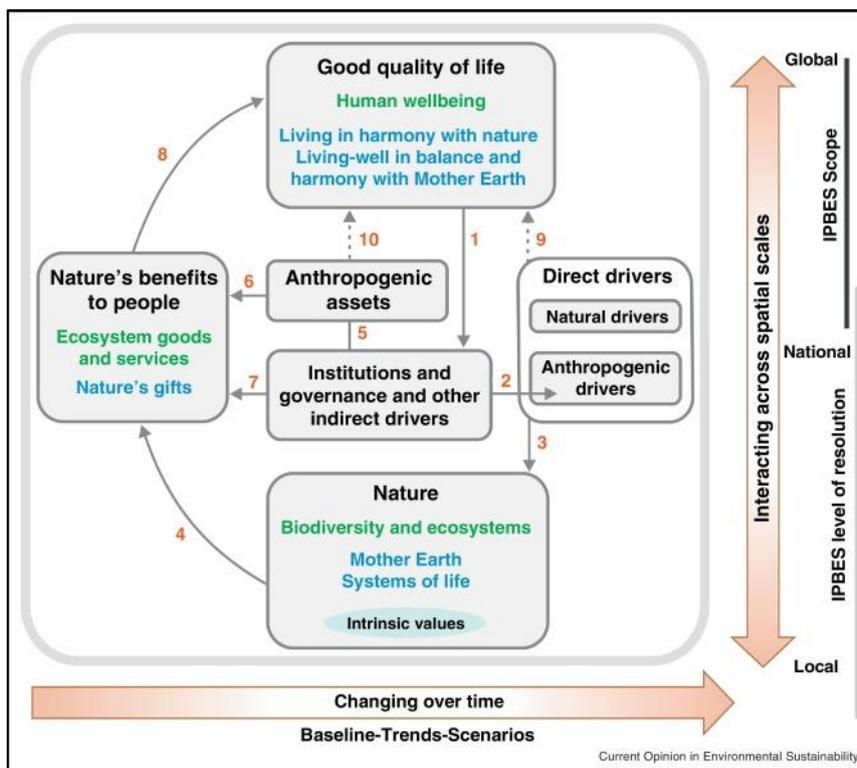


Figure 3.2 IPBES conceptual framework (source Diaz et al., 2015)

The services that humans receive from ecosystems can be divided into: provisioning services such as food and medicines; regulation services such as pollination and climate regulation; supporting services such as soil formation and fixation of solar energy; and cultural services such as artistic inspiration and recreation (Figure 3.3). The global condition of most ecosystem services except for the provisioning of food and raw materials has declined over the past fifty years (Carpenter et al. 2009; MEA 2005a). In fact, ecosystems have changed more in the last fifty years than in any other period of human history (MEA 2005b). This change can also be seen clearly in Vanuatu and Port Vila (McEvoy et al. 2016; Mackey et al. 2017; this project).

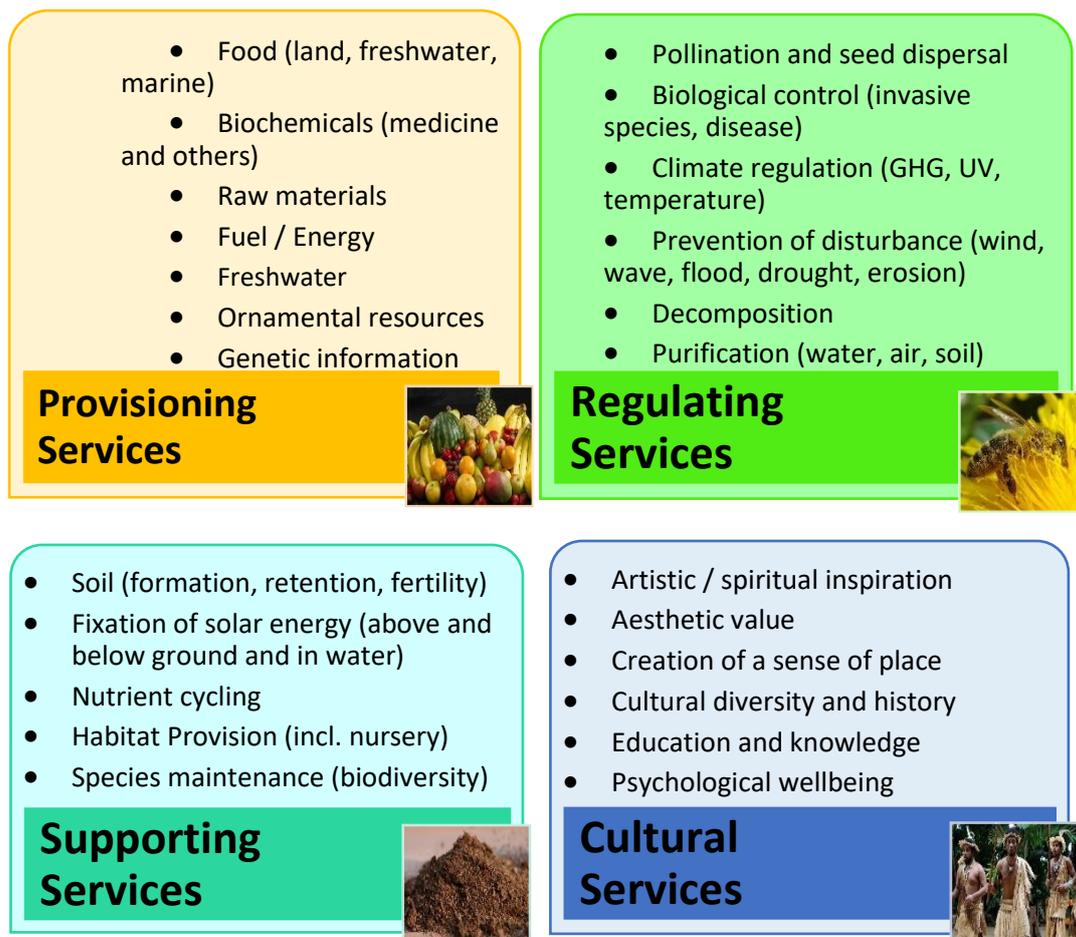


Figure 3.3 Ecosystem services (adapted from: Pedersen Zari 2012)

Understanding ecosystem services aids in the setting of policy and development of tools to support the development of EbA approach and other environmental management approaches. It also supports the development of financing mechanism for these approaches, e.g. determining how much polluters should pay or how much protectors and regenerators of ecosystem services should be compensated (Carpenter et al. 2009; TEEB in Local Policy 2011). Examples of the many schemes incorporating an ecosystem services approach that have emerged in the last decade include: direct compensation paid to land owners for ecosystem services; payments for environmental management services; conservation banking; tradable habitat rights; debt-for-nature swaps; insurance schemes; and tax relief programmes. Turner and Daily (2008) provide numerous case studies.

3.2 Causes and impacts of ecosystem degradation in Port Vila

The causes of ecosystem degradation can be split into two main categories in the Port Vila context: activities of people living in Port Vila (such as overharvesting, pollution, and rapid unplanned urbanisation), and climate change (impacts include changes to rain and weather patterns). Other causes of ecosystem degradation may be due to natural disasters such as earthquakes, tsunamis, cyclones or volcanic eruptions, some of which are outside the scope of this report.



Figure 3.4 Port Vila Landfill: a source of pollution of land, underground water and lagoons

Figures 3.5, 3.8 and 3.11 briefly summarise some major causes of ecosystem degradation in the Port Vila context in terms of terrestrial, freshwater, coastal and marine ecosystems (top rows) and illustrate that these ecosystems are linked within a ridge to reef context. They also demonstrate (bottom rows) the impacts that this degradation has both on other aspects of ecosystems and on human wellbeing, and therefore overall resilience to climate change. Figures 3.6, 3.7, 3.9, 3.10, 3.12 and 3.13 show a spatial representation of these changes across a Port Vila transect.

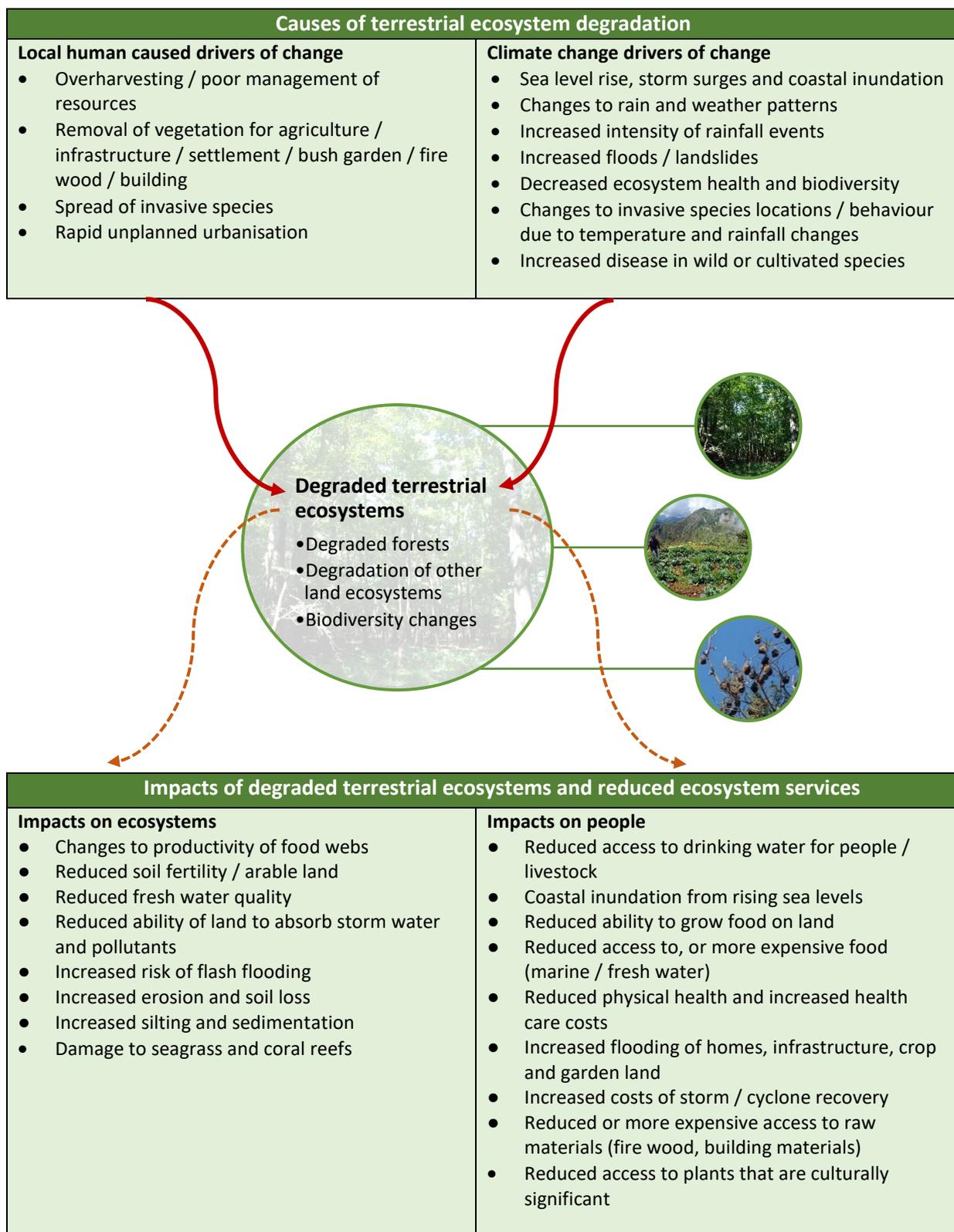


Figure 3.5 Causes and impacts of degradation in terrestrial Port Vila ecosystems

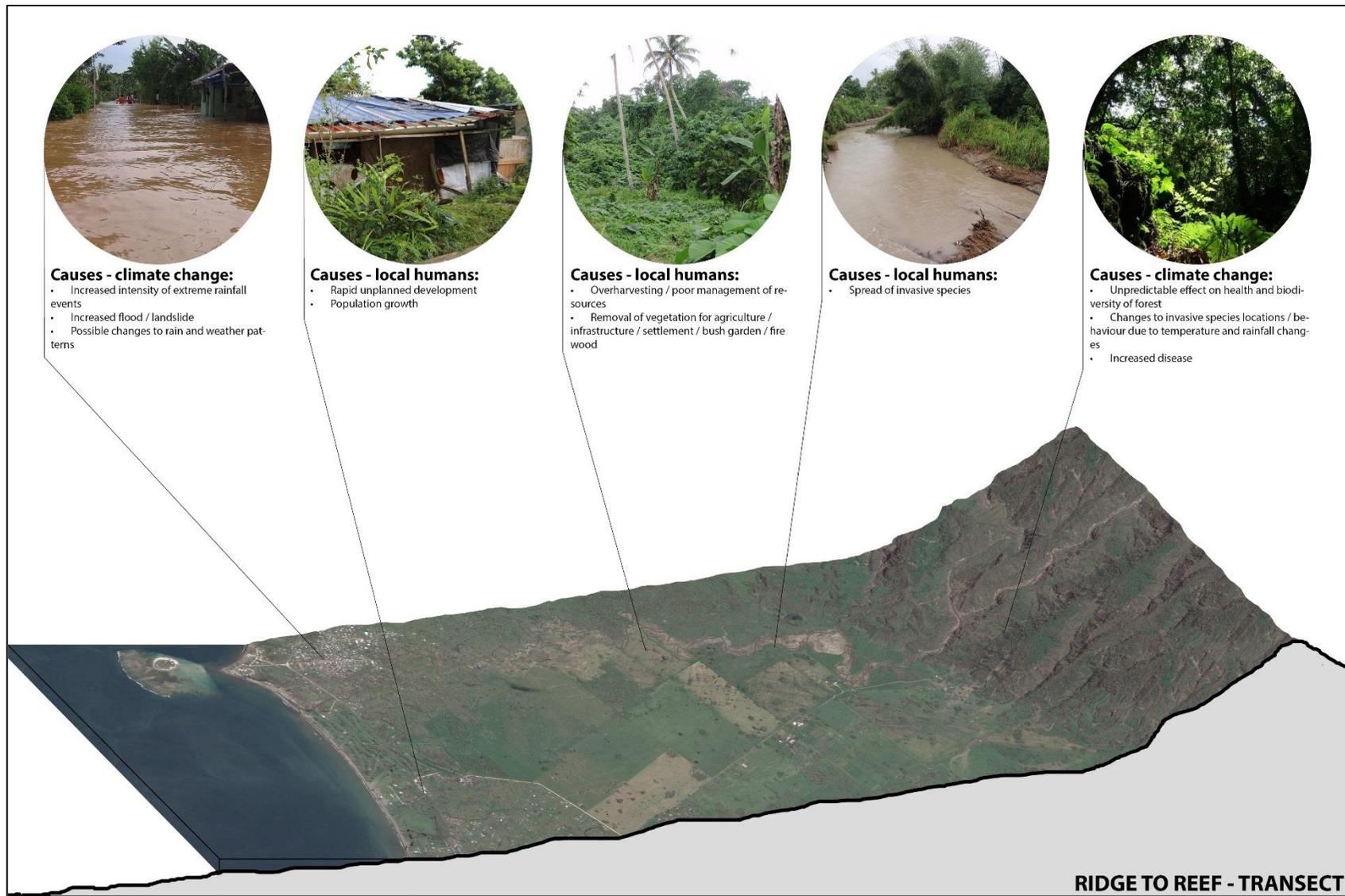


Figure 3.6 Causes of degradation of terrestrial ecosystems: Port Vila transect

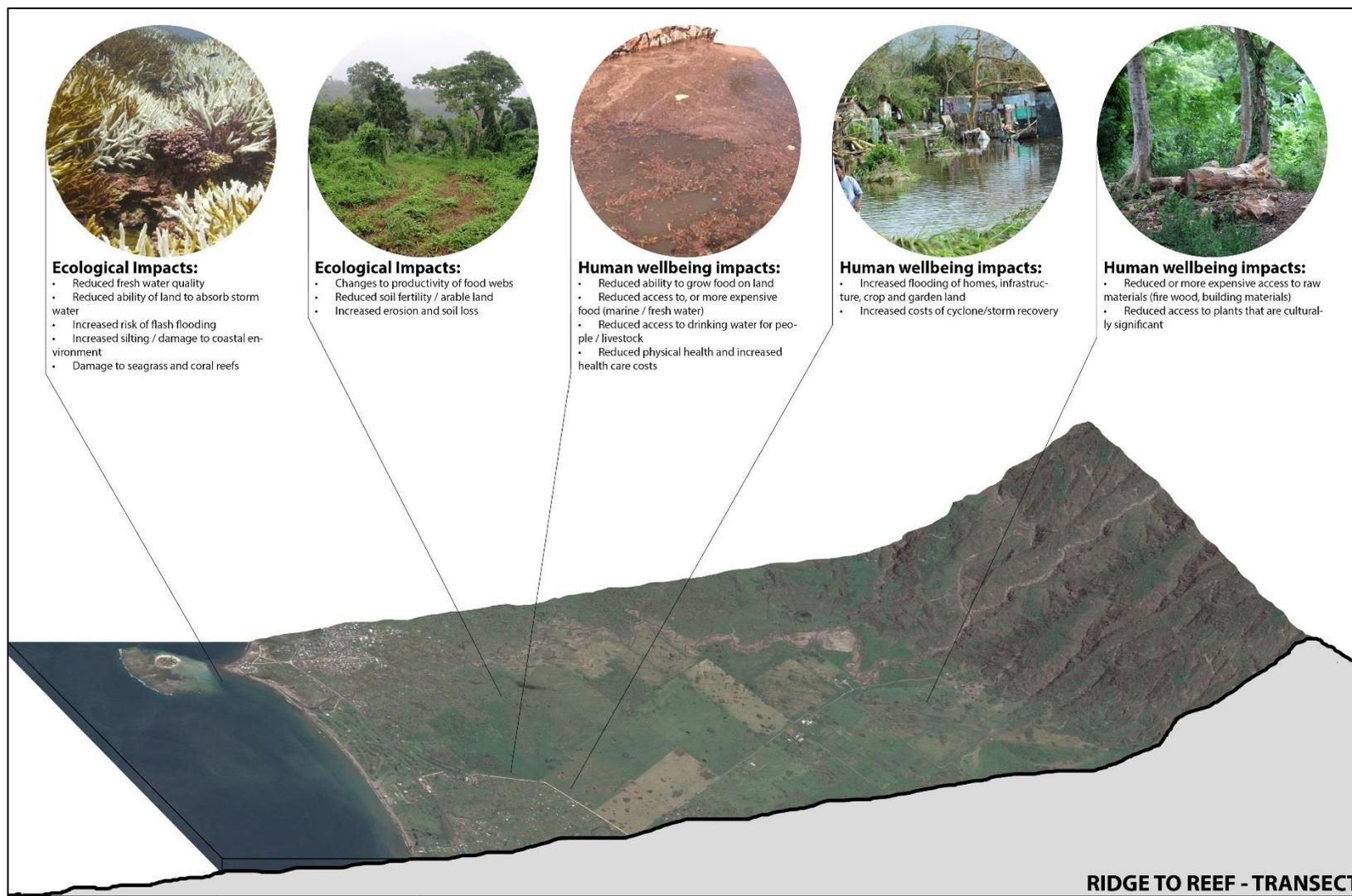


Figure 3.7 Impacts of degradation of terrestrial ecosystems: Port Vila transect

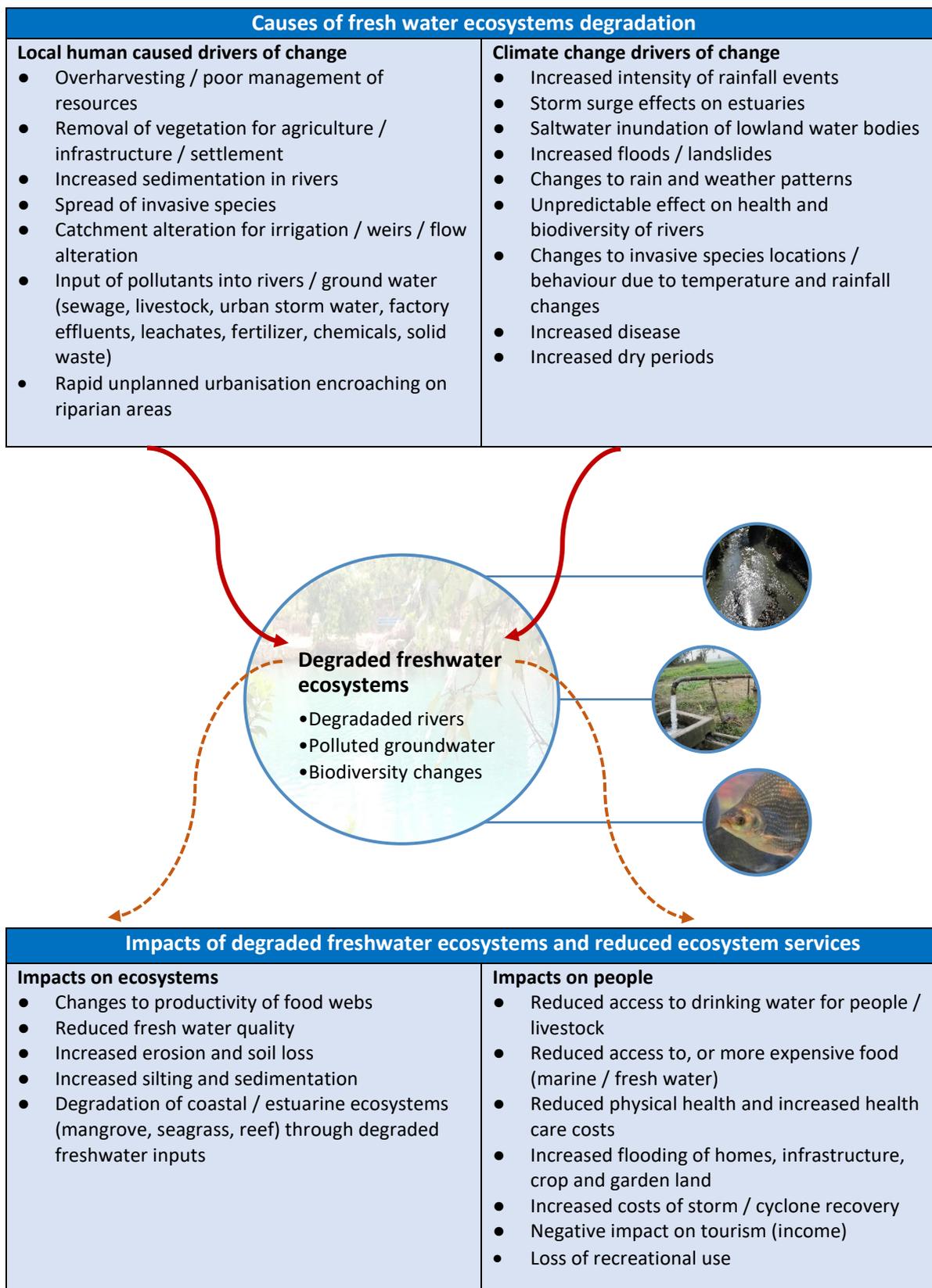


Figure 3.8 Causes and impacts of degradation in freshwater Port Vila ecosystems

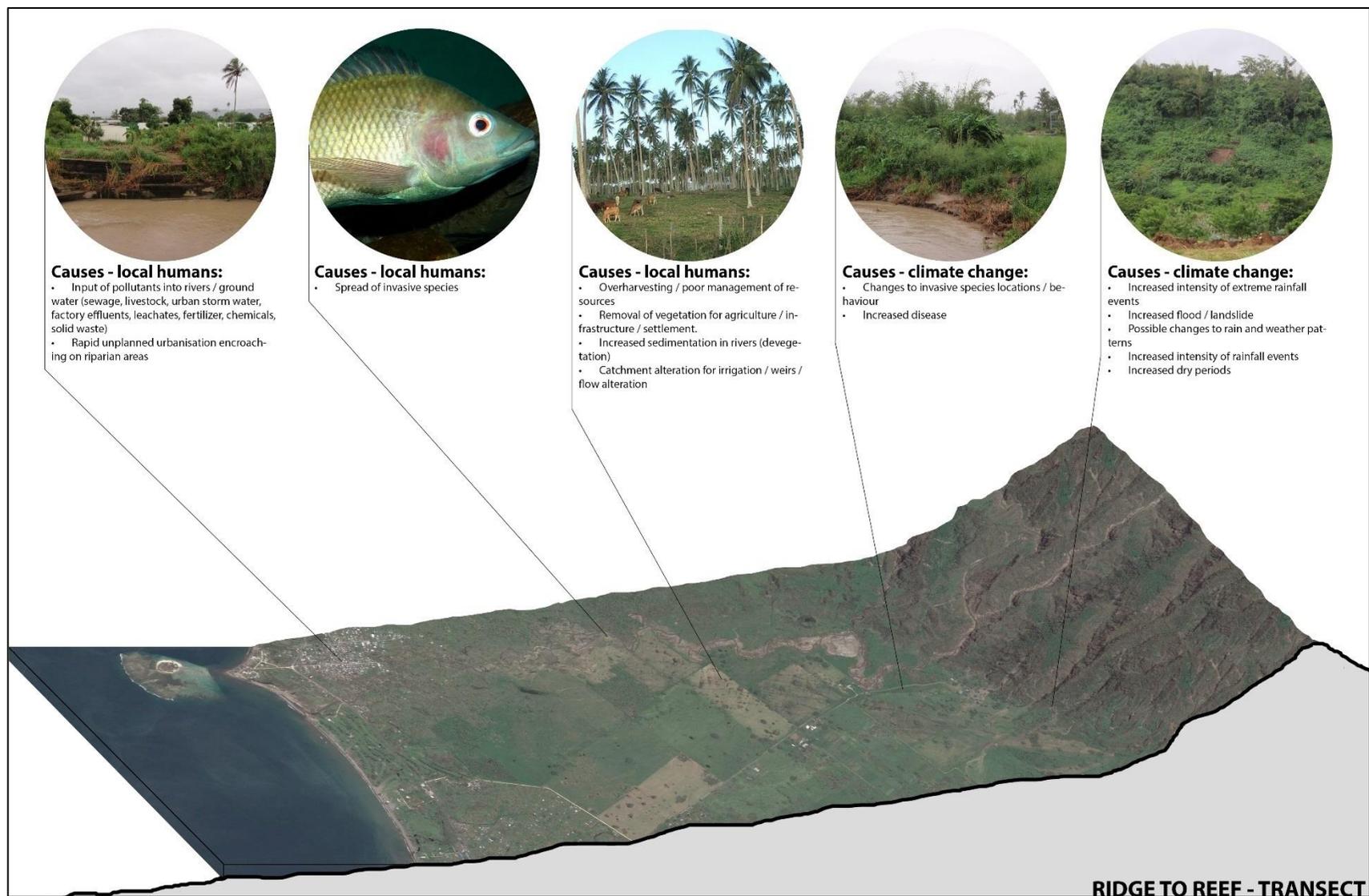


Figure 3.9 Causes of degradation of freshwater ecosystems: Port Vila transect

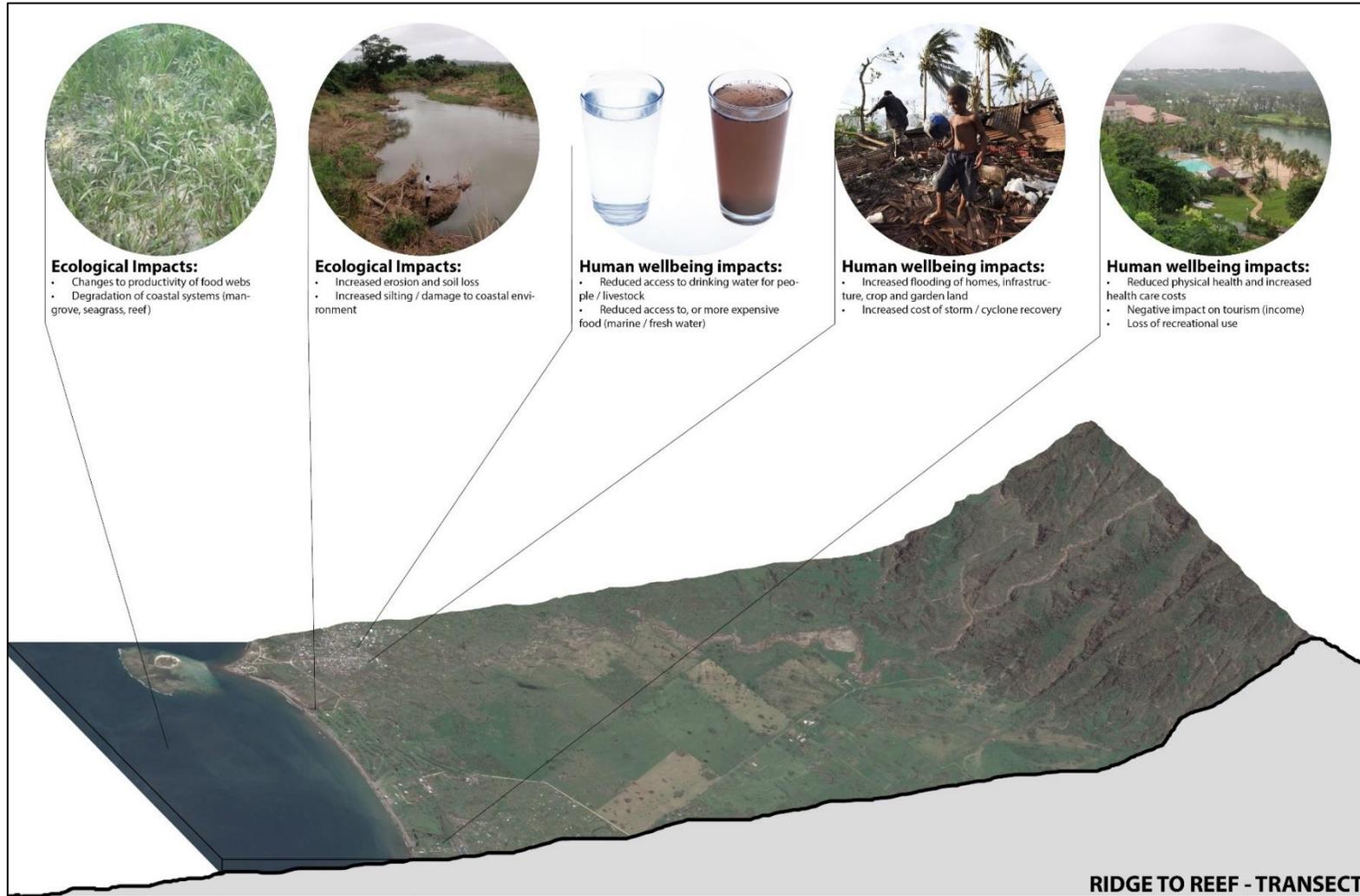


Figure 3.10 Impacts of degradation of freshwater ecosystems: Port Vila transect

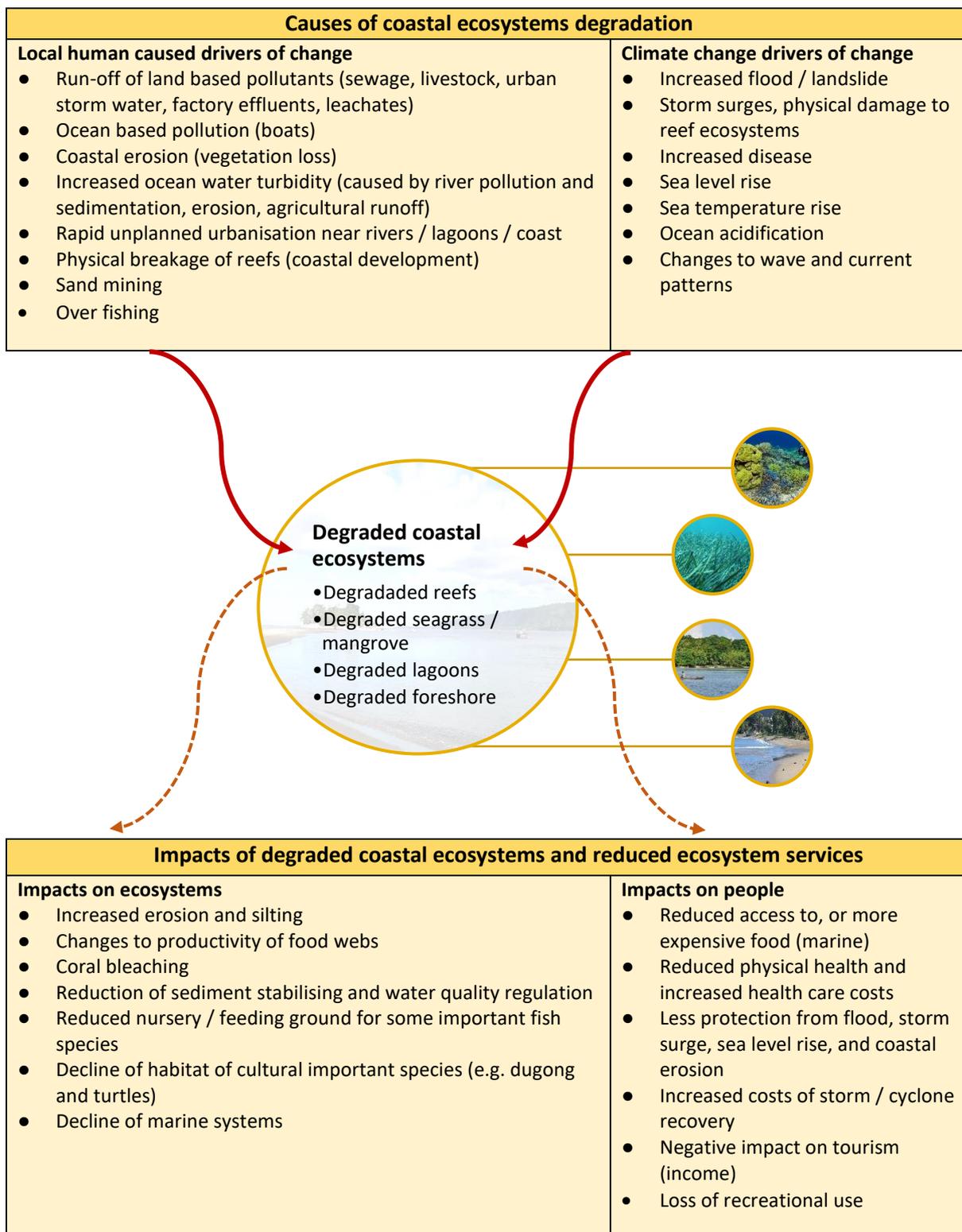


Figure 3.11 Causes and impacts of degradation of coastal Port Vila ecosystems

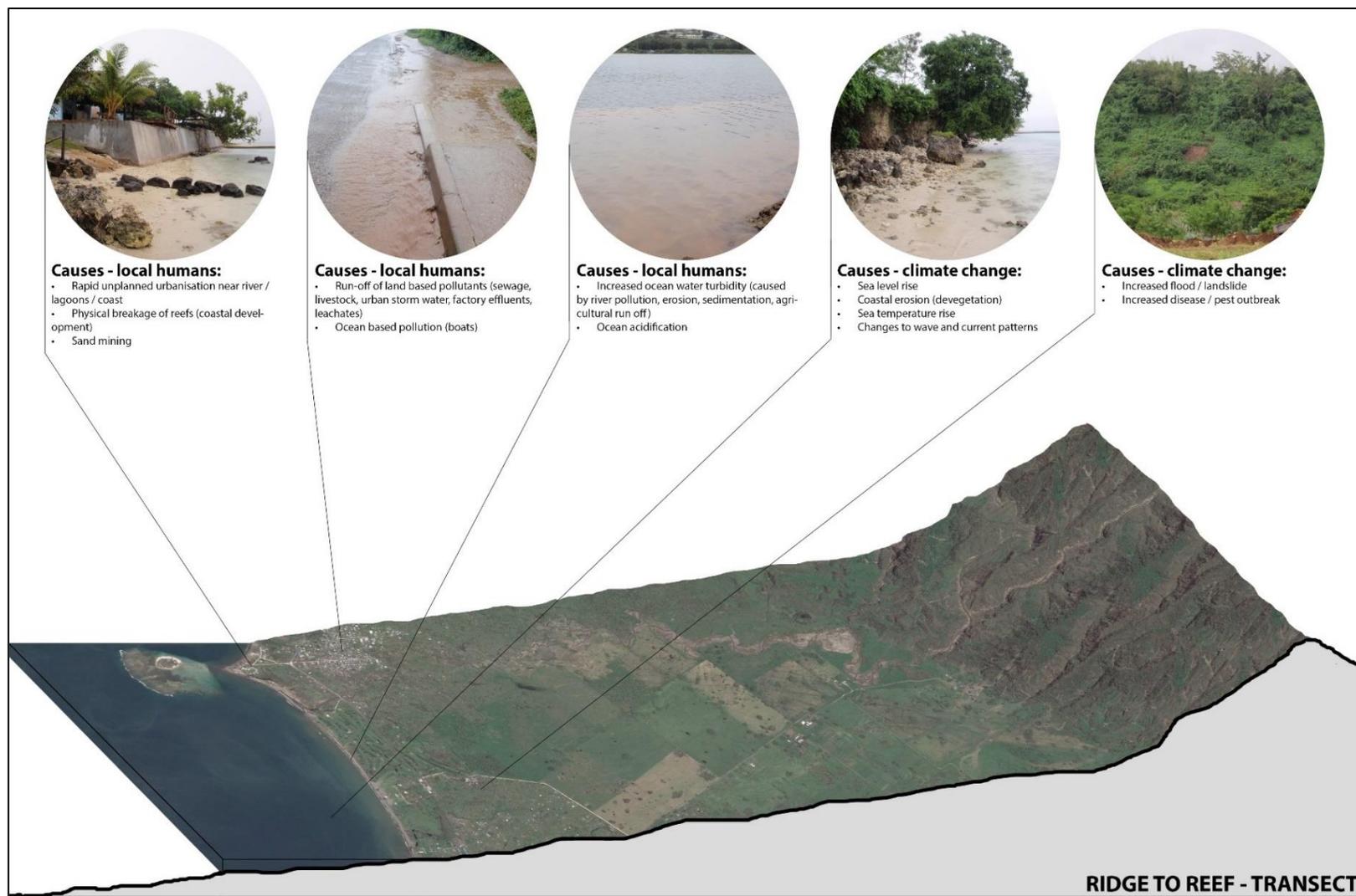


Figure 3.12 Causes of degradation of coastal ecosystems: Port Vila transect

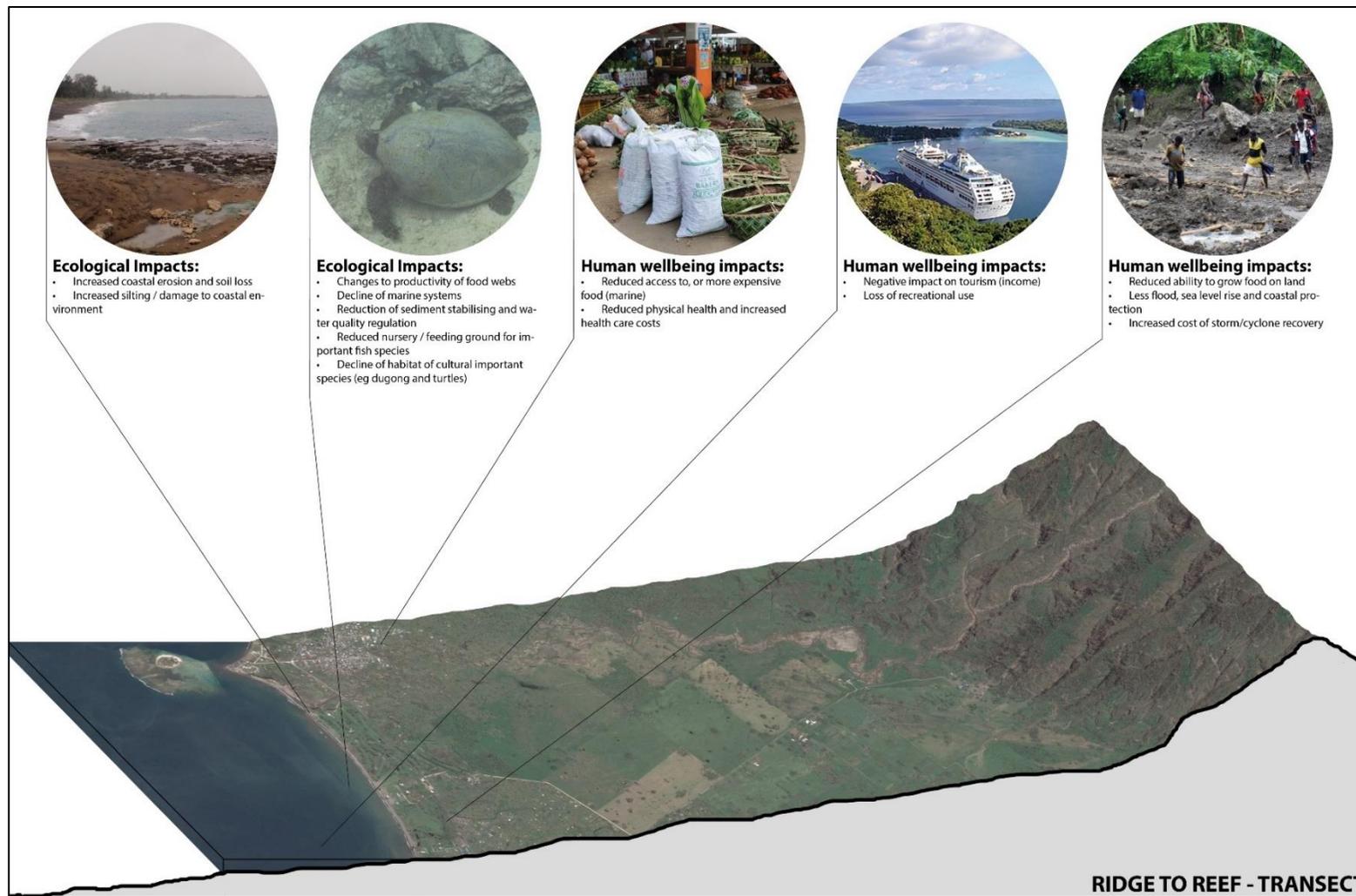


Figure 3.13 Impacts of degradation of coastal ecosystems: Port Vila transect

3.2.1 Impact of current harvesting regimes on ecological integrity and functional biology of Port Vila ecosystems

Subsistence fishing mainly targets intertidal, lagoon and near-shore reef species. Fish and invertebrates are gleaned, caught using gillnets, hand line, spearfishing and traps (Raubani 2009; McEvoy et al. 2016). Indiscriminate fishing methods especially in Pango (McEvoy et al. 2016) have reduced slow-growing species as well as top predators.

Sea cucumbers (Holothurians) are harvested when the Department of Fisheries declares the fisheries open. The Fisheries Department issued a five-year moratorium on sea cucumber harvesting from 2008 to 2012, and this has been extended for another five years to ensure the recovery of stocks (Pakoa and Bertram 2013). Decision-making over community harvesting is made by the landowner or settlement chief, although this appears to be poorly implemented in mixed-island communities such as Blacksands. Generally, over-exploitation of reef food fish, aquarium species and shells for sale is assumed to be occurring and McEvoy et al. (2016) documented reports of increased fishing effort to catch fewer and smaller food fish in most of their coastal community workshops.

On land, McEvoy et al. (2016) documented reports of increased pressure on firewood resources, and increased difficulty in getting adequate supplies of fuel for cooking. The cost of buying firewood at the market is a major economic hardship for many households, and survey participants reported their own concerns at being forced by circumstances to cut trees for firewood or charcoal that they would prefer to keep growing. Nationally, the main energy source for cooking for 85% of all households reported in the 2009 census was wood and/or coconut shells and, even in urban households, wood/coconut shell was used by slightly more than half of households, with the remainder using gas as their main energy source. Charcoal is only used by 3% of urban dwellers nationally but in Port Vila, it is a favoured energy source for cooking (McEvoy et al. 2016) and is highly visible at central market.

There were variable reports of ability to grow adequate food from home or bush gardens reported by McEvoy et al. (2016). They cited little specific evidence of adverse effects of agriculture practices other than in riparian areas, where uncontrolled vegetation clearance, soil disturbance and harvesting activities could have adverse effects on riparian ecosystems and consequently on freshwater quality if sediment or pollutants are not filtered by riparian vegetation. At our Port Vila workshop and amongst stakeholders spoken with, pollution from application of inorganic fertiliser was mentioned as an increasing issue, especially in the lower Teouma catchment (just outside the Port Vila urban area). This issue was not mentioned, however, in the workshop summaries reported by McEvoy et al. (2016).

3.2.2 Impacts of land-use activities on Port Vila's ecosystems

3.2.2.1 Agriculture

Agriculture occupies a large proportion of the metropolitan Port Vila area, probably more than 1,500 ha (Section 2), and provides ecosystem-based services to a large proportion of the Port Vila population; according to McEvoy et al. (2017), a much larger proportion than reported for urban dwellers in the 2009 census. Most of the agricultural area probably comprises subsistence home gardens although a significant proportion in the outer urban and peri-urban areas are likely to be more extensive bush gardens. The environmental impacts of

agriculture have been discussed in the section above. Agriculture taking place on riparian margins has some impact on those areas and on river freshwaters, depending on the width and vegetation composition of the riparian area (see Section 3.3.4 for results showing the potential flow of nutrients into different positions in the Port Vila catchments). From an ecological perspective, traditional subsistence agricultural patterns retain complexity in vegetation structure and composition, and the natural fertility of many soils in the Port Vila area would not appear to be limiting for plant growth, in spite of anecdotal reports of increasing fertiliser usage.

Urban and peri-urban agriculture could play an expanded role in increasing Port Vila's resilience in the face of natural disasters, changing climate, food supply pressures caused by the expected continued expansion of population coming to Port Vila, or increased prices of imported grains due to reduced global yields (in part due to climate change-induced reductions in global supply). A successful expansion of urban and peri-urban agriculture could provide additional and more affordable food supply, and additional employment opportunities, but in the longer term could have implications for urban sprawl.

There are only small areas of commercial agriculture, in the order of 140 ha, but much larger areas of grassland on which cattle are grazed (up to 3,000 ha). Home-garden-based smallholdings may be able to produce crops commercially or for a saleable surplus over subsistence needs, to a much greater extent than is currently the case.

3.2.2.2 Infrastructure

Although infrastructure provision was not a specific focus of the PEBACC project, there was a consensus among workshop participants and stakeholders spoken to, that most infrastructure in Port Vila is under significant pressure, and that this in turn could lead to a decline in environmental quality and ecosystem service provision. Inadequate water and sewerage supply, roading and waste management were often referred to. The provision of water and sewerage is far from complete in many settlement areas, leading to significant inequalities in the availability of basic infrastructure, and also to environmental degradation when, for example, bush toilets are used. The common use of well-known river access points for washing variously bodies, clothes and private motor vehicles was also referred to. Only two in three households in Vanuatu's urban areas dispose their waste using the authorized waste collection⁴.

There are a number of major current projects addressing infrastructure provision in Port Vila, some of them also working in other parts of Shefa Province or nationally. Projects include the Roads for Development Programme to enable the Government of Vanuatu to effectively plan, build and maintain its road transport infrastructure (funded by Australian Department of Foreign Affairs and Trade), the Port Vila Urban Development Project, supporting urban sanitation and sewerage development (Asian Development Bank), and development and implementation of a National Waste Management and Pollution Control Strategy (Japan International Cooperation Agency).

⁴ 2009 Vanuatu census

3.2.2.3 Tourism

Tourism is a very important part of the national and Port Vila economy and a major employer. It is also a strong driver of ecosystem service demand in some areas, particularly in terms of food, water, and energy provision. It is also a leading user of building services and materials. Resort development in and around Port Vila, often situated on coastal land, has been responsible for the destruction of some mangrove and coastal forest habitat. Although a small number of resorts and tourism service providers are associated with environmental protection projects, generally the tourism sector in Port Vila does not appear to strongly promote or support ecotourism or tourism sustainability initiatives, at least publicly so.

3.2.2.4 Industrial development

Vanuatu is very lightly industrialised, but the industrial activity that does occur is heavily concentrated in Port Vila and a number of point sources were identified in the Port Vila workshop that were seen as polluting, particularly located in the lower Tagabe catchment. The actual level of pollution resulting from industrial or other activities, if monitored, does not appear to be public knowledge. Sand mining for construction sand, particularly on Mele Beach, is a well-known activity, and is widely assumed to be a cause of beach erosion.

3.2.3 Current trends and future forecasts for these land-use types and their spatial impacts

3.2.3.1 Population growth

Population growth in Port Vila as a whole is much higher than other provinces of Vanuatu and most and the city is attracting internal migrants from all other islands in Vanuatu. However, although the population of Vanuatu as a whole is a young one, the median age in Shefa province is relatively higher (22.5) than over the whole of Vanuatu (20.5). The proportion of the population under 14 is 33% in Shefa, but 39% in Vanuatu. This is presumably a reflection of the fact that many adults come to Port Vila to take up or seek employment, sometimes leaving families behind in other islands. This may have the consequence that demand for education, perinatal healthcare and larger houses is relatively lower compared to other islands. On the other hand, internal migration of this nature may increase the breakdown of traditional knowledge and social systems that was noted by many workshop participants and people we interviewed. This has relevance to resilience and adaptation strategies, as the breakdown of traditional *tabu* systems was frequently mentioned as a cause of many environmental pressures such as over-harvesting of both terrestrial and marine resources.

3.2.3.2 Spatial change and constraints to land use impacts

Different parts of Port Vila show striking differences in population density and population change rates (McEvoy et al. 2016, Figures 6 and 7). Some, but not all of these differences reflect differences between landowner villages and migrant settlements. Migrant (often informal) settlements tend to be expanding at a much faster rate because migrants from other islands of Vanuatu into Port Vila, tend not to have a land base on which to expand. This is seen, for example, in the higher population densities and growth rates in Malapoa, Blacksands and Freswota settlements. These high population density areas put pressure on

ecosystem resources, particularly coastal resources. This is reflected in the differences seen in coral reef condition between different parts of Port Vila Harbour (Section 2.4.2).

Generally, Vanuatu's land tenure system would suggest significant constraints in spatial change processes, as different population groups have different access to land and ecosystem-based resources. The lack of tenure security for some but not all migrant settlers also constrain the use made of ecosystem services, as well as differences between the planning regimes of Shefa Province and the Port Vila Municipal Area.

3.2.3.3 Summary: implications of the impacts of degradation on the sustainable production of ecosystem goods and services

The issues discussed in preceding sections cumulatively imply a lack of resilience in the Port Vila ecosystems and their ability to deliver ecosystem services, in the face of increasing population pressure on ecosystems and resources over the last two or more decades (Section 2; McEvoy et al. 2016). The lack of resilience was both exacerbated and illuminated by the devastation caused by TC Pam in 2015 (Nishijima et al. 2015; United Nations et al. 2015). The analysis and sources summarised above suggest a generally decreasing production potential of Port Vila ecosystems, in both terrestrial and coastal marine ecosystems, and probably decreasing fresh and coastal water quality. In the next section, the impacts of physical water, sediment and nutrient flows, as well as the impacts of climate change, are added to the description.

3.3 Flows of water, sediment and nutrients in the Port Vila catchments

This section of the project models and maps the Port Vila catchments and assesses ecosystem services using Land Utilisation and Capability Indicator (LUCI). LUCI is a land management decision support tool and ecosystem process modelling framework which can explore the impact of land management decisions on ecosystem services. This enables better spatial planning of land management interventions by being able to consider the spatial configuration and placement of landscape features and their effect of ecosystem service provision. As described in Jackson et al. (2013), Sharp et al. (2017) and Trodahl et al. (2017), LUCI supports the modelling of a range of ecosystem services including water quantity/quality, erosion and sediment delivery, habitat connectivity and agricultural productivity (amongst others). Individual ecosystem services can be assessed or LUCI can assess multiple services simultaneously to identify where trade-offs or co-benefits in the landscape exist. In this study, LUCI is used to evaluate flows, erosion risk and nutrient loads and concentrations under current land cover in the Port Vila catchments and identify areas where changes to land management might improve ecosystem service provision.

3.3.1 Methods

To run, LUCI requires a digital elevation model (DEM) (to produce a hydrological and topographically consistent surface), soils and land cover data (for scenario generation) and other inputs (if available, e.g. precipitation, evapotranspiration and stream network). Figure 2.14 displays the elevation, stream network, land cover and soils of Port Vila. Soils information was digitised from the *Carte Pédologique de Reconnaissance* of Efate (Quantin 1971), specifically for use in this LUCI application. The land use cover map developed for the project by the project team (Section 2) was used. A high-resolution DEM was not available for Vanuatu so the SRTM30 global DEM was used. This DEM has a resolution of 30mx30m and a relative vertical accuracy of 6m. A river network for the catchments was made available to the project team by SPREP.

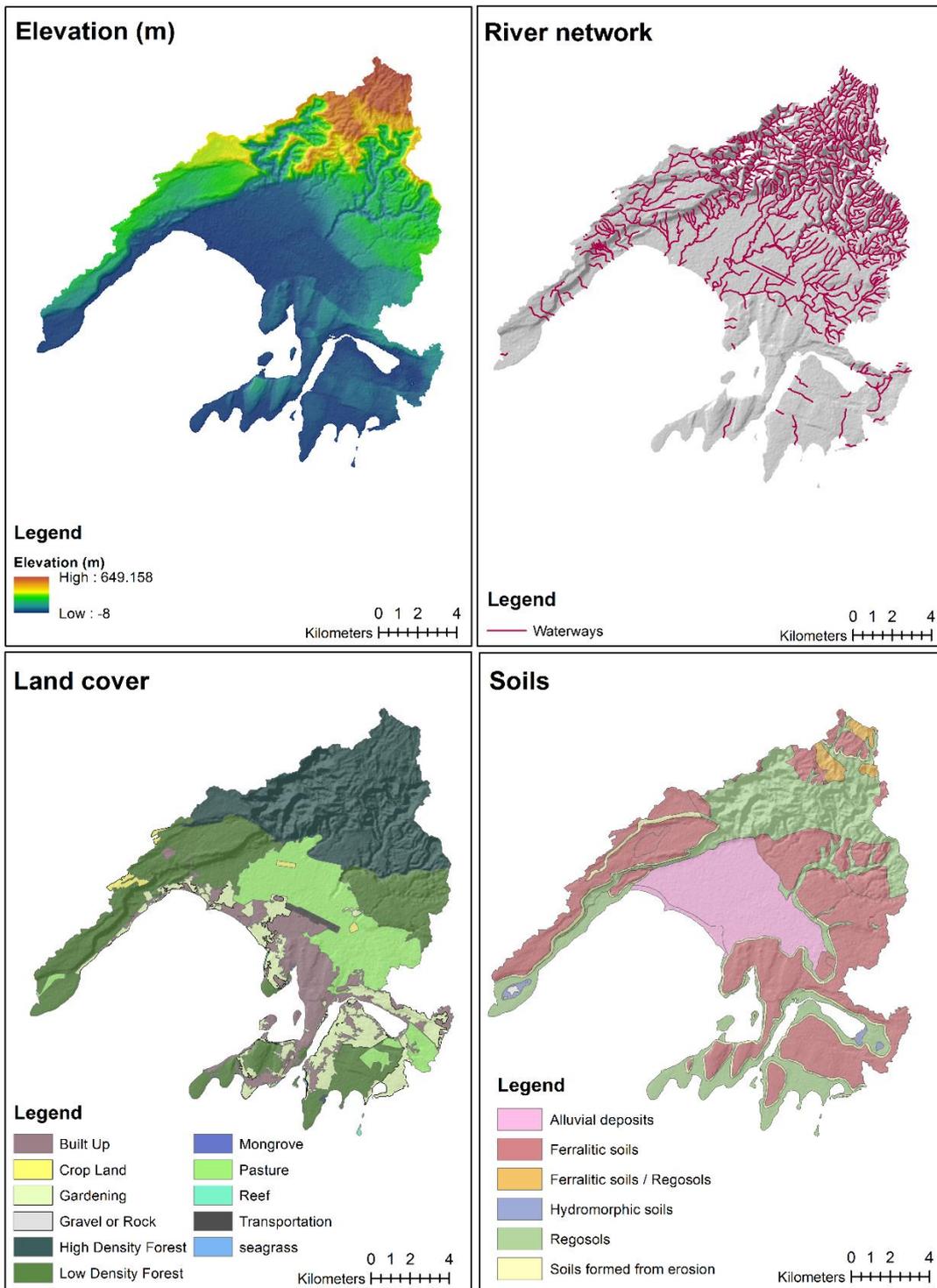


Figure 3.14 Port Vila catchment attributes
Elevation (top left), stream network (top right), land cover (bottom left) and soils (bottom right)

For robust application, a literature review and parameterisation effort is required for any new soil or land cover/habitat/use maps to bring in the best evidence to support predictions. This was beyond the scope or timelines of the wider project. In order to run LUCI quickly, the soils and land cover for the Port Vila catchments were linked to classifications supported by the framework. Land cover was translated to New Zealand’s Land Cover Database v4.0 (LCDB4), with some assumptions made to correlate land cover types. LCDB4 is a digital map of New Zealand which classifies land cover into 33 mainland classes (Dymond et al. 2017 and Landcare Research’s LRIS Portal⁵). Soils were translated into the top level (soil order) of New Zealand soil classification (Hewitt 2010 and NZ Soils Portal⁶), based on the descriptions of the Efate soils found in Quantin (1975). This is not a direct correlation and some subjective interpretation was required. The New Zealand classifications were used due to a number of similarities between land covers and soils. For example, many soils in New Zealand have a volcanic origin. This a dominant feature of some Efate soils. A table of translations for land cover is shown in Table 3.1 and that for soils in Table 3.2. Where two soil types were identified in the one place, we chose one of the soil types for the purpose of this study.

Table 3.1: Port Vila land cover classes translated to New Zealand LCDB4

Port Vila land cover	LCDB4
Built-up area	Built-up area
Main urban green spaces	Urban parkland/ Open space
Transport infrastructure	Transport infrastructure
Gravel or Rock	Coastal sand and gravel
Estuarine open water	Estuarine open water
Active subsistence gardening	Short-rotation cropland
Crop land	Short-rotation cropland
Pasture	Low producing grassland
Low density forest	Mixed exotic shrubland
High density forest	Indigenous forest
Mangrove	Mangrove

Table 3.2: Port Vila soil classes translated to New Zealand Soil Classification (soil order)

Efate Classification	NZ Soil Classification
Alluvial deposits with recent fluvial deposits	Recent
Alluvial deposits with recent fluvio-marine alluv.	Recent
Ferralitic soils, strongly desaturated, typical	Oxidic
Ferralitic soils, weakly desaturated, typical	Brown
Ferralitic soils, moderately desaturated, typical	Oxidic
Ferralitic soils, weakly desaturated, andic	Brown
Ferralitic soils, weakly desaturated, andic, active erosion	Raw
Ferralitic soils, moderately desaturated, andic	Pumice
Hydromorphic soils with sand limestone	Brown
Regosols with dacitic-andesitic tuffs	Recent
Regosols with limestone sand (assoc rendzinas)	Brown
Soils formed from erosion, lithic with limestone	Recent

⁵ See: <https://iris.scinfo.org.nz>

⁶ See: <https://soils.landcareresearch.co.nz>

3.3.2 Ecosystem service provision indicators assessed

Indicators of a number of ecosystem services, namely erosion, water quantity, and components of water quality (sediment, total nitrogen and total phosphorus) were assessed. These impact on ecosystem service provisions of importance to Vanuatu in a variety of direct and indirect ways. They affect for example: flood mitigation; water filtration/clean water provision; food and fibre production; and protection of key riverine and marine habitat (e.g. it is known reef condition and reliant species are negatively affected by high sediment and/or nitrogen and phosphorus loads). The provision of these ecosystem services further impact tourism and other economic opportunities for the island.

Using the soil map, land cover map, stream network and DEM, a hydrologically consistent DEM (and other relevant hydrological information) and land cover/soils scenarios were generated. These are used as input to LUCI to assess ecosystem service provision. The water quantity tool uses land cover, soil and topography as the main inputs. These are used to calculate flow, direction of flow, and subsequently where flow accumulates taking into account storage and permeability characteristics of elements in the landscape (Jackson et al. 2013; Sharp et al. 2017). Areas of high permeability and/or storage capacity (high infiltration capacity) act as sinks in the landscape for overland or near-surface water, where it can be stored or routed more slowly through the sub-surface. The water quality aspect of LUCI estimates loads generated at any point in the landscape using an export coefficient approach in order to model total nitrogen (TN) and total phosphorus (TP) exports to water. Export coefficients are determined for every point in the landscape based on land cover types (Trodahl et al. 2017). More recent developments also consider the impact of soil, climate, stocking density and fertilizer inputs among other factors. However, due to the limited data available for collation, use of this more nuanced approach was not possible. The export coefficients applied in this study are based on land cover only, and linked to those estimated for New Zealand land cover types. It is also important to note they use an average of export rates indicated in the literature, which can vary considerably, suggesting data evidence is limited. These loads are then routed through water and sediment pathways, with the model considering and highlighting existing sinks where nutrients can be intercepted before entering the stream network, and opportunities to create additional sinks.

Erosion and sediment delivery is modelled using the Compound Topographic Index (CTI) (Thorne and Zevenbergen 1990). The CTI represents the erosive potential of overland flow in the landscape and considers the slope and curvature of the landscape as well as flow accumulation and magnitude. The occurrence of soil erosion is also dependent on soil and vegetation characteristics. The spatial extent of soil erosion is represented in LUCI by the CTI critical threshold values above which areas are considered vulnerable or extremely vulnerable to erosion from overland flow. The subsequent transfer of eroded sediment to rivers and streams relies on the existence of hydrological connectivity between the point of origin and the watercourse (cf. Lane et al. 2009). Further work to enhance the estimation of erosion and sediment delivery in LUCI, by bringing detail in regarding how erosion changes with more nuanced land management, climate, and to account for landslides/gully erosion, is being brought into the framework in 2017. These enhancements would be particularly relevant within the Port Vila and whole of Vanuatu contexts.

3.3.3 Results & discussion of the LUCI analysis for Port Vila

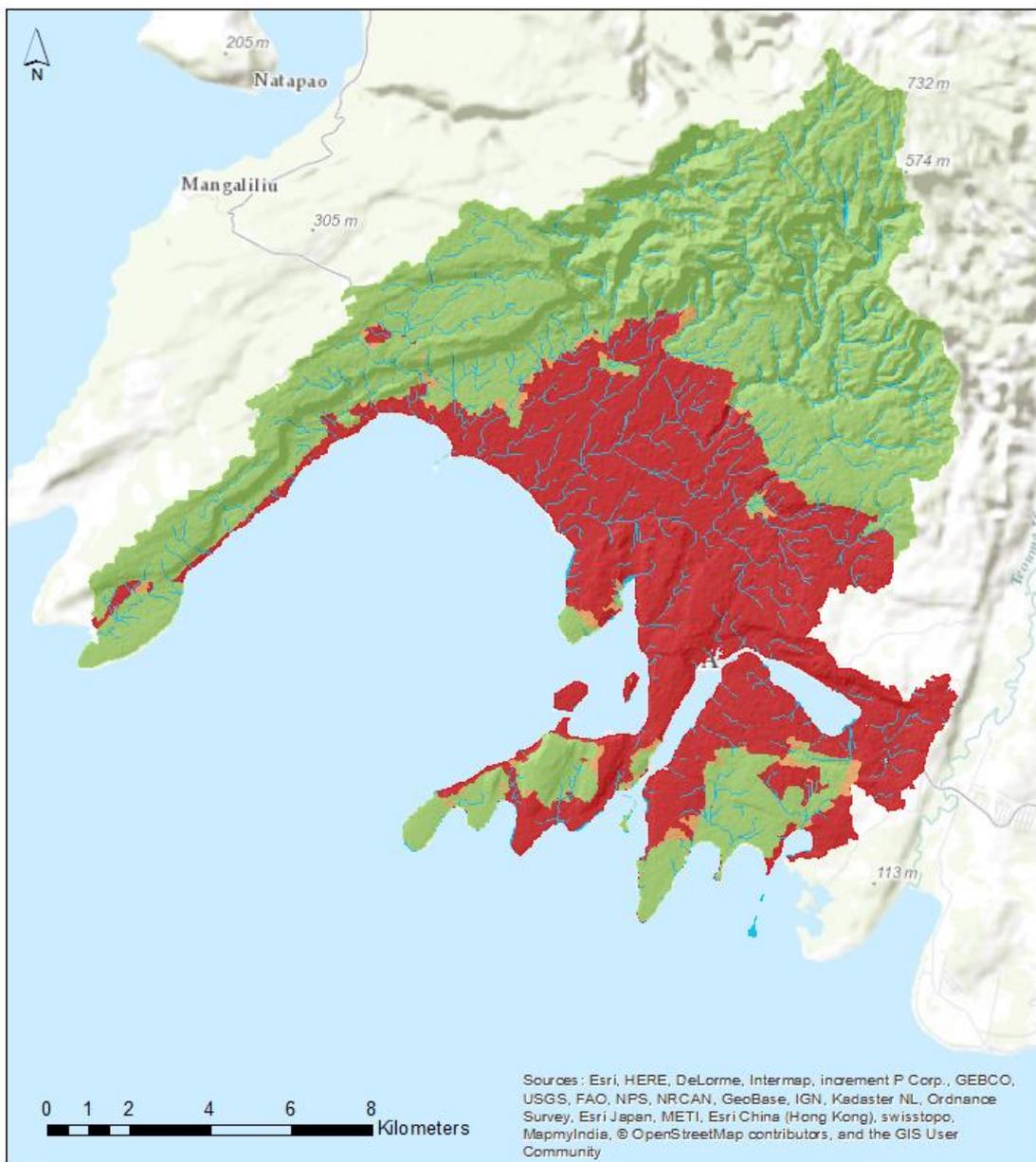
3.3.3.1 Water Quantity

Water is distributed through the catchments via a network of rivers and streams draining from the higher elevation areas of the north and west, into the lowland area of Port Vila. The flood mitigation output shows the land cover classified according to its mitigation capacity. Mitigating features are those that provide mitigation of flow (i.e. trees, ponds, deep permeable soils, etc.). In the Port Vila catchments, forested areas at higher elevations are the principal means of flood mitigation to the lowland areas (Figure 3.16).

Unmitigated features (pastoral areas) are those with low storage and/or permeability that do not flow through any mitigating features before reaching the stream network. Areas offering very little mitigation against flooding are primarily located in the built-up areas of the catchments as well as areas of pasture and subsistence gardening. It is in these areas that flow tends to accumulate. Figure 3.17 highlights areas where there are opportunities to make modifications in the landscape to reduce flood risk. High flood concentration areas tend to be found in lowland areas of the catchments, close to waterways.



Figure 3.15 Flooding in Port Vila, Cyclone Cook, 2017 (source: Radio New Zealand)



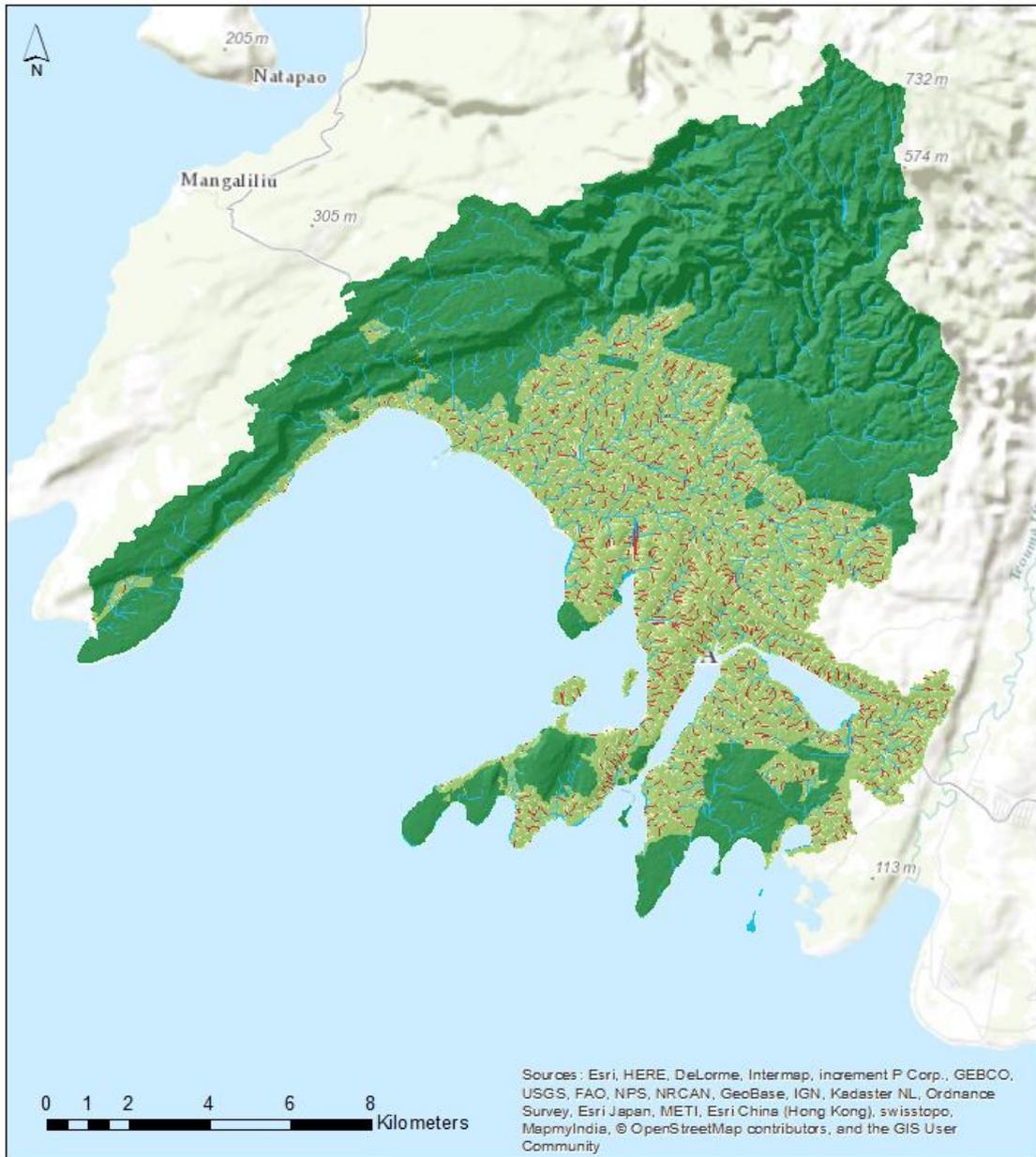
Legend

Mitigation classification

- Mitigating features
- Mitigated features
- Non-mitigated features
- Water bodies

Figure 3.16 Port Vila flood mitigation

Green areas indicate areas already providing mitigation. Flow generated in orange areas flow through mitigating features before reaching the stream network. Red areas have low permeability and/or storage and do not flow through a mitigated area before reaching the stream network.



Legend

Flood interception classification

- Flood mitigating land
- Low flood concentration
- Moderate flood concentration
- High flood concentration
- Water bodies

Figure 3.17 Port Vila flood concentration

Red areas show areas of high flow concentration (large contributing area with no flood mitigation ability (see section 3.3.3.1) and where landscape could benefit from flood mitigation.

3.3.3.2 Water Quality

Nitrogen and phosphorus were the two nutrients assessed in terms of water quality around Port Vila. LUCI produces maps showing terrestrial load (kg/ha/yr), accumulated load (kg/yr) and accumulated concentration (mg/L) to any point in the landscape as well as instream nutrient load (kg/yr) and concentration (mg/L). Based on the assumed nutrient export coefficients used in this study, pastoral areas generated the largest amount of nitrogen compared to any other land use in the catchments (Figure 3.18). Areas of pasture are dominant in the central lowland parts of the catchments, as well as to the south-east. Consequently, the major rivers and streams draining these areas into Mele Bay are predicted to have the highest levels of nitrogen (Figure 3.19 and Figure 3.20).

While pastoral areas were also a significant source of phosphorus, areas of active subsistence gardening generated the largest amount of phosphorus in the catchments (Figure 3.21). These areas are located significantly around coastal areas, often directly adjacent to marine areas and reefs. Built up areas (also located around coastal areas of Port Vila) also contributed to phosphorus load as well. Consequently, rivers and streams in these areas show a high load and concentration of this nutrient (Figure 3.22 and Figure 3.23). Most of these streams drain directly to the sea around Port Vila. Recent water quality assessment work conducted by the UK Centre for Environment, Fisheries and Aquaculture (CEFAS) indicated that near- shore activities play a significant role in water quality around Mele Bay and Port Vila⁷.

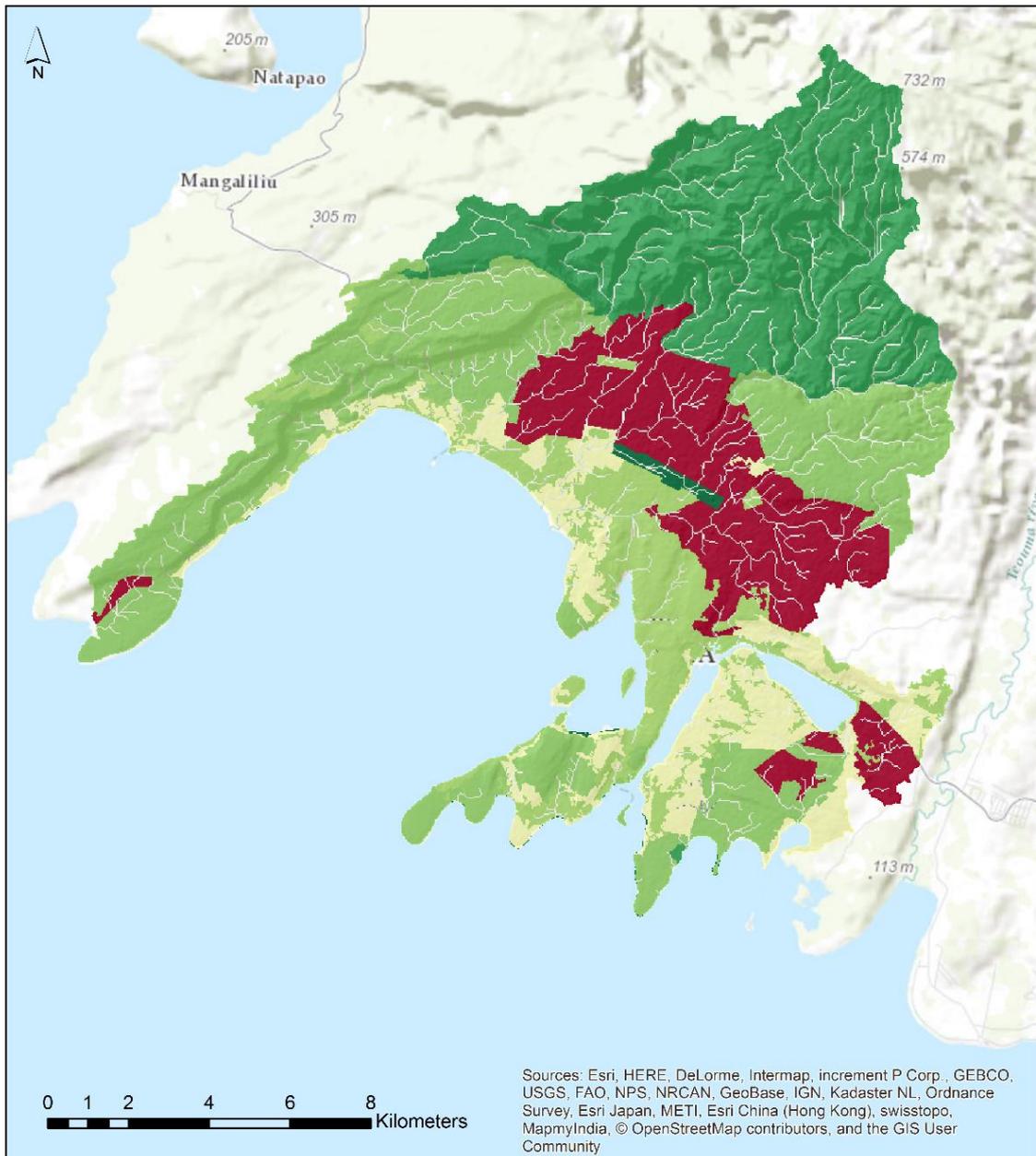
3.3.3.3 Erosion and sediment delivery

Areas of land which are vulnerable to severe soil erosion and at risk of being linked to proximate watercourses by uninterrupted overland flow are identified in LUCI by combining the CTI layer with the water supply tool described in Section 3.3.3.1. This allows users to identify and prioritise areas of land for sediment delivery mitigation efforts (e.g. buffer zone creation; Muscutt et al. 1993).

Areas most vulnerable to ephemeral gully erosion can be found in steeper areas of the catchments around cliff faces and steeper valley walls of the highlands (Figure 3.24). Sediment which is eroded in the higher elevation areas tends to be captured within the forest landscape. In lowland parts of the catchments where the topography is flatter, the erosion risk is relatively low. The coarse resolution of the SRTM DEM means that the fine scale at which erosion can be initiated is not easily represented. To address this, we have reduced the CTI thresholds to identify areas susceptible to erosion. Further work would be needed to refine these thresholds; however, the map provided does give an indication of areas most at risk of erosion in the Port Vila catchments. Areas that exceed CTI threshold values are potential areas to target mitigations. It is in these vulnerable areas that are readily connected to water ways that sediment delivery could become an issue. Sediment and erosion rates vary considerably, often coinciding with large rainfall events which result in pulses of sediment at various times of the year, particularly in the wet season from November to April.

⁷ Reported

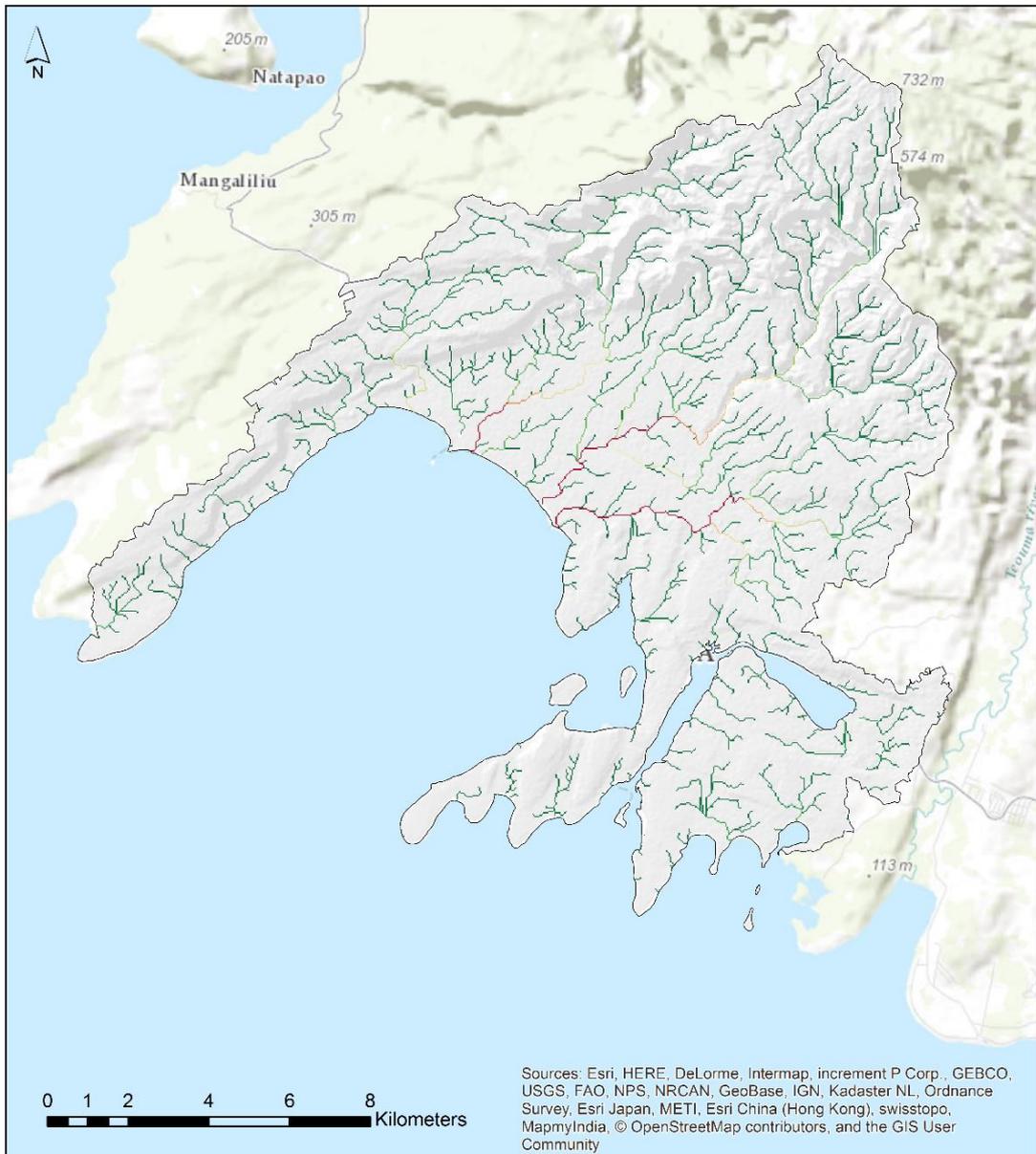
on https://www.sprep.org/attachments/bem/PEBACC/Newsletter/PEBACC_Newsletter_June_2017.pdf



Legend



Figure 3.18 Port Vila total terrestrial nitrogen load (kg/ha/yr) generated at any point within the landscape. Red areas have the highest load with darker green areas the lowest load



Legend

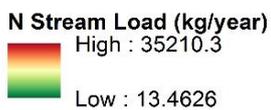
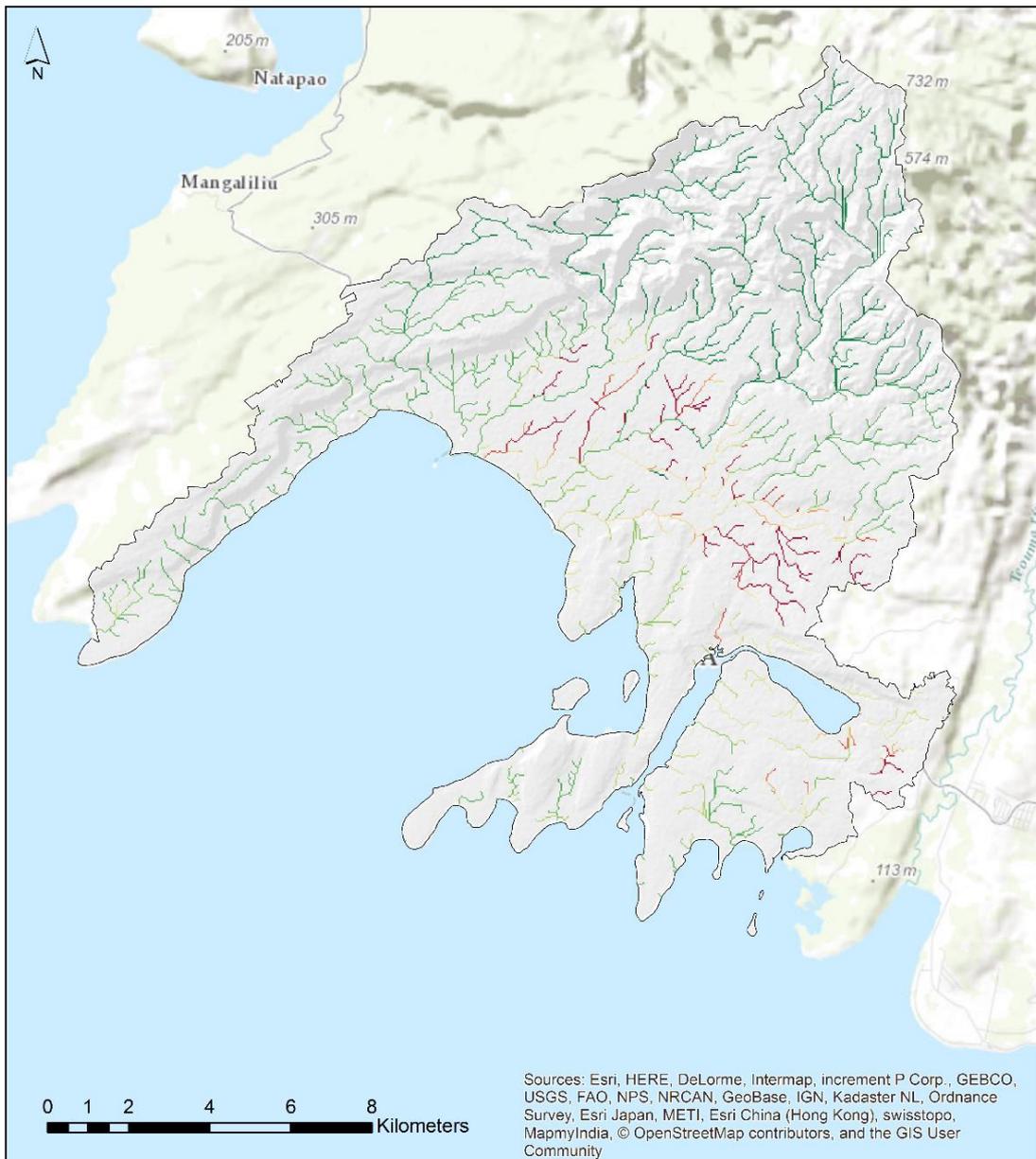


Figure 3.19 Port Vila in-stream nitrogen load (kg/yr) at all points in-stream
 High values (red) suggest catchments of these points/reaches should be targeted for mitigation/interception opportunities



Legend

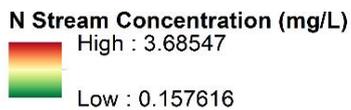
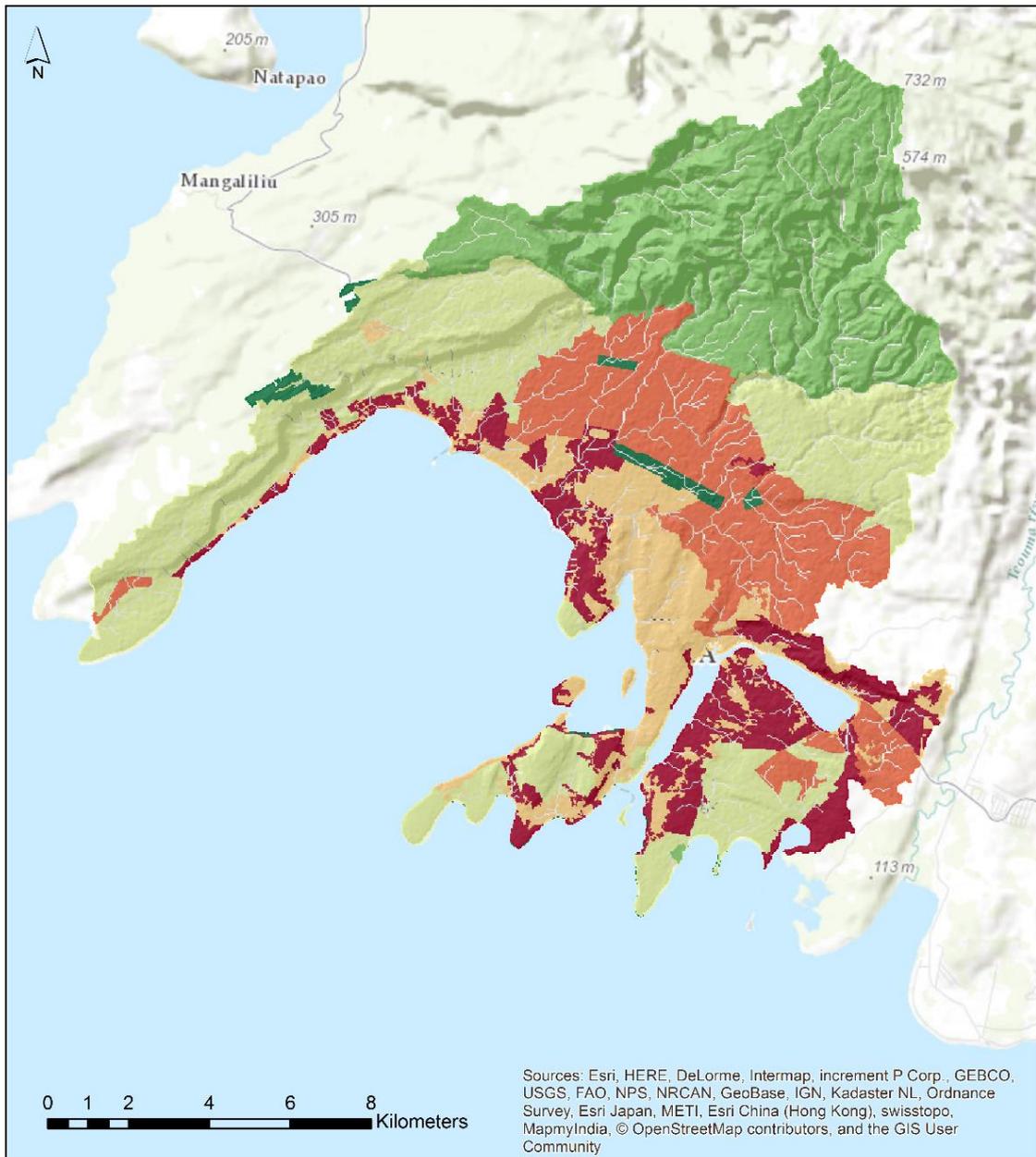


Figure 3.20 Port Vila in-stream nitrogen concentration (mg/L) at all points in-stream
 High values (red) suggest catchments of these points/reaches should be targeted for mitigation/interception opportunities



Legend

P Load (kg/ha/yr)

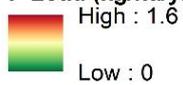
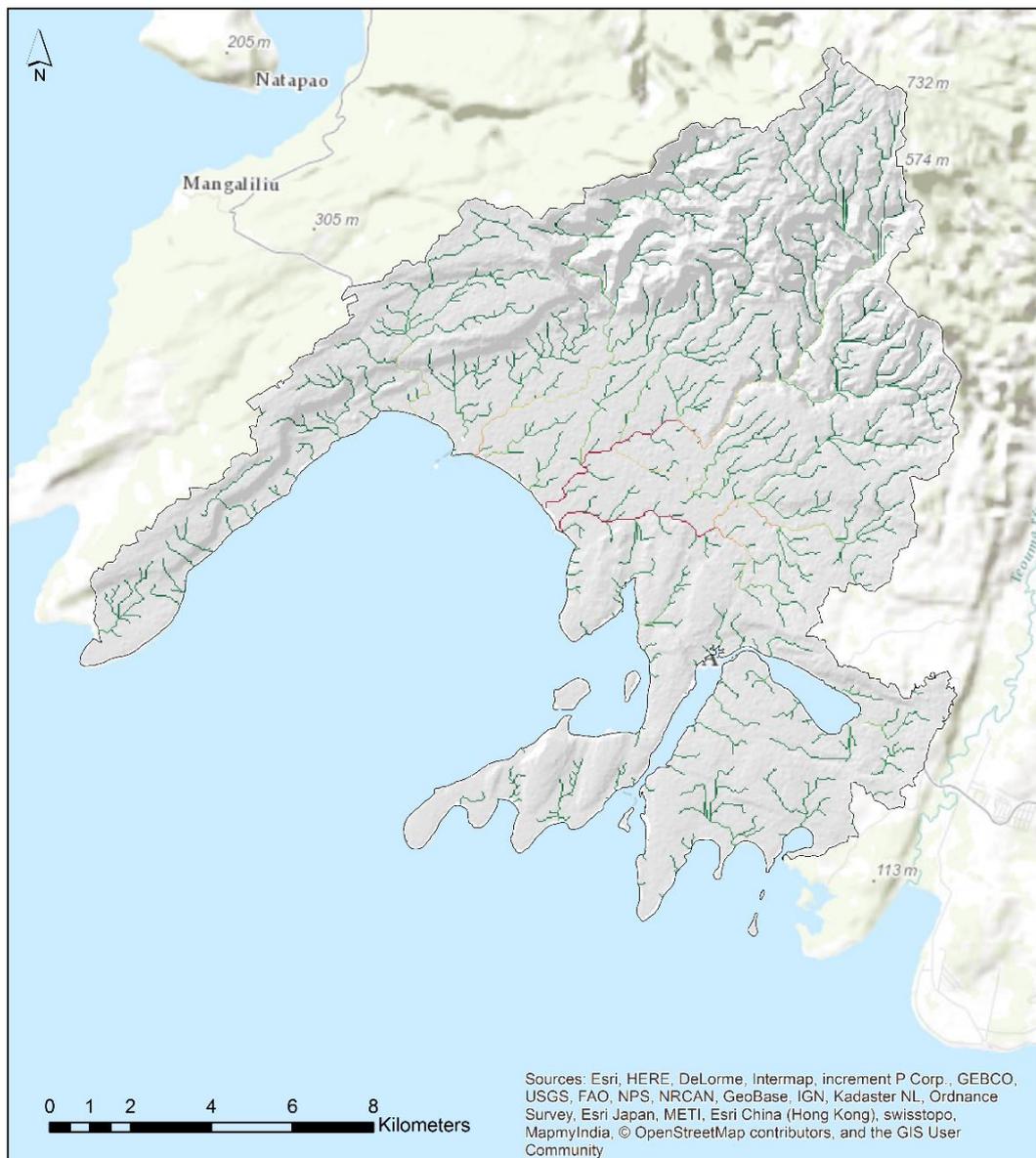


Figure 3.21 Port Vila total terrestrial phosphorus load (kg/ha/yr) generated at any point within the landscape

Red areas have the highest load with darker green areas with the lowest load



Legend

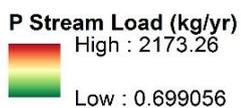
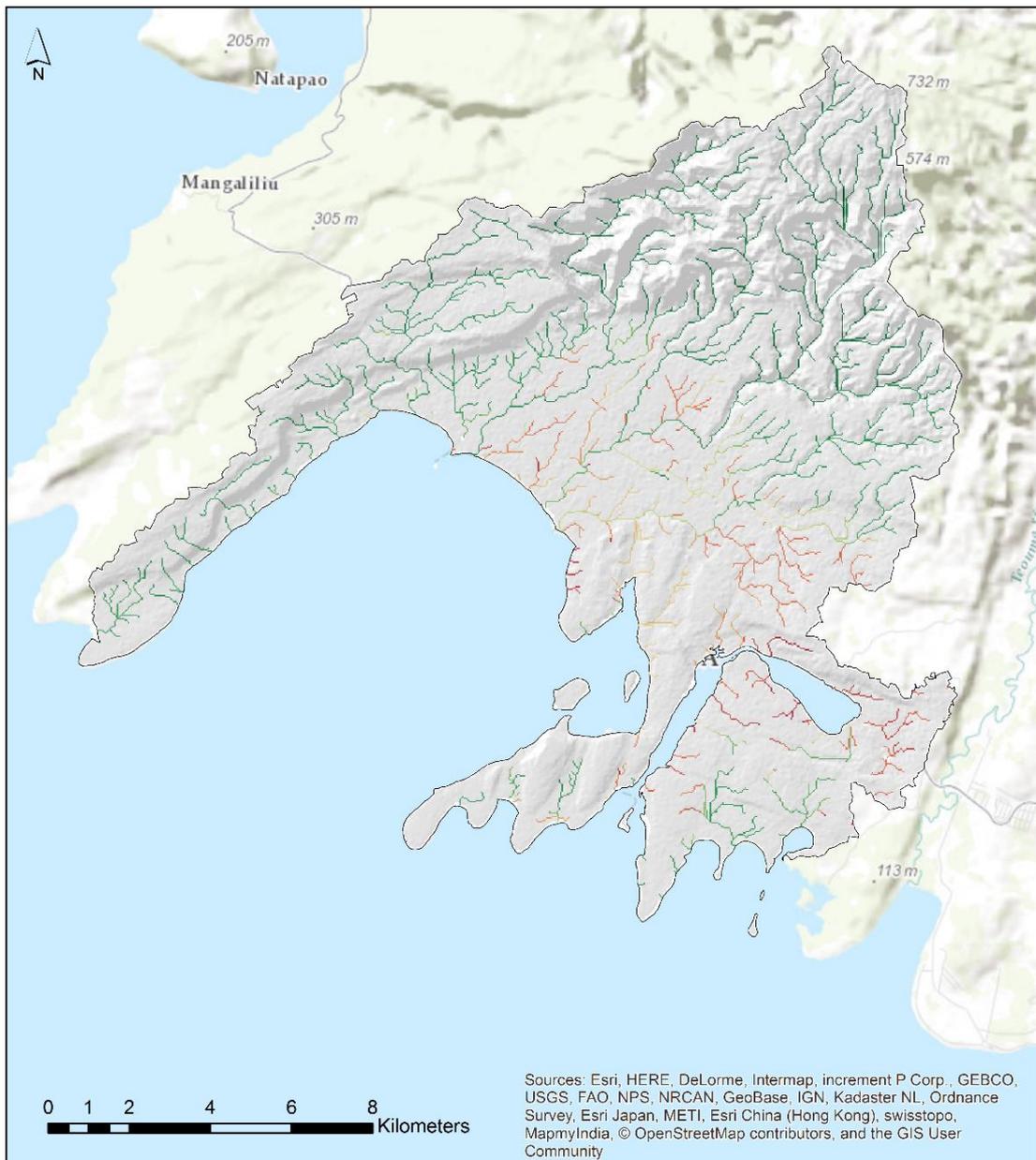


Figure 3.22 Port Vila in-stream phosphorus load (kg/yr) at all points in-stream
 High values (red) suggest catchments of this point should be targeted for mitigation/interception opportunities



Legend

P Stream Concentration (mg/L)

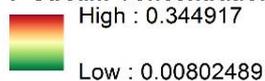
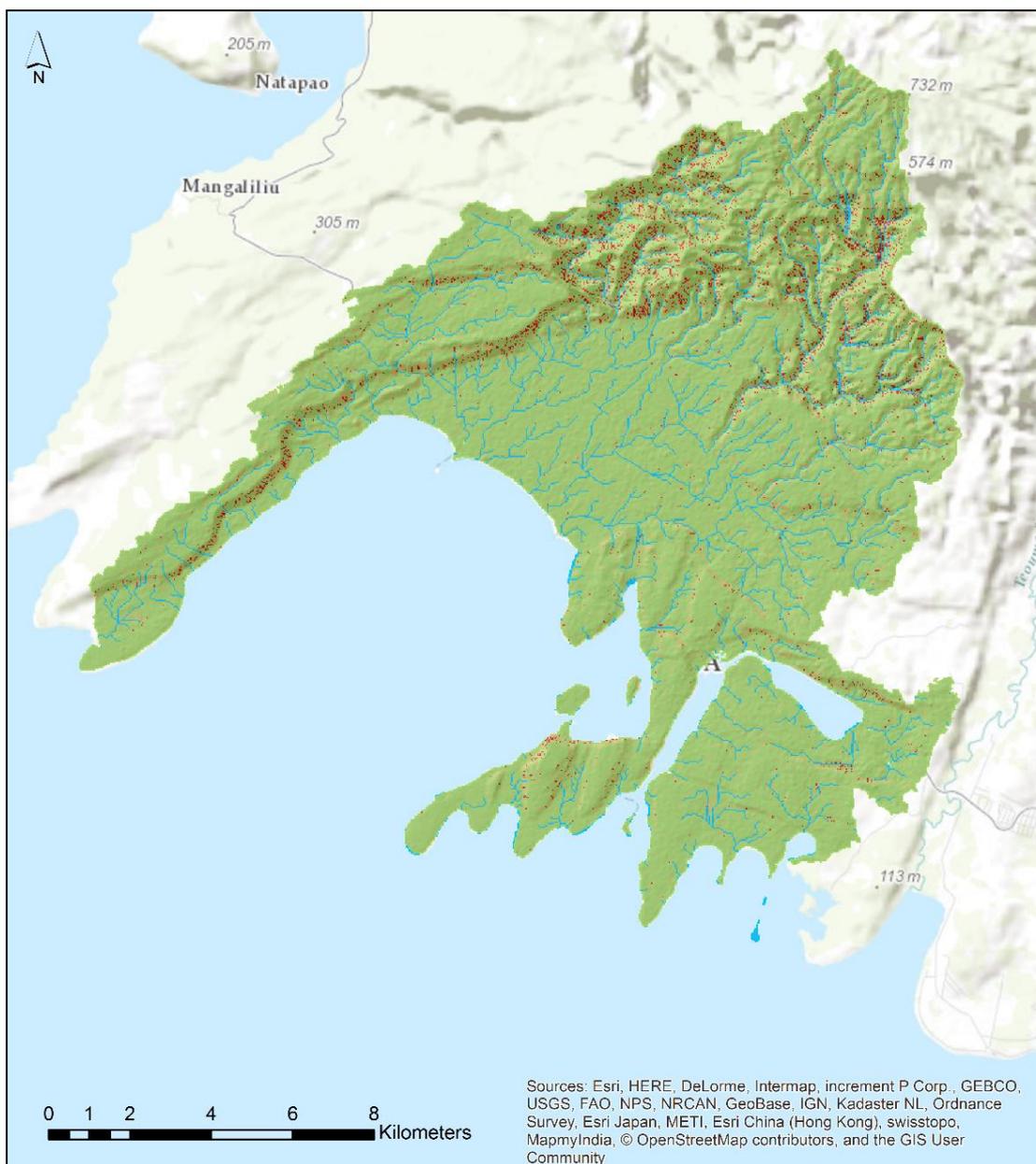


Figure 3.23 Port Vila in-stream phosphorus concentration (mg/L) at all points in-stream
High values (red) suggest catchments of this point should be targeted for mitigation/interception opportunities



Legend

Erosion risk

- Negligible erosion risk
- Moderate erosion risk
- High erosion risk
- Water body

Figure 3.24 Port Vila erosion risk

Areas most at risk from soil erosion are shown in red and tend to be located on steeper valley walls/slopes and escarpment faces

3.3.4 Conclusions of the LUCI analysis

LUCI was used to model and map the current state of flows, sediment and nutrients in the Port Vila catchments. Lowland areas of the catchments are at the most risk from accumulating water flows, sediment delivery and nutrients. These areas drain directly to important marine areas. This means the delivery of sediment and nutrients in these areas could have an impact of these ecosystems, as recognised in the recent CEFAS assessment of coastal water quality noted in the section above. LUCI has identified terrestrial areas which can be targeted to reduce these adverse impacts. Areas of pasture are the main source of nitrogen, while active subsistence gardening contributes the most phosphorus. Those areas readily connected to waterways will directly impact instream nutrient and sediment loads. Upland areas of the catchments already provide mitigation against these effects, due to the nature of the vegetation which acts as a sink in the landscape to interrupt the flow of sediment and water moving downstream. An additional contribution is the digitised soil map of Efate, which will be made available to the PEBACC project via SPREP.

The results generated should be viewed in context. Although a limited application, this is the first application of LUCI to a small Pacific Island, where nationally available and fine resolution data is not readily available. A number of assumptions were made in order to achieve results within the limited timeframe of this project, due to limited readily available information on relevant input data (e.g. spatial land management, temporal river flow information) and the soils and land cover information not being available in classifications directly supported by LUCI. Further detailed information would reduce uncertainty, while ground-truthing and calibration of model outputs would help to provide more robust predictions. Despite this, the outputs generated provide useful information and insights into areas most at risk from high flow concentration, erosion and nutrients. Specific areas where there are opportunities to make changes in the landscape to reduce these risks have also been identified (see: Figures 3.18 to 3.24).

3.4 Climate change effects on Port Vila ecosystems

Port Vila has a tropical climate which is influenced by the Trade Winds. Average daytime temperatures range between 26° and 32°C year-round. Precipitation is differentiated into a dry season from May to October (monthly rainfall typically ~100mm) and a wet season from November to April (monthly rainfall typically ~300mm). During the wet season, much of the precipitation is associated with the South Pacific Convergence Zone (SPCZ), the core of which on average lies just to the north of central Vanuatu (Widlansky et al. 2011). There is considerable interannual variability in Port Vila precipitation as the location and intensity of the SPCZ are influenced by El Niño-Southern Oscillation (ENSO) activity (Folland et al. 2002). Vanuatu is often affected by tropical cyclones as the country lies in the Southwest Pacific region of most frequent tropical cyclone formation and occurrence (Diamond et al. 2013). Natural ecosystems in the region of Port Vila (see: Section 1 of this report and Mackey et al. 2017) are adapted to the tropical climate here described.

Greenhouse gas emissions are changing the global climate, causing global sea level rise and a decrease in the pH of ocean waters worldwide (known as ‘ocean acidification’). Statistics and

figures related to climate changes in Vanuatu and the Port Vila area are taken from the work of the Pacific-Australia Climate Change Science and Adaptation Planning Program (PACCSAP) (PACCSAP 2014) and are also consistent with the findings of the IPCC AR5 (IPCC 2013). Consistent with global trends, temperatures in the Port Vila area have risen on the order of 1°C in the past 40 years (Hartmann et al. 2013) while precipitation has shown no significant trends in recent decades. Sea levels in the western Tropical Pacific have risen at around 4-5mm/year over the past 20 years⁸, faster than the global mean rate of 3.3mm/year.



Figure 3.25 Port Vila sky

The future magnitude of climate change impacts for Port Vila depend strongly on how global greenhouse gas emissions reduction policy and technology develop. At the low end of the scale, if the goals of the Paris Agreement⁹ are met, global temperatures would rise around 0.5°C from the present day (approximately 1.5°C above pre-industrial temperatures) by 2100. At the high end, if emissions of greenhouse gases continue as they have done over the past 20 years, global temperatures would rise by another 3–5°C from the present day (4–6°C above pre-industrial levels) by 2100. Whatever the future of emissions, global temperatures are virtually certain to rise another 0.2–0.3°C above present-day levels over the coming 30 years (IPCC 2013).

Climate futures for Vanuatu are based on the climate change scenarios considered in the 5th Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC). The

⁸ See: https://www.cmar.csiro.au/sealevel/sl_hist_last_decades.html

⁹ See: http://unfccc.int/paris_agreement/items/9485.php

various scenarios are known as Representative Concentration Pathways (RCPs) (Van Vuuren et al. 2011) and range from RCP2.6 (broadly consistent with Paris Agreement goals) to RCP8.5 (broadly consistent with a continuation of recent rates of emissions).

3.4.1 Temperature changes

Future temperature rise in the Port Vila region (and in Vanuatu generally) is expected to be somewhat slower than the global average rate, but all future scenarios show temperatures rising significantly above what has been observed in recent decades. Figure 3.26 shows projected temperature change during December–February for the range of RCPs considered in the IPCC AR5 (IPCC 2013). Even with moderate warming scenarios, the occurrence of extreme events increases rapidly (Frame et al. 2017).

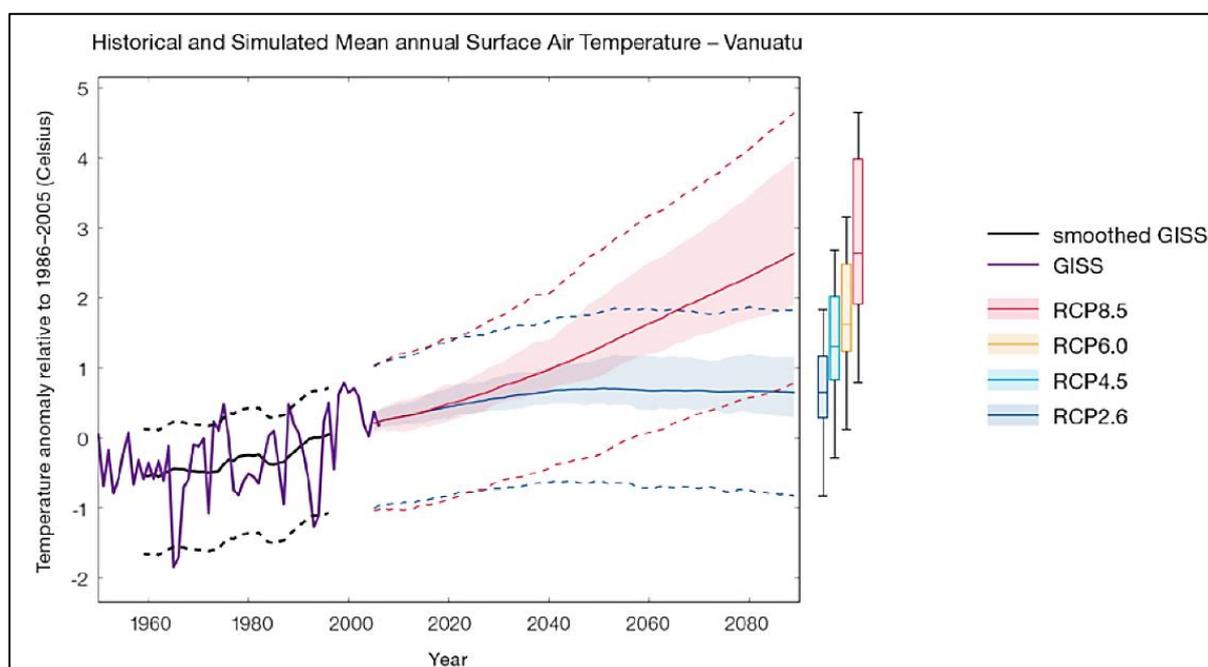


Figure 3.26 Historical and simulated surface air temperature time series for the region surrounding Vanuatu

The graph shows the anomaly (from the base period 1986–2005) in surface air temperature from observations (the GISS (Goddard Institute of Space Studies) dataset, in purple), and for the CMIP5 models under the very high (RCP8.5, in red) and very low (RCP2.6, in blue) emissions scenarios. The solid red and blue lines show the smoothed (20-year running average) multi-model mean anomaly in surface air temperature, while shading represents the spread of model values (5–95th percentile). The dashed lines show the 5–95th percentile of the observed interannual variability for the observed period (in black) and added to the projections as a visual guide (in red and blue). This indicates that future surface air temperature could be above or below the projected long-term averages due to interannual variability. The ranges of projections for a 20-year period centred on 2090 are shown by the bars on the right for RCP8.5, 6.0, 4.5 and 2.6. From Australian Bureau of Meteorology and CSIRO (2014).

3.4.2 Precipitation changes

Precipitation change is on average expected to be small through the rest of the 21st century, but variability is expected to increase. Figure 3.27 shows projected changes in wet-season precipitation for Vanuatu. Increasing variability is a consequence of a moister atmosphere

combined with circulation changes. For many regions of the globe, this translates to the rule of thumb ‘the wet get wetter and the dry get drier’ (IPCC 2013). This applies to individual events (storms deliver more rain, droughts are more intense), seasons and years. The South Pacific Convergence Zone (SPCZ) is expected to become more variable in its movements in the future (e.g. Cai et al. 2012) and the El Niño–Southern Oscillation (ENSO) cycle is expected to be associated with more intense precipitation extremes as the planet continues to warm (Power et al. 2013, Cai et al. 2014; Wang et al.,2017). A summary of the impacts of El Niño and La Niña on rainfall, sea level and tropical cyclone risk in Pacific islands indicates that El Niño conditions are likely to be associated with drier conditions in Vanuatu (Lough et al. 2014).

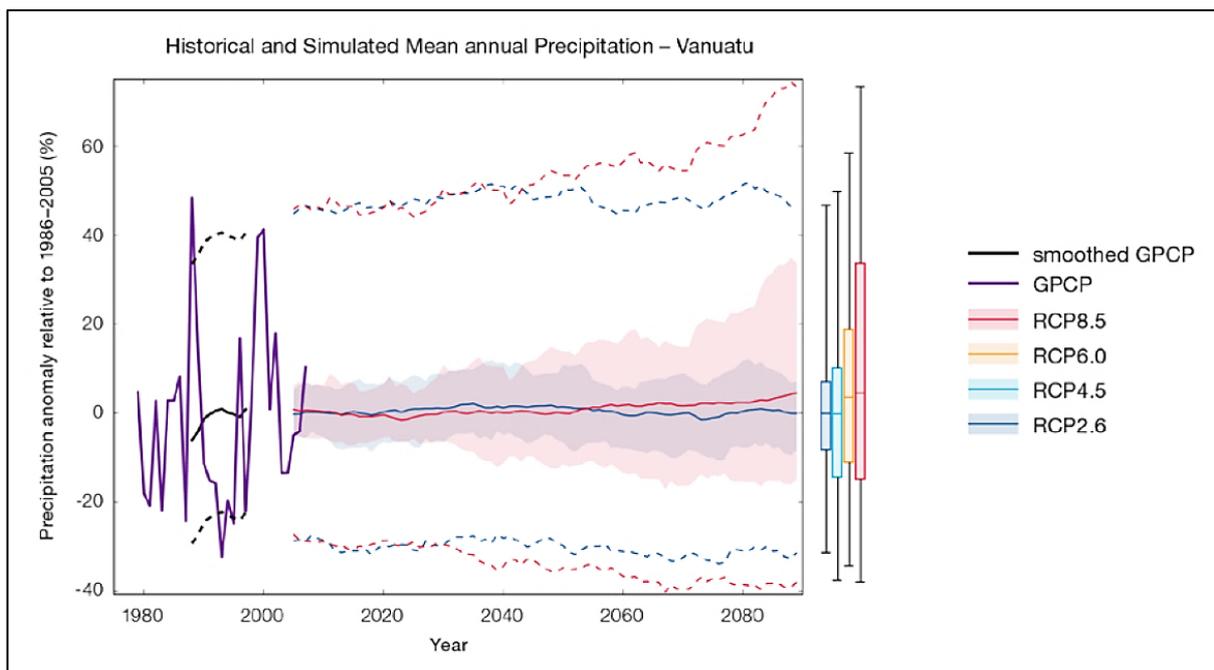


Figure 3.27 Historical and simulated annual average rainfall time series for the region surrounding Vanuatu The graph shows the anomaly (from the base period 1986–2005) in rainfall from observations (the GPCP dataset, in purple), and for the CMIP5 models under the very high (RCP8.5, in red) and very low (RCP2.6, in blue) emissions scenarios. The solid red and blue lines show the smoothed (20-year running average) multi-model mean anomaly in rainfall, while shading represents the spread of model values (5–95th percentile). The dashed lines show the 5–95th percentile of the observed interannual variability for the observed period (in black) and added to the projections as a visual guide (in red and blue). This indicates that future rainfall could be above or below the projected long-term averages due to interannual variability. The ranges of projections for a 20-year period centred on 2090 are shown by the bars on the right for RCP8.5, 6.0, 4.5 and 2.6. From Australian Bureau of Meteorology and CSIRO (2014).

3.4.3 Changes to the ocean

Sea level rise in the region of Vanuatu is projected to continue at a rate slightly greater than the global average. Globally, sea levels are projected to rise by between ~50cm and ~80cm by the end of the century, depending on emissions scenario (Figure 3.28). For all scenarios, sea levels keep rising for centuries, with an eventual rise of around 1m for the lowest warming scenario (RCP2.6) and possibly tens of metres for the highest warming scenario (after several

centuries, RCP8.5). For all scenarios, around 20cm further rise (compared to the present day) is projected by mid-century.

Absorption of carbon dioxide by the oceans lowers the pH of ocean water (making it more acidic) and reduces the availability of calcium carbonate in the water column, interfering with coral growth and shell formation (from micro-organisms to shellfish). A common way of assessing change is to measure aragonite saturation (aragonite is a form of calcium carbonate) in the water column. Figure 3.30 shows observed and projected aragonite saturation levels for the Vanuatu region, indicating that reef health may become marginal by 2030, if significant global emissions reductions are not achieved.

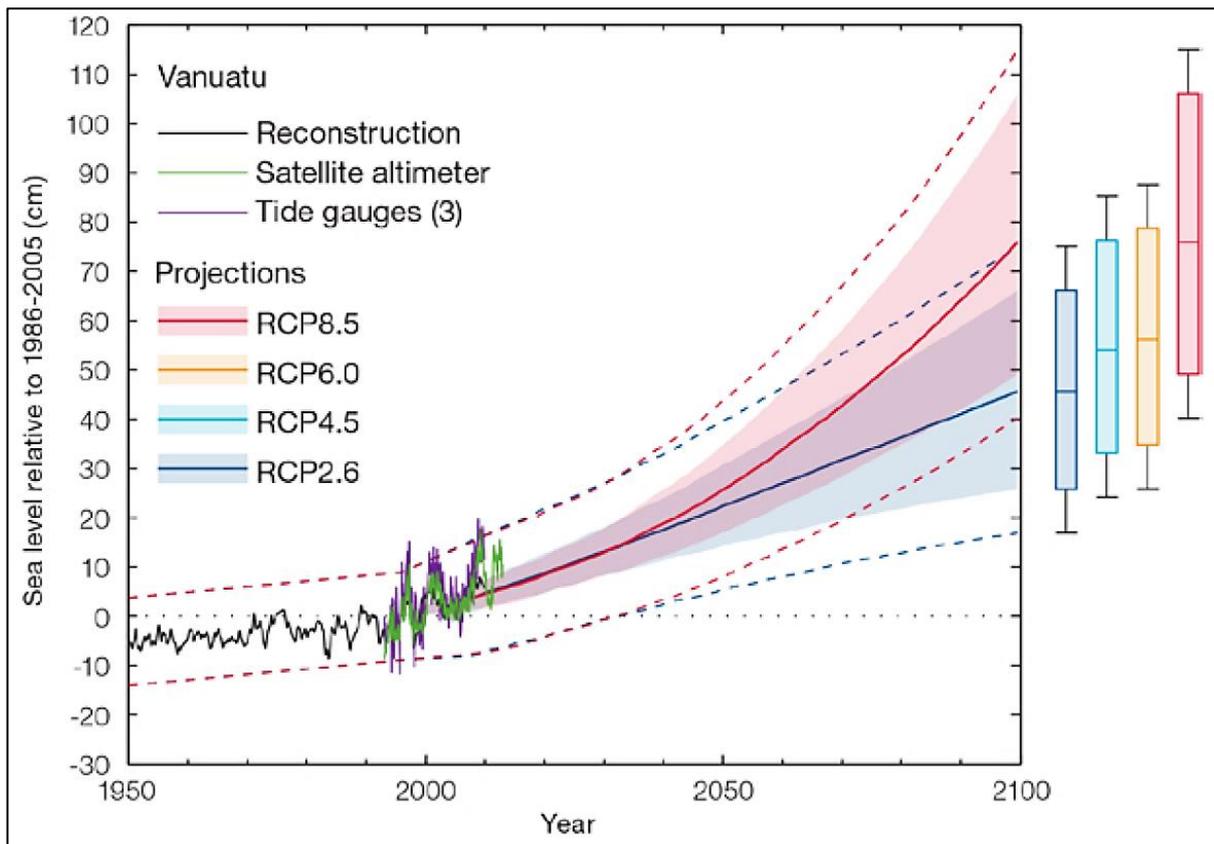


Figure 3.28 Sea level rise, Vanuatu

Observed Vanuatu tide gauge records of relative sea-level (since the late 1970s) are indicated in purple, and the satellite record (since 1993) in green. Gridded (reconstructed) sea level data at Vanuatu (since 1950) is shown in black. Multi-model mean projections from 1995–2100 are given for the RCP8.5 (red solid line) and RCP2.6 emissions scenarios (blue solid line), with the 5–95% uncertainty range shown by the red and blue shaded regions. The ranges of projections for four emission scenarios (RCPs 2.6, 4.5, 6.0 and 8.5) by 2100 are also shown by the bars on the right. The dashed lines are an estimate of interannual variability in sea level (5–95% uncertainty range about the projections) and indicate that individual monthly averages of sea level can be above or below longer-term averages. From Australian Bureau of Meteorology and CSIRO (2014).



Figure 3.29 Vulnerable coastline, Port Vila (2017)

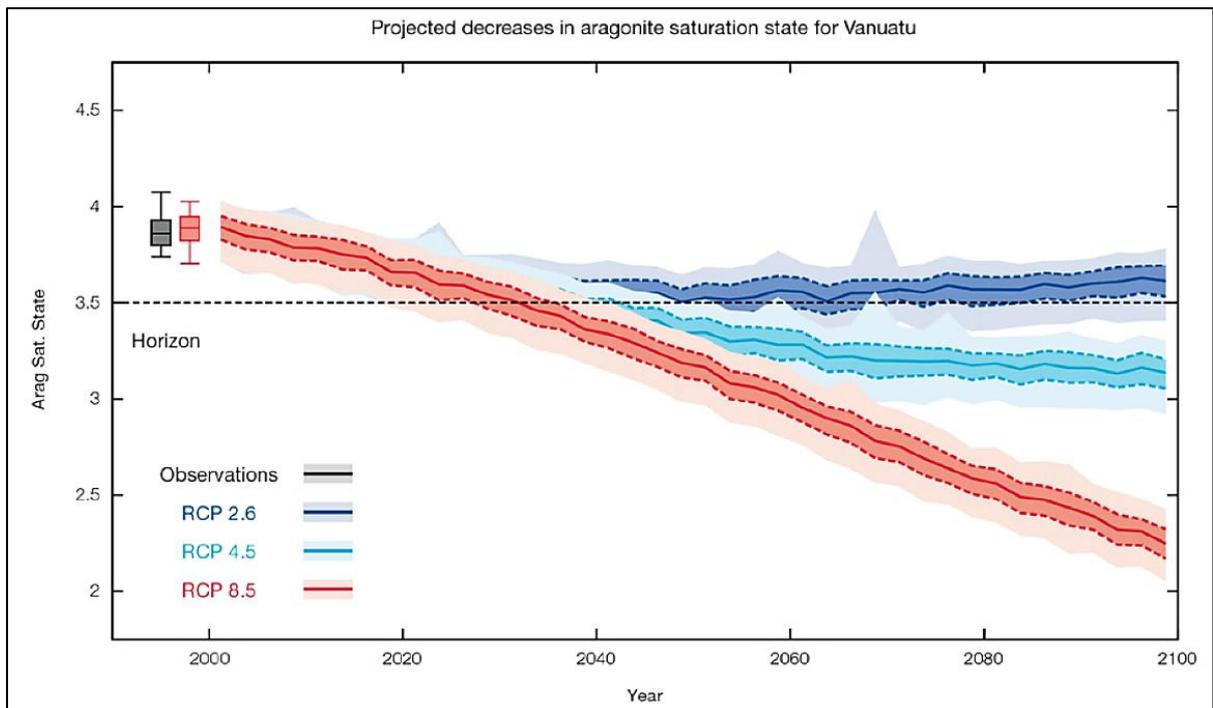


Figure 3.30 Observed state and projected changes in aragonite saturation in Vanuatu under RCP2.6, 4.5 and 8.5

Shown are the median values (solid lines), the interquartile range (dashed lines), and 5% and 95% percentiles (light shading). The horizontal line represents the transition to marginal conditions for coral reef health (from Guinotte et al. 2003). From Australian Bureau of Meteorology and CSIRO (2014).

3.5 Summary of impacts of degradation on Port Vila's ecosystems and people

The impacts of the changes described in this section on the ecological and human systems of Vanuatu and the ability of these systems to adapt depends heavily on which greenhouse gas emissions pathway is followed. In archipelagic countries such as Vanuatu, residents in the more urban 'core' are often better informed and have better understanding of the potential impacts of climate change which increases their capacity for adaptation compared to those residing in more rural areas (Nunn et al. 2013). The scientific community is in strong agreement about the extreme vulnerability of small island nations, but detection and attribution of direct impacts from climate change is challenging for a number of reasons including the strong influence of natural climate variability and the presence of other anthropogenic drivers of change in a constrained environment (Nurse et al. 2014). However, the pattern of expected changes suggests that the major impacts will fall into the broad categories of flooding and coastal / marine processes (Trundle and McEvoy 2015).

Insufficient drainage systems and degraded watersheds (especially on river margins) compromise Port Vila's ability to cope with flooding even under average conditions now. Any increase in rainfall or storm surges will exacerbate this issue (Trundle and McEvoy 2015). In addition, standing water resulting from poor drainage systems has implications for local human health and is likely to have contributed to outbreaks of dengue fever and malaria that have occurred in Efate (Maguire et al. 2006; Roth et al. 2014). Vector control through good freshwater management near to houses continues to be an integral component of vector-borne infectious disease control (Elder and Lloyd 2006). Water shortages will also have human health impacts. Potential precipitation changes (heavier rainfall or increased incidence of drought) will also impact local agricultural systems as well as the health of the native forest. The impacts of extreme events, such as cyclones, could have cascading impacts on the human population as both local crop production and import availability (via damaged ports and shipping lanes) is likely to be compromised (ibid).

Impacts of sea-level rise on human and natural systems in Vanuatu are exacerbated by Vanuatu's geographic location on a tectonically active subsiding area (Kouwenhoven 2013). Thus, coastal and marine processes that are affected by sea level rise, such as coastal erosion, are more severe on Vanuatu than on other more stable landmasses in the region. There is evidence that ocean warming increases the risk of coral bleaching events (above) and crown-of-thorns outbreaks (Uthicke et al. 2015), which could have significant impacts on both Vanuatu's tourism economy and the provision of traditional food.

4 Development Scenarios

4.1 Likely future Port Vila scenarios to 2030 based on alternative development pathways

In order to evaluate and prioritise the initial EbA project ideas for Port Vila, a development scenarios exercise was conducted to try to predict how each project might work in different possible futures. This is a way to evaluate potential risks or future issues that might affect the success of the proposed projects, and informs the choice and design of proposed projects. The most important variables when devising possible future scenarios for the Port Vila context are illustrated in Figure 4.1.

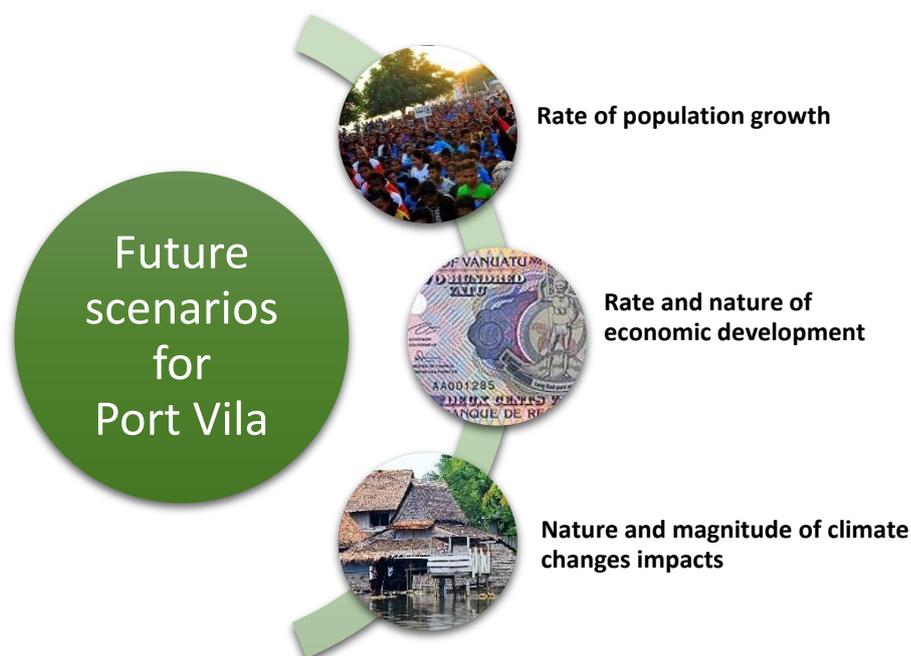


Figure 4.1 Factors in future scenarios building for Port Vila to 2030

4.1.1 Population growth

There is an accelerating trend in urbanisation across Vanuatu, particularly in and around Port Vila. Between 1999 and 2009 the Port Vila Municipality and surrounding areas experienced very high rates of population growth: 8 percent p.a. for the Municipality and 6.5 percent p.a. for the Metro Port Vila region (Section 1; McEvoy et al. 2016). It is believed that a similar rate of population growth has continued since 2009. This growth is principally due to migration from other parts of Vanuatu. McEvoy et al. (2016) state that it can be reasonably argued that the rapid urbanisation processes currently being experienced by Port Vila are likely to continue for the foreseeable future (if not accelerate as environmental ‘push’ factors in regional/rural/island areas are worsened by climate change).

4.1.2 Rate and nature of economic development

Tourism is the largest contributor to Vanuatu's exports and is the fastest growing sector in the economy (VNSO 2014). Agriculture (kava, beef, copra, coconut oil, cocoa, coffee), forestry and fishing also contribute to export earnings (VNSO 2017).

Currently Vanuatu receives close to 300,000 visitors a year: for about 70 percent, the main purpose of the visit is to have a holiday (VNSO 2015). The Vanuatu Government has ambitious goals to increase the number of visitors (both cruise ship and overnight visitors). Currently, about 95 percent of all visitors go to Port Vila (VNSO 2015). Although there is a desire to have a greater proportion of visitors travel to the outer islands (NSDP 2016), any increase in visitor numbers will undoubtedly increase the number of visitors to Port Vila and increase the size of the 'visitor service' sector in Greater Port Vila.

In the future, the nature of the tourism infrastructure and experience in Port Vila could remain much the same as it is now, and the emphasis on increasing visitor numbers could remain. Alternatively, following the direction set out in the Vanuatu Government's National Sustainable Development Plan 2016–2030, the emphasis could move from increasing the number of visitors towards increasing the value per visitor, and towards tourism infrastructure and visitor experiences that are environmentally and economically sustainable.

Figure 4.2 Left: Cruise Ship in Port Vila (image source: Red Vanuatu) **Right: Farm in Port Vila**



The Government also wants to increase economic activity in the agriculture, forestry and fishing sectors (NSDP 2016). Increased activity in these sectors is unlikely to have substantial direct effects on Greater Port Vila but, if successful, such initiatives might reduce migration from other islands to Greater Port Vila.

4.1.3 Magnitude of climate change impacts

As discussed in Section 3 of this report, the best available information indicates that it is likely that the most significant direct impacts of climate change on people of Port Vila through to 2030 and beyond will be related to changes in coastal processes, flooding patterns and the health of reefs and marine fisheries.

The primary driver of the impacts on coastal processes is expected to be sea level rise. These impacts are likely to include the loss of coastal habitat (in most places in Greater Port Vila coastal ecosystems are unable to migrate inland), increased coastal erosion and increased flooding from storm surges.

Average temperatures have been increasing in Port Vila for some time and this trend is expected to continue; there is also the issue of extreme warmth, which increases dramatically in the tropics even with small warming (Frame et al. 2017). It is unclear whether either the increase in average temperature or the extreme warmth will have significant effects on natural terrestrial ecosystems or on agricultural and forestry production systems. The extreme warmth (i.e. heat waves) in particular, may have an adverse effect on human health.

Ocean temperatures have also been rising and are expected to continue to rise. This, together with increasing ocean acidification, threatens the health of reefs and marine fisheries, and therefore access to important food sources, cultural practices, and tourism revenue opportunities.

Increased flooding is expected to occur due to higher sea levels and possibly more intense rainfall events. The most vulnerable locations are likely to be around the lower reaches of the Tagabe and other rivers, in particular places where mangroves and other vegetation has been removed. Flooding will likely damage houses and gardens, infrastructure and commercial buildings.



Figure 4.3 Left: Efate flood 2014 (image source: Floodlist). **Right: Coral bleaching** (image source: Hawaii DLNR).

As discussed earlier in Section 4, the rate at which these climate change impacts will be manifested, and the magnitude of the impacts by any particular date, are uncertain, in part because they depend to a large degree on future rates of build-up of greenhouse gases in the atmosphere. For this reason, assessments of future climate change impacts are usually expressed as ranges.

4.2 Three future scenarios for Port Vila

There are a multitude of potential futures for Port Vila, depending on numerous complex factors. Based on the above considerations three possible future scenarios were constructed for Greater Port Vila through to 2030, that were plausible and showed a range of possible futures. All three possible future scenarios involve climate change impacts at the high end of the range. The reason for holding climate change impacts constant across all three scenarios is to better indicate the different effects of the drivers that are able to be influenced by human agents in Vanuatu, namely rate of population growth, rate of economic development and nature of economic development. Climate change is a different driver in that it is not able to be influenced to any significant degree by agents in Vanuatu alone.

Climate change impacts are not going to stop or level off in 2030; indeed, the impacts of climate change will continue to build for a very long time and the greatest impacts will occur after 2030. If in fact the actual climate change impacts turn out to be lower than the high end of the range this does not mean that Port Vila will have avoided the impacts at the higher end of the range: it merely means that Port Vila will experience the impacts at the high end of the range some time later than 2030.

1. High impacts scenario

- Greater Port Vila's population continues to grow rapidly, as fast or faster than it has in recent years.
- The rate of economic development increases strongly, driven primarily by large increases in visitor numbers; tourism infrastructure is substantially expanded and the nature of this infrastructure remains much the same as it is at present; effective land use planning and controls are not put in place and the policies that are in place are not effectively enforced.
- The rate and magnitude of climate change impacts is at the higher end of the possible range.

2. Business-as-usual scenario

- Greater Port Vila's population continues to grow rapidly.
- The rate of economic development continues much as it has over the past decade, driven primarily by steady increases in visitor numbers; tourism infrastructure continues to expand and the nature of this infrastructure remains much the same as it is at present; policies concerning land use planning are put in place but are seldom effectively enforced.
- The rate and magnitude of climate change impacts is around the higher end of the possible range.

3. Low impact/sustainable development scenario:

- Greater Port Vila's population grows less rapidly than it has in recent years.
- The rate of economic development continues much as it has over the past decade; there are modest increases in visitor numbers but the emphasis has changed from increasing the number of visitors towards increasing the value per visitor; tourism and

other infrastructure continues to expand but it is built and operated in ways that are environmentally and economically sustainable and that enhance natural ecosystems; effective land use planning and controls are put in place and are enforced.

- The rate and magnitude of climate change impacts is at the higher end of the possible range.

Table 4.1: Summary of future scenarios to 2030

	High impacts scenario	Business-as-usual with climate change scenario	Low impacts / sustainable development scenario
Population growth	High – at least as high as in recent years.	High – continuation of the growth of recent years.	High – but not as high as in recent years.
Rate of economic development	Higher than in recent years.	Similar to rate in recent years.	Similar to rate in recent years.
Nature of economic development	Substantial increase in number of visitors; substantial expansion of visitor-related infrastructure; little significant change in the nature or operation of the visitor-related infrastructure.	Moderate increase in number of visitors; moderate expansion of visitor-related infrastructure; modest changes in the nature and operation of the visitor-related infrastructure towards greater sustainability.	Focus on value per visitor; modest increase in number of visitors; modest expansion of visitor-related infrastructure; substantial changes in the nature and operation of the visitor-related infrastructure towards greater sustainability.
	Little significant progress with adopting a Greater Port Vila Plan or with effective enforcement of controls that protect and enhance natural ecosystems and the services they provide. Adaptation to climate change through hard engineered options.	Some progress with adopting a Greater Port Vila Plan but poor enforcement of controls that protect and enhance natural ecosystems and the services they provide.	A Greater Port Vila Plan is adopted and there is effective enforcement of controls that protect and enhance natural ecosystems and the services they provide. Adaptation to climate change incorporates soft engineered options.
	Ecosystems continue to degrade but at an accelerated rate compared to the present.	Ecosystems continue to degrade at a rate comparable to the present.	The extent and productivity of home gardens and commercial agriculture is increased; fewer food imports; major thoroughfares and focal points of Greater Port Vila are made more attractive and productive by extensive planting of trees; a focus on sustainable housing and development is adopted; and there is some restoration of riparian and coastal ecosystems.
Climate change impacts	High end of the range.	High end of the range.	High end of the range.

4.2.1 Future scenarios descriptions

Two possible future scenarios at either end of the spectrum of possibilities for Greater Port Vila through to 2030 are described. Other scenarios, including the 'business as usual' scenario outlined in Table 4.1 will likely fall in-between these two described scenarios (high impact and low impact).

4.2.1.1 High impacts scenario: Port Vila in 2030

Over the period to 2030 in Port Vila, sea level has risen by about 4–5 cm and continuing trends in acidification and temperature are causing an ongoing deterioration in reef health. It is becoming more likely that reef health will continue to significantly deteriorate and reefs may no longer be able to protect coastlines from storm surges. Sedimentation has continued to degrade freshwater and coastal ecosystems. The acidification, higher sea temperatures and sedimentation may have led to significant changes in the species composition of marine ecosystems and the abundance of species that are important food sources. Similar changes have occurred across the whole country so it is unlikely that reduced food from marine sources in Greater Port Vila will have been made up for by increased supply from other parts of the country, or potentially even other countries in the region.



Figure 4.2 Sedimentation in lagoon

High in-migration, large increases in visitor numbers, and little effective control of land use (in particular resort development, coastal housing for the wealthy, and sand mining) have resulted in substantially more coastal vegetation, including mangroves, being removed due to the construction of resorts and other valuable properties.

With higher sea levels, much of the coastal area is under increasing threat but no longer has the protection afforded by mangroves and other coastal vegetation. There is inundation of

some low-lying coastal areas. Those owning property on the coast, and especially those owning expensive property there, have constructed their own 'hard' infrastructure protection. This is often ineffective and inflexible, and/or is exacerbating adverse effects at other points along the coast. There is agitation for increased public funding of 'hard' adaptation strategies.

Higher sea levels, and higher intensity rainfall events, have led to water levels in the rivers being higher at their mouths and in their lower reaches than they were in 2017. When there is significant rain, there is flooding and ponding of water in lowland areas such as Blacksands. This has damaged houses, gardens and infrastructure and has generally decreased the quality of life for the increasingly densely and poorly housed residents. The rainfall distribution appears to have become more extreme, and to be exacerbating the flooding and ponding issues, which in turn appear to have increased the incidence of some non-communicable diseases. This has been further compounded by higher temperature extremes.

Extremes in water availability appear to adversely affect food production, and possible population health. These adverse effects are further compounded by more extreme temperatures. These conditions apply elsewhere in Vanuatu as well, meaning the availability and price of Vanuatu-grown food in Greater Port Vila is constrained and prices have increased. Such constraints on access to affordable food mean an increased reliance on imported foods such as tinned fish, rice and noodles. This is associated with a decline in nutritional and public health status (e.g. an increase in diabetes) and an increase in health care costs.

High population growth in Port Vila, coupled with largely unplanned and unsustainable urban development, has increased the number and extent of informal settlements, the use of land for bush gardens, the removal of vegetation for firewood, the over-harvesting of species such as natangura and pandanus, and has increased harvesting pressures on marine food sources. It has also put increased pressure on existing social structures and the authority of Chiefs and significant tensions between landowners and settlers.

The problems associated with the apparent effects of climate change, largely uncontrolled development of the tourism and industrial sectors, and rapid unplanned population growth has made Port Vila a less attractive destination for visitors. This has resulted in forecasts of substantial reductions in visitor numbers and corresponding large adverse social and economic effects.

4.2.1.2 Low impacts/sustainable development scenario: Port Vila in 2030

Over the period to 2030 in Port Vila, sea level has risen by about 4–5 cm and it is likely ocean acidification and temperatures will increase such that reef health will deteriorate further. Sedimentation has continued to degrade freshwater and coastal ecosystems. The acidification, higher sea temperatures and sedimentation may have led to significant changes in the species composition of marine ecosystems and the abundance of species that are important food sources. Similar changes have occurred across the whole country so it is unlikely that reduced food from marine sources in Greater Port Vila will have been made up

for by increased supply from other parts of the country, or potentially even other countries in the region.

A lower rate of in-migration, modest increases in visitor numbers and effective control of land use (in particular resort development, coastal housing, and sand mining) has resulted in most of the existing coastal vegetation, including mangroves, remaining. Effective implementation of policies to protect beaches and restore coastal vegetation has increased the area of mangroves and other coastal ecosystems.

With higher sea levels, much of the coastal area is under increasing threat but many areas are afforded a measure of protection by beaches, mangroves and other coastal vegetation. There is inundation of some low-lying coastal areas.

Those owning property on the coast, and especially those owning expensive property there, have begun to put in their own 'hard' protection and agitate for public funding of hard protection. However, as a result of the more modest increase in visitor numbers and effective implementation of land use policies, fewer additional resorts have been built and those that have been, have been designed and constructed to avoid the need for 'hard' protection from rising sea levels, and to avoid the destruction or degradation of natural coastal ecosystems. Similarly, any additional coastal housing has been built in a way that did not destroy or degrade natural coastal ecosystems.

With higher sea levels, and possibly higher intensity rainfall events, water levels in the rivers are higher at their mouths and in their lower reaches than was the case in 2017 but because of improved management of water flows not to the same extent as in the high impacts scenario. When there is significant rain, there is likely to be some flooding and ponding of water in lowland areas such as Blacksands but at a reduced level compared to the high impacts scenario; this may damage houses and gardens and possibly infrastructure. Rainfall events appear to have become more extreme, exacerbating the flooding and ponding. The inundation and increased flooding and ponding appear to have increased the incidence of some non-communicable diseases, and has been compounded by the higher temperatures. Although the temperature rise is the same as in the high impact scenario, the scale of this impact is reduced compared to the high impacts scenario because of the sustainable development and climate change adaptation measures adopted. Water availability, food security, food importation, and health impacts are still likely to occur as outlined in the high impacts scenarios but these effects are less severe.

Lower population growth in Port Vila, effectively implemented planned urban development, and successful implementation of a suite of ecosystem-based adaptation projects and other ecological and social initiatives have reduced the pressure on terrestrial and marine ecosystems, and on social systems, compared to the high impact scenario. More extensive and more productive home gardens are making an important contribution to addressing constraints on access to food and are also helping to reduce pressures on terrestrial and marine ecosystems. Improved and effectively implemented land use controls and practices have reduced sedimentation and pollution of rivers and coastal ecosystems. Some coastal

ecosystems have been restored and there has been extensive planting of trees in the urban area.

Despite relatively high population growth and effects from climate change, Port Vila becomes a more attractive destination for visitors (especially those wishing to enjoy tourism promoted as part of Vanuatu's sustainable tourism strategy) and possibly wealthy immigrants; it has become much more socially, economically and environmentally sustainable.

4.2.2 Comment on the Port Vila in 2030 scenarios

The economic development pathway outlined above in the low impacts scenario helps to address issues arising from high population growth and unplanned and ineffectively controlled urban development. However, the usefulness of that scenario in addressing the effects of climate change is modest because the effects of climate change were assumed to be still at the high end of the range.

It can therefore be seen that there will still be significant resilience challenges for Port Vila, regardless of the adaptation and development scenarios chosen, because of these high climate change impacts. This underlines the critical importance of global mitigation efforts so that in the years following 2030 the climate change effects are not as great as indicated by the RCP8.5 scenario and the adaptation measures adopted can be more effective.

These are short-term scenarios, and climate change impacts will not cease in 2030. Some, such as sea level rise, will continue for many decades even if global emissions of greenhouse gases are reduced sufficiently rapidly to achieve the goals of the Paris Agreement. This means that some climate change impacts that are at the high end of the range for 2030 may be at the low end of the range by 2050 or 2100. This suggests that it would be instructive to consider future scenarios over a longer timeframe, and/or conduct scenario planning at regular long-term intervals.



Figure 4.5 Vanuatu sea level rise (source: J. Waeda, Loop News)

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APPENDIX 1 Limitations of mapping and cover estimates in conducting the ecosystem assessment

Due to the lack of sufficient data for ecosystem mapping, and because of relatively low spatial resolution of the satellite imagery, the identification of additional classes/subclasses was not practically possible. More specifically, some ecologically important patches of vegetation in the class Forest remained unclassified. The subclass Thicket, for example, was merged with the class Low Density Forest in order to avoid misclassification of land cover types resulting from the lack of spatial resolution. Although a rich land and coastal cover classification could increase the quality of the research, in the absence of enough scientific materials and methods, the precautionary policy was taken into consideration to avoid unrealistic approaches for increasing the number of classes/subclasses. The principal aim was to define a realistic, relatively accurate and reliable land and coastal cover classification system based upon the available data. In addition, although rapid field survey was undertaken to increase the accuracy of the required data for ecosystem mapping, more advanced equipment (e.g. drone, GPS, etc.) was necessary to identify the right location of each land cover type in order to establish a more robust relationship between the created maps and the realities on the ground. In such a situation, it was impossible to specifically identify the boundaries of land cover type classes in some cases using remote sensing in the Arc Map environment. Furthermore, while ecosystem mapping was undertaken in two different scales (i.e. catchment and urban), there was no additional source of information to show the study area's land cover pattern on a spectrum of scales ranging from fine to broad. Thus, the 2016 satellite imagery (5m resolution) was the only basic input to map the study area at the catchment and urban scales. For these reasons, the created maps are subject to error, despite the significant level of effort made to create them. The maps should be improved in the future research not only based on more updated data including high resolution satellite images, but also through more advanced data collection methods and tools including field verification equipped by proper tools such as GPS and/or drone.



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