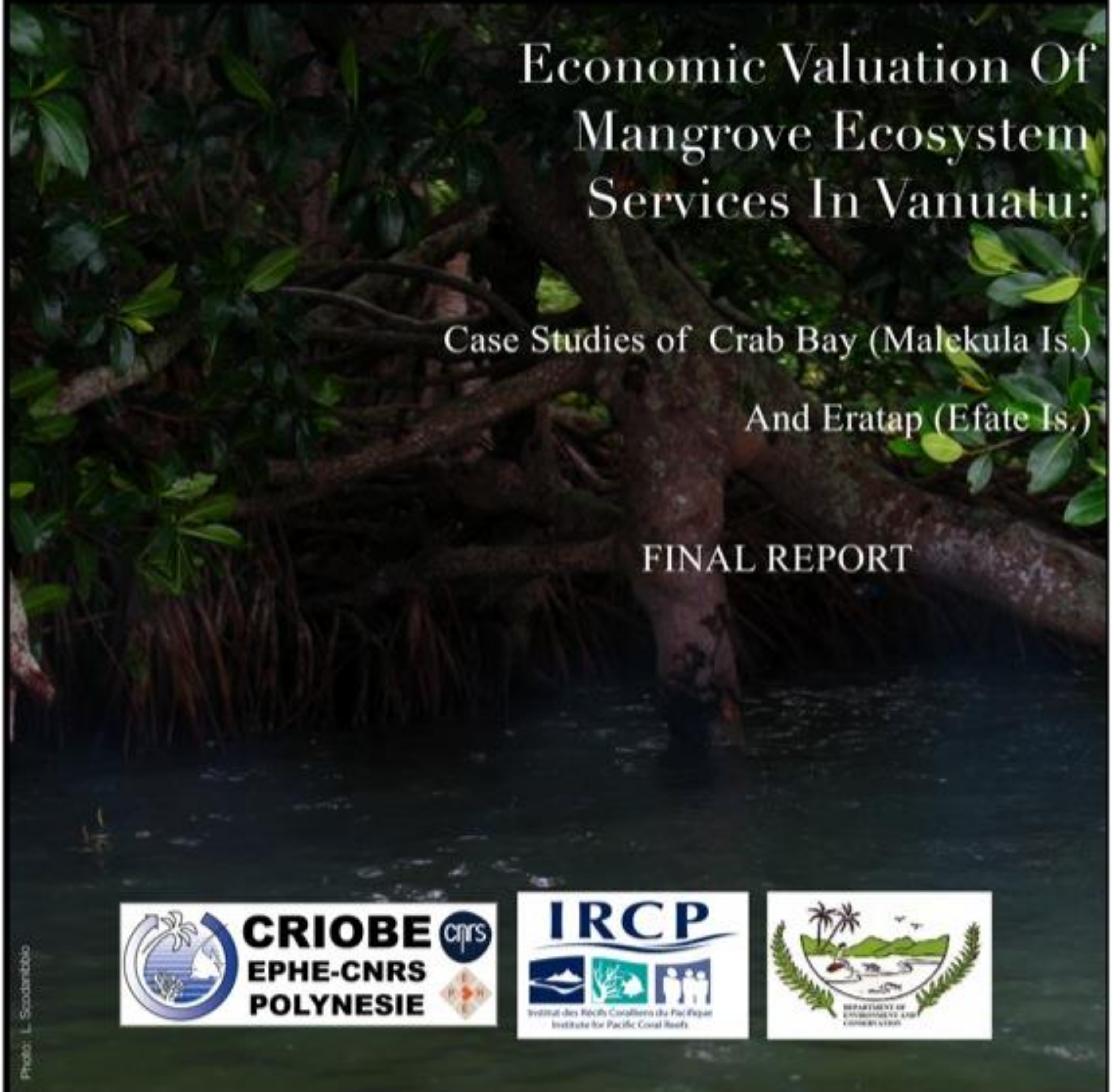
Technical report

April 2013



Economic Valuation Of Mangrove Ecosystem Services In Vanuatu:

Case Studies of Crab Bay (Malekula Is.) And Eratap (Efate Is.)

FINAL REPORT

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Economic valuation of mangrove ecosystem services in Vanuatu

Case study of Crab Bay (Malekula Is.) and Eratap (Efate Is.)

FINAL REPORT

October 2014

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This study is the result of financing provided by IUCN ORO (International Union for Conservation of Nature and Natural Resources, Oceania Regional Office). IUCN Project Number 77162-000.

For:

Project MESCAL, Mangrove EcoSystems for Climate Change Adaptation & Livelihoods. Implemented by IUCN Oceania under the emerging Pacific Mangroves Initiative. The project is funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMUB) under its International Climate Initiative. Project partners include the University of the South Pacific (USP), the Secretariat of the Pacific Regional Environment Programme (SPREP), the WorldFish Solomon Islands Pacific Base, and the Tonga Community Development Trust, as well as the governments of the participating countries.

Project by IUCN Oceania Regional Office funded by the Federal Ministry for the Environment,, Nature Conservation, Building and Nuclear Safety (BMUB) with support for publication by the Marine and Coastal Biodiversity Management in Pacific Island Countries and Atolls (MACBIO) and Mangrove Rehabilitation for Sustainably-Managed Healthy Forests (MARSH) projects.

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The method described in the report annexes is based on a working paper coordinated by the author with Michel Allenbach (UNC), Thomas Binet and Pierre Failler (CEMARE), Julien Hardelin (MEEDTL/SEEI/ERNR1), Arthur Katossky (CGDD/SEEI/ERNR3), Elen Lemaître-Curri (MEEDTL/SEEI/ERNR1), Gilbert David (IRD), Philippe Méral (IRD), Mahé Charles (AAMP) and Jean-Baptiste Marre (CRIOBE).

ACKNOWLEDGMENTS

This project would not have been possible without the support of the Vanuatu Government Department of Environment Protection and Conservation, which provided supervision and assistance. Coordinating the MESCAL project in Vanuatu, Rolenas Baereleo was also essential to the study's success.

We acknowledge Milika Sobey from IUCN ORO (International Union for Conservation of Nature's Oceania Regional Office)—who is coordinating the German funded MESCAL project—for her financial support and making possible this study.

We also acknowledge the Vanuatu Government departments that met with us, particularly the Department of Fisheries, the Department of Lands, Survey and Registry, the Department of Forestry and the Malampa Province.

Undertaking more than 500 surveys in 20 villages in a limited time was a challenge. Difficulties in the field mean the data collection team needed patience and self-confidence. I, Molu Bulu, thank the team: Ms Donna Kalfatak, Ms Primrose Malosu, Mr Trinison Tari, Mr Reedly Tari, Mrs Rolenas Baereleo, Mr Tony Kanas, Mr Philip Koroka, Mr Rodson Aru, Mr Peter Kalmasing, Mr Fred Numa, Mr Jonah Spetly, Mr Josen Ritson, Mr Mark Leonie, Ms Susan Tahi and Mr Ruben Morry. And I, Nicolas, acknowledge the capacity of Molu Bulu to face field realities with my remote support.

We especially thank the 480 households surveyed in the 20 communities of both demonstration sites. These households shared their time with the survey team, along with their knowledge from their use of the mangroves and fisheries.

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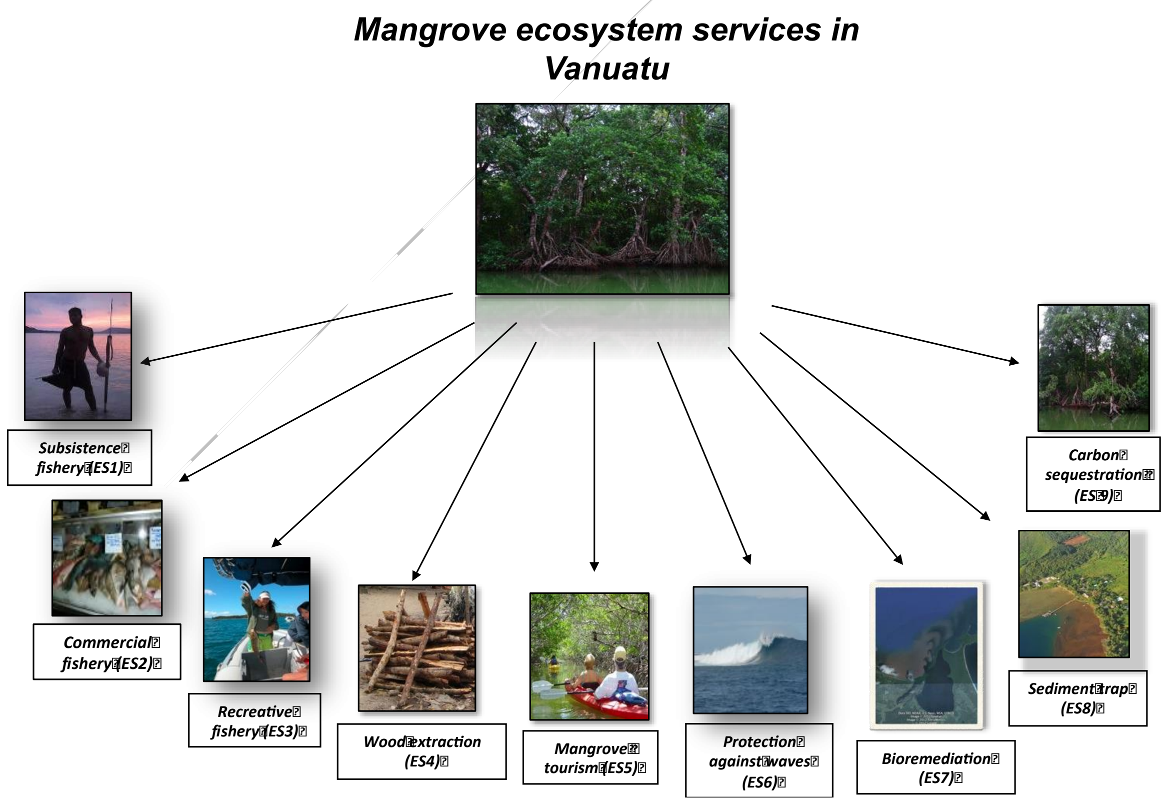
This study aimed to determine an economic value of nine mangrove ecosystem services (figure A) at two sites in Vanuatu: Crab Bay and Eratap. It is part of the MESCAL project, which looks to address the main challenges to mangrove management and conservation. Specifically, the study contributes to MESCAL outcome 1 (National baseline information about climate change scenarios, use and values of mangroves and associated ecosystems) and outcome 4 (Increased awareness, advocacy and capacity development).

In response to market failures, economic valuation of mangrove ecosystem services (ES) is viewed as a promising approach. We undertook the ES valuation to raise awareness among decision makers, policy makers and the public of the environment's benefits for society. From that awareness, we intend for the valuation to strengthen support for environment regulation and resource management. At the same time, this study can be part of a monitoring routine to inform management with economic indicators—a case of being able to better manage what we can measure.

Figure A: Mangrove ecosystem services in Vanuatu



In summary, the study used literature review, expert opinion and surveys to establish an economic value for each of the nine ES at each of the two sites, and then a consolidated ES value for each of the two sites:

- We conducted field surveys to determine the cultural and commercial uses of mangrove resources (subsistence and/or commercial artisanal fisheries, firewood, timber, medicine etc.) and assess their economic values. The survey team questioned the villages of Crab Bay (16 villages and plantation settlements on Malekula Island) and Eratap (10 settlements on Efate Island), which each comprise 10–50 households with a mean household size of five persons (generally an extended family). The Crab Bay population totals 750 people and Eratap totals 240 people, approximately.
- We conducted a desktop review of *indirect* mangrove uses (coastal protection, water treatment, sediment trapping and carbon sequestration), to assess the economic values of those uses too.

For this study, we used the MESCAL mangrove baseline vegetation mapping study conducted in 2012 in Crab Bay and Eratap. The MESCAL mapping study found the common back boundary mangrove species at this study's two sites is *H. litoralis* and the common offshore mangrove is *R. stylosa*. Its baseline maps show the total area of mangroves from offshore to the high water mark and to the back boundary species of mangroves is 135.5 hectares and 31.2 hectares in Crab Bay/Amal and Eratap respectively (Vanuatu Department of Environment and Conservation).

WHAT WE FOUND

WHAT IS THE VALUE OF THE ECOSYSTEM SERVICES?

We found the following total economic values for the nine ecosystem services (ES1–ES9, figure A) in the two mangrove systems:

- In Crab Bay in 2012, mangroves (136.5 hectares) produced ES worth an estimated Vt53 million (equivalent to US$586 000). This total comprised ES values ranging from Vt36 million to Vt70 million.
- In Eratap in 2012, the mangroves (31.2 hectares) produced ES worth an estimated Vt24 million (equivalent to US$266 000). This total comprised ES values ranging from Vt17 million to Vt31 million.

For comparing sites, these valuations are equivalent to ES worth Vt386 000 per year per hectare (US$4300 per year per hectare) in Crab Bay and Vt768 000 per year per hectare (US$8500 per year per hectare) in Eratap.

In Crab Bay, the principal ES in economic terms are carbon sequestration (ES9), the proteins from subsistence fishery (ES1), the commercial fishery (ES2) and wood extraction (ES4), which add to 99 per cent of the mangroves' total value (figure B). Coastal protection is the other ES in Crab Bay. In Eratap, the principal ES are carbon sequestration (ES9), the proteins from subsistence fishery (ES1), the revenue from tourism linked to mangroves (ES5), and the avoided costs from coastal protection against flood (ES6), which add to 87 per cent of the total value (figure C). Commercial fishery (ES2), wood extraction (ES4) and recreational fishery (ES3) are the other ES in Eratap.

Table A shows the main study results, which are described later in the report.

Table A:Economic valuation of ecosystem services of Crab Bay and Eratap mangroves in 2012

$US	Crab Bay			Eratap		
	min	max	**average**	min	max	**average**
ES1 Subsistence fishery	67 722	90 600	**79 161**	30 311	43 700	**37 006**
ES2 Commercial fishery	32 933	61 633	**47 283**	10 344	24 756	**17 550**
ES3 Recreational fishery	Service non-existent			800	1 200	**1 000**
ES4 Wood extraction	27 467	51 000	**39 233**	11 778	21 867	**16 822**
ES5 Mangrove tourism	Service non-existent			35 378	58 967	**47 172**
ES6 Coastal protection	4 156	7 133	**5 644**	34 833	59 722	**47 278**
ES7 Bioremediation	Service almost negligible			Service almost negligible		
ES8 Sediment trap	Service almost negligible			Service almost negligible		
ES9 Carbon sequestration	265 489	563 333	**414 411**	68 922	130 000	**99 461**
Total	297 111	773 700	**585 733**	192 367	340 211	**266 289**
Total per hectare	2 914	5 668	**4 291**	6 166	10 904	**8 535**

Figure B: Distribution of estimated total value (Vt53 million) in Crab Bay, 2012

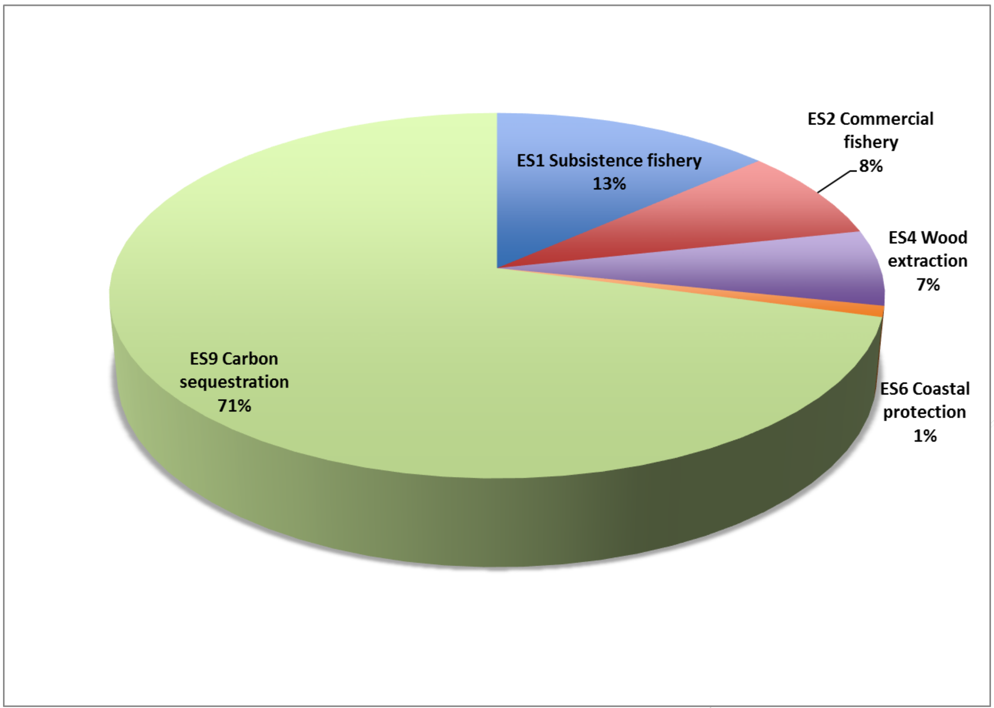
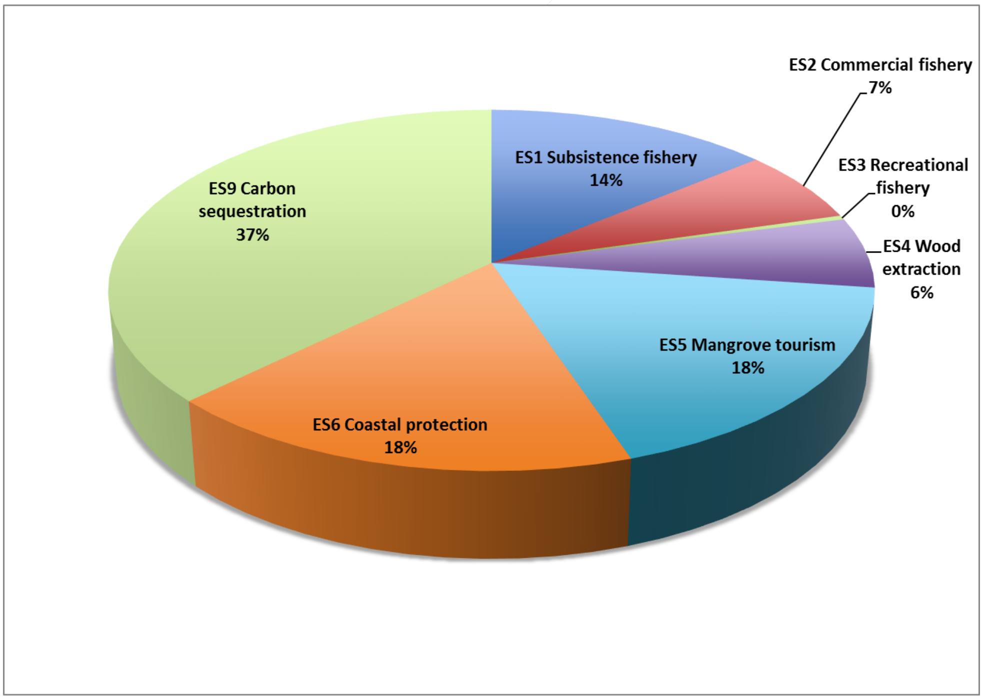


Figure C: Distribution of estimated total value (Vt24 million) in Eratap, 2012



WHO BENEFITS FROM THE ECOSYSTEM SERVICES?

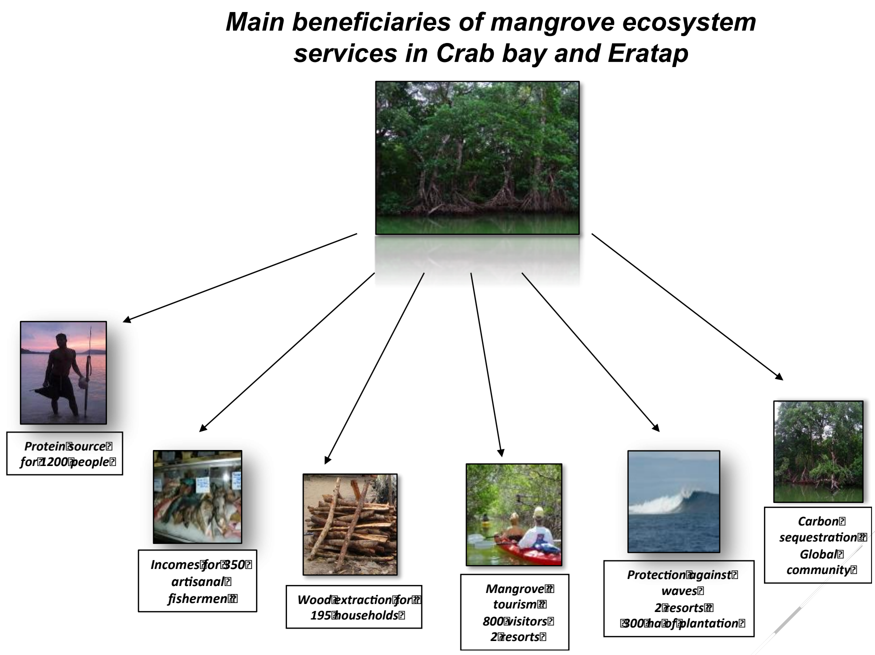
The following groups benefit most from mangrove ES in Crab Bay and Eratap (figure D):

- fishermen of the commercial artisanal fishery (300 in Crab Bay, 50 in Eratap)
- local families for whom fishing in the mangroves and in the reef is a source of regular protein (160 households in Crab Bay, 80 households in Eratap)
- local families benefiting from firewood and construction material (150 households in Crab Bay, 45 in Eratap)
- entrepreneurs in Eratap proposing mangrove tourism (two businesses, 800 tourists per year)
- real estate owners protected from coastal flooding (two tourism resorts in Eratap, covering a total area of 3000 m^2), as well as plantation owners (300 hectares in Crab Bay)
- tourism entrepreneurs in Eratap whose business depends on the quality of lagoon water and beach formation (two businesses, 21 jobs, 11 500 tourists per year)[1]
- the global community, which benefits from carbon sequestration and biodiversity.

In total, nearly 800 people depend on one or more of the mangrove ES in Crab Bay, as do 400 in Eratap.

[1] *The relationships between mangrove ecosystem processes and the benefits of clean water for recreational use need further study. This study mentions this service as a potential benefit but did not value it.*

Figure D: Main beneficiaries of mangrove ecosystem services in Crab Bay and Eratap



WHAT DID WE OBSERVE FROM THE SURVEY?

For Malekula Island, the majority of income earnings are derived from agricultural products, fish and handicrafts. The mangrove resources thus provide a majority of services needed by the locals, such as food security, shelter and housing means, and financial support. But for Eratap locals, little income is generated from the mangroves because the urban centre of Port Vila (on the same island) presents many other means of generating income. Eratap villages thus use the majority of their mangrove resources for consumption and sell a lesser percentage for income.

In summary, the surveyed villages depend on the mangrove ecosystem for their sustainable livelihood, because it satisfies their basic needs of food and shelter. The crabs, shells and fish ensure food security for the villages, especially those without stable salaries (the majority of villagers). In the context of fluctuating market prices, this ecosystem service of free food supply benefits the village. Further, the majority of the people depend on agriculture for income, but the seasonal nature of their produce means income is not consistent. So, the mangrove ecosystem also serves as a backup means of earning income.

OUR RECOMMENDATIONS

After presenting the study results to the officers of the Vanuatu Government Department of Environment Protection and Conservation, we identified the following two recommendations:

1. Regulation and policies addressing mangroves management and conservation should reflect the importance of the mangroves' benefits and value. Specifically, compensation for anthropogenic damages to mangroves (e.g. destruction, contamination, partial clearing) should account for the nine ES identified in this study. MESCAL outcome 2 includes having a 'Policy and legislative review, so that loop holes and gaps in existing separate policies and regulations that lightly address mangrove ecosystems can be addressed'. Additionally, the Vanuatu Government should assign a policy, or incorporate legislation into the existing Environmental Management and Conservation Act, that will govern and set laws on mangrove forests to prevent further destruction or differently manage it.

   Given the main principle of compensation is 'no nature loss', every mangrove destroyed should be compensated[2] for by a mangrove of similar characteristics (in kind) and in the proximity (in site). Compensation can be made through restoration, re-seeding or conservation of existing mangroves, and it is always the responsibility of the developers. The ratio of compensation applied accounts for ecological differences, recovery time and the risks of ecological engineering. Payments for damages are made only when the developers do not have the technical capacity to subcontract the compensation measures. In this case, one option is to pay the compensation amount to a structure regulated by the government. Most international organisations recommend this approach but many countries are still exploring it. The wetland compensation banks in the United States are one illustration of such a mechanism.

2. The Vanuatu Government should incorporate the study findings in a policy brief to convince policy makers to better support mangroves management. Clear communication of ES beneficiaries, values and policy needs should contribute to this 'inform & convince' objective. The Vanuatu Government's Environment, Fisheries and Lands departments, non-government organisations and bilateral agencies might use the results in their communication and strategy. With the same objective, identifying the rate of mangroves degradation will help make a concrete case for strengthening mangroves management.

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[2] *Offset laws usually recommend compensating for project impacts as the last option after undertaking strategies to avoid and reduce impacts.*

ABOUT THE STUDY

THE MESCAL CONTEXT

Most Pacific Island territories face challenges such as:

- increased fish demand from human population growth; the human population is estimated to increase by 50 per cent by 2030, with projected food requirements well in excess of what coastal areas are currently likely to produce without significantly improved management and productivity (Bell et al. 2009)
- the rapid introduction of a market economy with its associated rural migration, loss of traditional customs and urban poverty (Cinner and Aswani 2007)
- a small island context with limited economic options (Beukering et al. 2007)
- potential climate change effects on the islands' marine ecosystem services (Knowlton 2000).

Reinforcing these challenges, the Pacific Islands' national budgets are usually small and face considerable demands to meet human development priorities such as health, education and food production. This context means mangrove ecosystems in the Pacific Islands are under threat from overharvesting, degradation and land reclamation. The threat continues despite the mangroves being renowned for providing services that Pacific people highly value. Weak governance, a disconnect between formal and traditional management systems, limited baseline information, weakening traditional management, a lack of awareness, and limited capacity are some of the key challenges for mangroves management and conservation in the Pacific.

The MESCAL project was developed under the Pacific Mangrove Initiative to address these key challenges. Adopting an Ecosystem based Management (EbM) approach, the project focuses on finding stakeholder based solutions supported by scientific evidence and traditional knowledge to influence decision making positively at all levels of governance. It aims to help climate-proof coastal communities and sustain livelihoods by promoting investments in mangrove and associated coastal ecosystems in the five participating countries: Fiji, Samoa, Solomon Islands, Tonga and Vanuatu.

Specifically, the desired MESCAL project outcomes are:

1. National baseline information about climate change scenarios, use and values of mangroves and associated ecosystems
2. Co-management of mangroves for adaptation to climate change governance
3. Improved conservation and/or restoration of mangroves at selected demonstration sites
4. Increased awareness, advocacy and capacity development.

OUR OBJECTIVES

Before examining the study objectives, it is important to understand how economic valuation can be used. In response to market failures, economic valuation of mangrove ecosystem services (ES) is viewed as a promising approach to address one or several of the following objectives (Laurans et al. 2013):

1. *Decisive valuations* are intended to allow an ex-ante choice or ex-post appraisal of options by weighing the ecological and economic consequences of those options. They incorporate the present and future values of negative and positive externalities with a common metric, and provide 'correct' signals (Campbell and Brown 2003; Whitten and Bennett 2004).
2. *Technical valuations* are designed to finetune economic instruments that internalise externalities. They may, for example, provide the price baseline for negotiating a payment for ecosystem services, user fees or environmental taxes (Chevassus-au-Louis et al. 2009; Engel et al. 2008; Meignien and Lemaître-Curri 2010; PNUE 2004).
3. *Informative valuations* are intended to raise awareness among decision makers and the public of the environment's condition. Recognising that 'money talks', their role is to strengthen support for environment and resource management actions. At the same time, they can be part of a monitoring routine to inform management with economic indicators—a case of being able to better manage what we can measure (Beukering et al. 2007; David et al. 2007; Pascal et al. 2008).

This study's total economic valuation (TEV) of mangrove ES fits the third category: it has informative objectives. TEV is defined as the sum of the consumer surplus and the producer surplus of all the services of direct use, indirect use and non-use (as explained in the 'The theory behind our method' section). Usually covering more than 12 services (Moberg and Folke 1999), mangrove TEV is useful for comparing very different services (e.g. a comparison of subsistence fishery with coastal protection). Decision makers understand you can't manage what you don't measure (Seidl et al. 2011). For this reason, TEV estimates help decision makers manage an ES portfolio (one that includes both those services that are well reflected in markets and those that are not). They also help identify the main beneficiaries from the ecosystem processes, and thus who will be the socioeconomic groups affected by a particular policy.

The results of the cost-benefit analysis should strengthen the support from policy makers for environment and resource management actions. It will make visible most of the costs and benefits of public investments in conservation such as MPAs.

Cost–benefit analysis (CBA) of a project or a policy belongs to both the first and third categories of economic valuation. It improves decision making by comparing different scenarios, appraising investments and informing decision makers about implicit or explicit costs and benefits for host communities, nations and donor agencies. That is, CBA quantifies in monetary terms the value of all consequences of a policy for all members of society. The CBA of a project or policy generally leads to an aggregate value or net social benefit. Although not all benefits and costs are or should be quantifiable, CBA provides a useful tool to help social decision making and make it more rational. An example is the CBA of Marine Protected Areas (MPAs), which are essential for preserving coastal ecosystems (Bell et al. 2009a; Mumby and Steneck 2008b): it is expected to convince policy makers of the return on public investments in MPAs and identify the losers and winners among the main stakeholders (Mangos and Rojat 2008; TEEB 2009).

WHAT WE VALUED—A SUMMARY

This study focused on economic valuation of mangrove ES in two locations in Vanuatu (figures 1 and 2). Specifically, the study team conducted field surveys to determine the cultural and commercial uses of mangrove resources (subsistence and/or commercial artisanal fisheries, firewood, timber, medicine etc.) and assess their economic values. The team also conducted a desktop review of *indirect* uses of mangrove ecosystems (coastal protection, water treatment, sediment trapping and carbon sequestration) and assessed the economic values of those uses too.

The most common definition of ecosystem services are ‘services that human populations derive, directly or indirectly from ecosystem functions’ (Costanza et al. 1997) or, more simply, ‘services that people obtain from ecosystems’ (Boyd and Banzhaf 2007; MEA 2003). The Millennium Ecosystem Assessment defines an ecosystem as ‘a dynamic complex of plant, animal, and micro-organism communities, and the non-living environment interacting as a functional unit’ (MEA 2003). This report presents the TEV results for nine ES:

- subsistence fishery (ES1)
- coastal commercial fishery (ES2), including professional and nonprofessional fishery as well as coastal and mangrove linked pelagic fishery
- recreational or sport fishery (ES3)
- other extractive uses such as wood, medicine (ES4)
- tourism activities linked to mangroves (ES5)
- coastal protection against flood (ES6)
- bioremediation of waste waters (ES7)
- sediment trapping to reduce coastal erosion (ES8)
- carbon sequestration (ES9).

Figure 1: Crab Bay study site (Malekula Island)

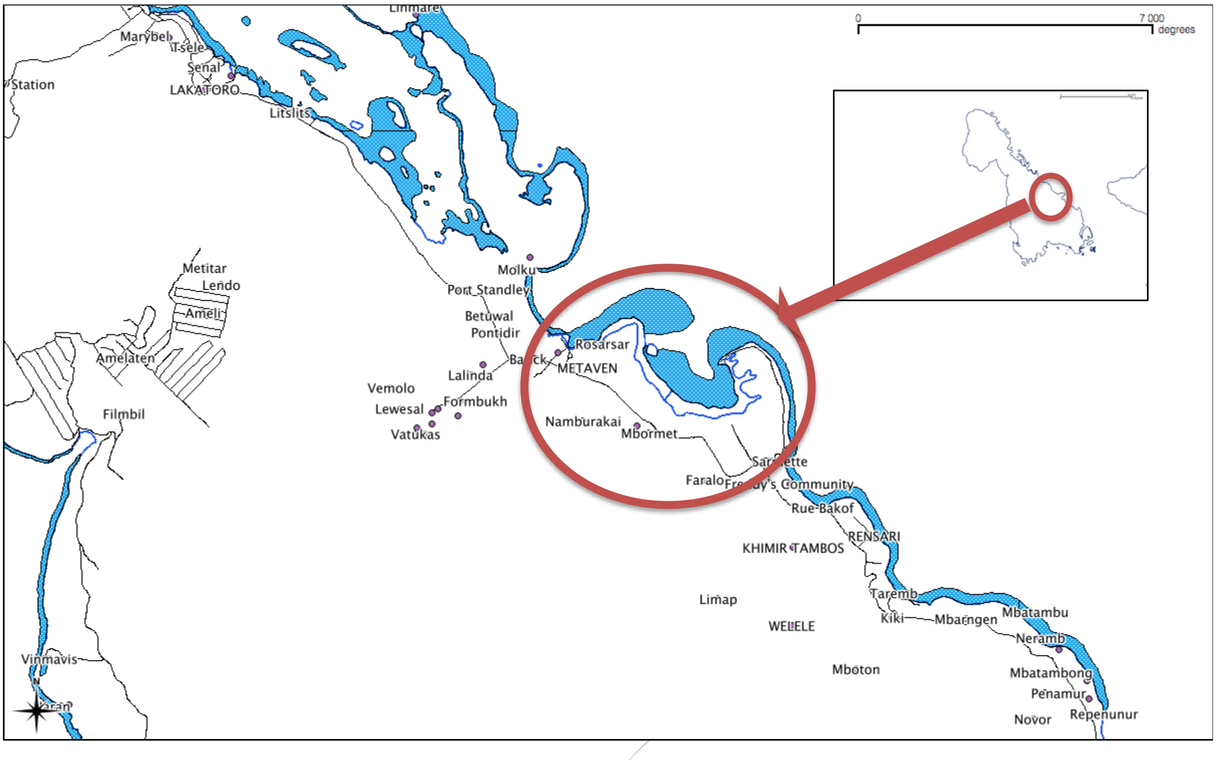
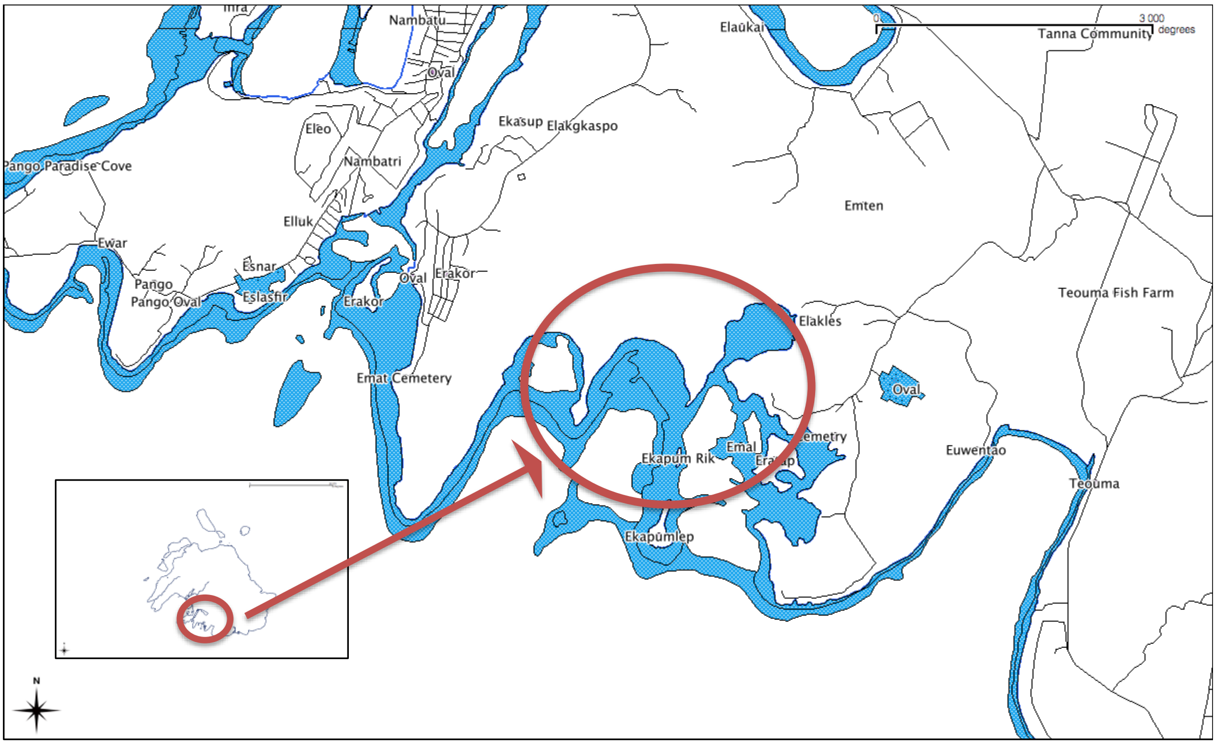


Figure 2: Eratap study site (Efate Island)



HOW WE VALUED THE ECOSYSTEM SERVICES—A SUMMARY

Table B summarises the different methods that we used for a monetary valuation of ES1–ES9. Below the table is an overview of our valuation method and assumptions. For more detailed information, please see the following annexes:

- Annex 1 Classification of ecosystem services
- Annex 2 Valuation of direct extractive uses (ES1, ES2, ES3 and ES4)
- Annex 3 Valuation of tourism ecosystem services (ES5)
- Annex 4 Valuation of coastal protection against flood (ES6)
- Annex 5 Valuation of bioremediation (ES7)
- Annex 6 Valuation of sediment trap (ES8)
- Annex 7 Valuation of carbon sequestration (ES9).

Table B: Summary of methods for valuing mangrove ES1–ES9

Services	*Evaluation method*	*Service quantification*	*Spatial perimeter*	*Turn over*	*Intermediary costs*	*Multiplier*
Subsistence fishery (ES 1)	Producer surplus	Catch volumes (kg) of coastal species	Catch in mangroves and ontogenic migration (spillover area around the mangroves)	Replacement price of protein equivalent	Intermediary costs of fishery and distribution circuit	Weighting factor
Coastal fishery (ES 2) (professional and non professional)	Business Expenditure Survey (BES) with fishermen Producer surplus	Catch volumes (kg) of coastal species		Final consumer prices	Intermediary costs of fishery	Fishery sector and distribution
Recreational coastal fishery (ES3)	Producer surplus	Catch volumes (kg) of coastal species		Final consumer prices + elasticity factor	Intermediary costs of fishery and distribution circuit	Fishery sector and distribution
Wood extraction (ES4)	Producer surplus	Volumes of wood extracted per type of use	Mangrove zone	Market price		
Medicine use (ES4)	Producer surplus	Volumes of active ingredient extracted per type of use	Mangrove zone	Replacement cost		
Mangrove tourism (day tours, guided visits) (ES5)	Producer surplus Business Expenditure Survey (BES) with tourism operators	Visits	Mangrove zone	Price of services	Intermediary costs of activity	Tourism sector
Associated expenses linked to activities in mangroves (ES 5)	Producer surplus BES and surveys with users Advertising Image Analysis	Quantification and segmentation of tourists per category of use	Tourism zones	Local expenses (accommodation, food, local transport) + international transport	Intermediary costs of activity	Tourism sector
Coastal protection (ES6)	Biophysical and oceanographic model Damage costs avoided	Coastal zone in potential flooding zone (probability) Contribution of mangroves to coastal protection Urbanized area and damage valuation	Coastal protection zone (back of mangroves)	Real estate values		
Bio-remediation (ES7)	Biophysical model Replacement costs	Quantification of nutrient charge and water treatment	Mangrove zone	Replacement costs of water treatment unit		
Sediment trap (ES 8)	Biophysical and oceanographic model Replacement costs or damage costs avoided on tourism activities	Quantification of sediment charge and spatial dispersion	Mangrove zone and sea current regime	Replacement costs or damage costs avoided on tourism activities		
Carbon sequestration (ES 9)	Market price	Quantification of carbon annual sequestration and CO2 eq. trapped in soil	Mangrove zone	Market Price or OTC for mangrove CER		
Biodiversity credits (ES 10)	Market option price	Specific biodiversity indicators	Mangrove zone	Due diligence agreement for mangrove		
Non use value (existence) (ES 11)	Willingness to Pay		Villages closed to mangroves, tourists, urban inhabitants			

In the section 'The theory behind our method', we discuss the three main methods for valuing absolute or marginal values of ecosystem services, and whether those methods have previously been applied in mangrove or reef valuations (see figure 11):

1. The method of production inputs, which evaluates the physical volumes that an ecosystem generates and that are considered an input in the production of services
2. The revealed preference method, which observes individual behaviours and translates them as the value that people place on the environment
3. The stated preference method, which surveys users about their practices and preferences, and determines a 'willingness to pay' value for an ecosystem service.

The three methods are complementary and have their own biases. In particular, we had to address the following study parameters:

- *What is the potential and sustainable level of an ecological service?* The estimation of a monetary value to characterise an ES must be contextualised with information about environmental sustainability and the potential of the ES evaluated.
- *What is the spatial distribution, and how would it affect the analysis?* We had to choose whether to assess the place of the ecosystem processes, the place where human activity occurs, or the place where benefits are transformed into money. We also had to address the spatial extent of any knowledge gaps in the marine ecological processes. Considering the complexity of these processes, we relied on the most recent scientific results.
- *How does the community context challenge the assumption of individual maximisation of welfare?* We had to consider whether customary tenure arrangements in the Pacific significantly skew the community influence on individual choice. Many natural resources in the Pacific Island territories are communally owned (without formally defined or recorded boundaries), which affects how those resources are used and managed.
- *What would be our time perimeter?* We focused on financial flows or economic values from the previous year (2012). And, when possible, we compared the calculated use values with data from the previous five years to identify potential biases and unrepresentative situations.
- *How would we distinguish between ecosystem processes and systems?* We needed to define core ecosystem system processes and beneficial ecosystem processes, and how the latter are involved in producing ecosystem services to humans.
- *What is the effect of ecosystem connectivity?* Because coastal habitats are biologically linked, we had to allow for how that connectivity might affect our assessment of the ecological functions underlying key ecosystem services such as coastal protection.

HOW WE CONDUCTED THE SURVEYS—A SUMMARY

Below is an overview of how we surveyed the Crab Bay and Eratap villages about their mangrove use. The survey team used three separate questionnaires for the socioeconomic survey conducted in each village: one survey focused on crabs, one on mangroves and one on reef fish. For more detailed information, please see annex 8.

In the field, the survey team encountered three main issues: difficulty with transportation for the long distances between villages on Malekula; low attendance at group discussions and a lack of cooperation in interviews, which the responsible locals in Eratap organised; and additional expenses. The latter issue arose because most villages or stations expected a return for helping the survey team; in particular, they expected accommodation and lunch, which put pressure on the team's limited budget.

SURVEY 1: HOUSEHOLD CRABS

The objective was to collect information about:

- the interviewee (status, age, gender, marriage, island, religion, household members)
- the types of crab that the interviewee commonly catches (preferably the species in the mangroves)
- the language name of the interviewee's commonly caught or preferred crab type, the common area in which the crabs are caught (from the areas devised by the MESCAL team), the transport means of getting there, how many people in the household hunts crabs, the quantity caught per person in a week or per trip, the harvesting techniques used, the length of a usual crab hunting trip, the purpose of catching crabs (consumption or sale for income), the number of crabs that the family consumes after a catch, the quantity of crabs sold weekly/monthly
- any taboos / management systems in place in the village that aim to preserve or conserve any resources or ecosystems, and whether they are effective (and why).

SURVEY 2: MANGROVES

The objective was to collect information about:

- the interviewee (status, age, gender, marriage, island, religion, household members)
- income earning activities of the family, and how much the household earns monthly in total
- whether the family uses or has used mangroves (if so, what use, what collection area, what species)
- how the mangroves are used, how often they are cut (week/ month), how many are cut (posts/bundles), who the usual mangrove-cutter is
- any alternatives for firewood and house posts, and whether firewood is bought (sometimes/never)
- knowledge/impressions of the mangrove ecosystems.

SURVEY 3: REEF FISH RESOURCES

The objective was to collect information about:

- the interviewee (status, age, gender, marriage, island, religion, household members)
- the types of fish that the family normally catches, common fishing techniques used by the family, the number of weekly fishing trips using the different techniques, the number of fish caught per trip
- common fishing grounds, use of the last catch (consumption or sale for income), market information (buyers, means of selling, transportation, middlemen, price of fish per kilo or rope)
- the amount and types of fishing gear used in the village.

SAMPLING

To randomly select village households for interview, the study team accounted for houses near the mangroves and those further away, for fishing and non-fishing households, and for different religious beliefs (such as a taboo against eating crab). The main hindrance to the survey was some villagers' unwillingness to be interviewed. The total number of valid surveys was 482 (table C).

Table C: Completed data entries

Questionnaires (no.)	Eratap	Amal/Crab Bay
Household crab	29	130
Mangroves	29	137
Reef fish	29	128
Total	**87**	**395**

In Crab Bay, surveying began on 4 September and ended on 12 September 2012, with the help of seven locals, an officer from the Department of Environmental Protection and Conservation, and a contracted resource environmental assistant. A total of 15 villages hosted the team. Despite a few field difficulties (such as responsible committee members having other commitments on the day we were supposed to visit their village), the villagers were very helpful and the survey was successful. In Eratap, surveying began on 24 September and ended on 10 October 2012; the longer period of data collection there was due to community related issues.

OUR SURVEY SITES—A SOCIOECOLOGICAL CONTEXT

Villages in Crab Bay (16 villages and plantation settlements on Malekula Island: figure 1) and Eratap (10 settlements on Efate Island: figure 2) comprise between 10 and 50 households with a mean household size of five persons (generally an extended family). The Crab Bay population totals 750 people and Eratap totals 240 people, approximately. In Malekula, most of the population is from the island, with some immigration in the 1970s. In Eratap, local populations from Efate cohabit with whole settlements of people from other islands (such as Tanna). These settlements generally do not follow the rules of the villages and do not recognise customary management from Eratap. No conflict has been identified so far but, as noticed by the survey team, this population mix affects the resource management of the area.

Our surveys found most of the villages have a young age structure, with around 40 per cent of the population aged less than 15 years and only 5 per cent aged over 60 years. These results are similar to those of the last demographic census (Vanuatu National Statistics Office 2009). On both islands, most of the village houses are permanent houses with a galvanised iron or similar roof and a cement floor. On Malekula, no village has access to electricity service; in Eratap, seemingly almost all houses were connected to electricity services 10 years ago.

All the households produced incomes through subsistence production (e.g. crop food, fish, firewood, house building materials) and the majority is engaged in the sale of agricultural products, fish and handicrafts. The Household Incomes and Expenses Survey (Vanuatu National Statistics Office 2008) estimated the average income of rural households in Vanuatu to be around US$500 per household per month. This revenue is equivalent to international US$1300 per household per month when applying purchasing power parity (PPP) and Geary–Khamis dollar conversion (Heston et al. 2009).

Nationally, approximately 40 per cent of this income comes from subsistence production. Surveys and focus groups conducted in the villages confirm subsistence production seems to be less important in Eratap but closer to the national level in Crab Bay. Following Cinner and Aswani (2007), this variability may be explained mainly by Eratap's proximity to the capital (Port Vila), which facilitates access to salaries and commercial markets. So, a different mix of subsistence and market economies is expected between the villages of the two study sites.

Fishing is a common activity in the villages. The last Household Incomes and Expenses Survey conducted in 2006 (Vanuatu National Statistics Office 2008) estimated more than 75 per cent of Vanuatu's adult population is implicated in a form of fishing. Yet, the commercial fishery is not developed as a formal activity and, for most of the households, represents a complementary and irregular income alongside agricultural activities (Amos 2007; Bartlett et al. 2009; Hickey 2008; Pascal 2011). As described in the following sections, the survey results confirmed this situation.

MARINE PROTECTION AND OTHER FISHERY MANAGEMENT

The Crab Bay MPA (*Amal-Krab bay Tabu Eria*, or AKTE) is linked to 16 villages and plantation settlements. Its size is less than 1 km^2, which is similar to the area of most small MPAs in the Pacific (Govan 2009) and represents an average 15 per cent of the reef fishing ground. The villages have managed the MPA since 2002 through a committee of village members. The MPA is a permanent closure for all harvest (fish, crabs, wood, shells), and periodic harvest events cannot occur for village subsistence or celebration. Other management rules include some restrictions on crab collection outside the AKTE (restricted number, size, spawning season). The AKTE was planned to last three years initially (until 2005) but communities have reactivated the AKTE every year. Some activities around the MPA were observed between 2010 and 2012 (e.g. regular meetings, participation in workshops and trainings, rubbish cleaning, an environment awareness campaign and monitoring).

In Eratap, no MPA or resource management is present. Attempts have failed mainly because villagers do not respect the rules. The settlements with people from outside of the community, and the site's proximity to Port Vila may explain this erosion of customary governance.

Other fishery management rules are in place in both sites. Following a classification adapted from Johannes and Hickey (2004), who studied fishery management in more than 20 villages in Vanuatu, we identified several fishery management rules in place: a trochus (*Trochus sp.*) ban, a giant clam (*Tridacna sp*.) ban and a taboo on the harvest of turtles and their eggs.[3]

ECOLOGICAL HABITATS

This discussion is based on the MESCAL mangrove baseline vegetation mapping study conducted in 2012 in Crab Bay and Eratap: 'The aim of the study was to develop and establish a Baseline boundary definition of the mangrove vegetation beyond Mean Sea Level, above Mean Sea Level and Mean Sea Level within the Project Site. The outcome of this activity is the determination of the total areas of mangroves from back boundary species to shoreline mangroves'.

The mapping team created a baseline map of the mangroves from the offshore mangroves to the highest high water mark and to the back boundary species of mangroves. The common back boundary mangrove species at this study's two sites is *H. litoralis* and the common offshore mangrove is *R. stylosa*. The MESCAL mapping study created baseline maps for three sites in Vanuatu: Amal, Crab Bay and Eratap. The maps

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[3] *In addition to those rules, a 'rule' exists for controlling the access permitted for non-residents.*

show the total area of mangroves is 135.5 hectares and 31.2 hectares in Amal/Crab Bay and Eratap respectively (Vanuatu Government Department of Environment Protection and Conservation).[4]

[4] *Data extracted from the Millennium Coral Reef Mapping Project show the dominant reef geomorphologic types are the ocean and the intra-seas exposed fringing reef (classes 222 and 230 respectively) (Andréfouët et al. 2005) in both sites.*

WHAT WE FOUND

CONSOLIDATED RESULTS—WHAT IS THE VALUE OF THE ECOSYSTEM SERVICES?

Based on an economic valuation of the nine ecosystem services (ES1–ES9) (figure A, 'Overview') in the two mangrove systems, we found the following results:

- In Crab Bay in 2012, mangroves (136.5 hectares) produced ES worth an estimated Vt53 million (equivalent to US$586 000). This total comprised ES values ranging from Vt36 million to Vt70 million.
- In Eratap in 2012, the mangroves (31.2 hectares) produced ES worth an estimated Vt24 million (equivalent to US$266 000). This total comprised ES values ranging from Vt17 million to Vt31 million.

For comparing sites, these valuations are equivalent to ES worth Vt386 000 per year per hectare (US$4300 per year per hectare) in Crab Bay and Vt768 000 per year per hectare (US$8500 per year per hectare) in Eratap.

In Crab Bay, the principal ES in economic terms are the value of carbon sequestrated (ES9), the proteins from subsistence fishery (ES1), the commercial fishery (ES2) and the wood extraction (ES4), which add to 99 per cent of the mangroves' total value (figure B, 'Overview'). Coastal protection is the other ES in Crab Bay. In Eratap, the principal ES are the value of carbon sequestrated (ES9), proteins for subsistence fishery (ES1) the revenue from tourism linked to mangroves (ES5), and the avoided costs from coastal protection against flood (ES6), which add to 87 per cent of the total value (figure C, 'Overview'). Commercial fishery (ES2), wood extraction (ES4) and recreational fishery (ES3) are the other ES in Eratap.

Table D indicates the main results described in the following chapters.

Table D: Economic valuation of ecosystem services of Crab Bay and Eratap mangroves, 2012

$US	Crab Bay			Eratap		
	min	max	**average**	min	max	**average**
ES1 Subsistence fishery	67 722	90 600	**79 161**	30 311	43 700	**37 006**
ES2 Commercial fishery	32 933	61 633	**47 283**	10 344	24 756	**17 550**
ES3 Recreational fishery	Service non-existent			800	1 200	**1 000**
ES4 Wood extraction	27 467	51 000	**39 233**	11 778	21 867	**16 822**
ES5 Mangrove tourism	Service non-existent			35 378	58 967	**47 172**
ES6 Coastal protection	4 156	7 133	**5 644**	34 833	59 722	**47 278**
ES7 Bioremediation	Service almost negligible			Service almost negligible		
ES8 Sediment trap	Service almost negligible			Service almost negligible		
ES9 Carbon sequestration	265 489	563 333	**414 411**	68 922	130 000	**99 461**
Total	297 111	773 700	**585 733**	192 367	340 211	**266 289**
Total per hectare	2 914	5 668	**4 291**	6 166	10 904	**8 535**

CONSOLIDATED RESULTS—WHO BENEFITS FROM THE ECOSYSTEM SERVICES?

We identified the main beneficiaries (figure D, 'Overview') from mangrove ES in Crab Bay and Eratap are:

- fishermen of the commercial artisanal fishery (300 in Crab Bay, 50 in Eratap)
- local families for whom fishing in the mangroves and in the reef is a source of regular protein (160 households in Crab Bay, 80 households in Eratap)
- locals benefiting from firewood and construction material (150 households in Crab Bay, 45 in Eratap)
- entrepreneurs in Eratap proposing mangrove tourism (two businesses, 800 tourists per year)
- real estate owners protected from coastal flooding (two tourism resorts in Eratap, covering a total area of 3000 m^2), as well as plantation owners (300 hectares in Crab Bay)
- tourism entrepreneurs in Eratap whose business depends on the quality of lagoon water and beach formation (two businesses, 21 jobs, 11 500 tourists per year)[5]
- the global community, which benefits from carbon sequestration and biodiversity.

In total, nearly 800 people depend on one or more of the mangrove ES in Crab Bay, as do 400 in Eratap.

[5] *The relationships between mangrove ecosystem processes and the benefits of clean water for recreational use need further study. This study mentions this service as a potential benefit but did not value it.*

COMPARISON OF RESULTS WITH OTHER STUDIES

Table 1 compares our results per ES with other studies' economic valuation of mangrove ES. We based this approach on the outputs of two meta-analyses (Brander et al. 2012; Salem and Mercer 2012) of 41 and 44 studies of mangrove economic valuation respectively. For both meta-analyses, most studies were conducted in South East Asia, and the majority of values concern direct and indirect uses. We converted all values to values per hectare of mangrove in 2010 US dollars, using PPP conversion factors (c = 39.81) taken from the Penn World Table of 2011 (Heston et al. 2011).

Except for coastal protection in Eratap and carbon sequestration, most of the mangrove ES values in Crab Bay and Eratap are in the lower end of the results range of the meta-analyses. This finding may reflect the sites' low development of commercial fishery and mangrove tourism, as well as the low density of constructions on the shore. For coastal protection ES in Eratap, we found values slightly above the average values from the meta-analyses, reflecting the presence of the resorts protected by the mangroves. For carbon sequestration ES, we found values above the maximum value from the meta-analyses, which may reflect two reasons:

- Carbon markets have changed during the past 10 years, with the development and consolidation of calculations of carbon sequestration volumes and voluntary credits.
- We accounted for the stock of carbon sequestered in the upper part of the mangroves soil (to reflect the whole value of carbon sequestered and potentially released), whereas some studies may value only the avoided amount of carbon released into the atmosphere.

Table 1: Comparison of Crab Bay and Eratap mangrove ES values (per hectare) with other studies (2010 US$PPP)

Int. $US/hectare (2010)	Crab Bay			Eratap			Values from meta-analysis *		
	min	max	**average**	min	max	**average**	min	max	**average**
ES1 Subsistence fishery	1 122	1 501	**1 311**	2 196	3 166	**2 681**	10	555 168	**26 613**
ES2 Commercial fishery	545	1 021	**783**	750	1 794	**1 272**	10	555 168	**26 613**
ES3 Recreational fishery	Service non-existent			58	87	**72**			
ES4 Wood extraction	455	845	**650**	853	1 584	**1 219**			
ES5 Mangrove tourism	Service non-existent			2 563	4 273	**3 418**	1	507 368	**37 927**
ES6 Coastal protection	69	118	**93**	2 524	4 327	**3 426**	10	8 044	**3 116**
ES7 Bioremediation	Service almost negligible			Service almost negligible					
ES8 Sediment trap	Service almost negligible			Service almost negligible					
ES9 Carbon sequestration	4 397	9 330	**6 864**	4 994	9 420	**7 207**	40	4 265	**967**

*** Meta-analyses consulted are Brander et al. 2012 and Salem and Mercer 2012.**

SUBSISTENCE AND COMMERCIAL FISHERY (ES1 AND ES2) RESULTS

DESCRIPTION OF FISHERY

For reef fisheries at the two study sites, the main gear for catching fish are gillnets,[6] hand lines (from the shore or canoe) and spearguns.[7] The gear's frequency of use and distribution among households vary between the two sites (table 2). Notably, women at both sites conduct few fishing activities (mainly just hand collecting and handlining from the shore).

Table 2: Distribution of use of fishing gear (% of total households surveyed)*

% of total households surveyed	Use canoe	Spear gun at day	Spear gun at night	Cast net	Reef net	HandLine	Boat with engine
Eratap (average)	45%	15%	24%	18%	33%	80%	3%
Crab bay (average)	29%	20%	15%	13%	45%	65%	4%

*** Eratap, n = 30; Crab Bay, n = 112.**

CRAB BAY

Reef fishing activity (see map: figure 3) was well spread throughout the community, with 25 per cent of households doing at least three fishing trips per week and 50–60 per cent of households doing one fishing trip per week, on average. Reef fishery is mainly a subsistence activity, with less than 15 per cent of the households (concentrated in two to three villages) selling their catches to a wholesaler (usually from the villages) or directly to the market in Lakatoro. Fundraising activities—when people sell prepared meals or fresh fish in their village to raise funds for community events or specific family events (weddings, school fees etc.)—were considered as subsistence activities because the transactions have a low price (less than Vt100 per ration of cooked fish). These activities are sporadic, depending on the context (e.g. school calendar).

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[6] *The gillnets are used principally in the form of circle nets. A fishing trip comprises two to three fishermen and up to 50 metres of nets. The nets are used to surround groups of fish in depths of 3–10 metres. The fishermen can repeat this action several times without moving the nets, or can set up the nets in a new location. Depending on water conditions and fish catches, a fishing trip can last one to five hours. Nets are monofilament gillnets with 3 inch diagonal mesh.*

[7] *This gear is usually used to target coral reef species such as Scaridae sp., Acanthruridae sp. and Serranidae sp. Other gear used on an irregular basis includes cast nets (depending on the migration of some species), hand collecting (common at low tide, and efficient for Octopus sp. and shells) and some traditional gear (e.g. hand spears).*

Annual catches of reef fish were estimated between 28 tonnes and 41 tonnes for all the 15 villages surveyed in Crab Bay.[8] Per village annual catches varied from 300 to 4000 kilograms, depending on the village size and fishing effort. These results are coherent with previous studies' qualitative estimates of fishing efforts (Hickey 2007). Approximately 75 per cent of the total catch was consumed, which is equivalent to an annual consumption of fresh fish of 17 kilograms per person. Recent studies found the annual level of consumption of fresh seafood varies between 16 kilograms and 26 kilograms per person in Vanuatu (Bell et al. 2009b; Pascal 2011; Vanuatu National Statistics Office 2008).

In Crab Bay, most households (80 per cent) collected white and black crabs (*Cardisoma carnifex and C. hirtipes*) at some time of the year in the mangroves. (The frequency of fishing trips seems independent of the crab season.) It is an activity shared by all the members of the family. They usually walk (85 per cent of households) and fish at low tide, or use a canoe to reach distant mangroves. Similar to fishing, crab collection is mainly a subsistence activity (approximately 70 per cent of the catches were consumed, with an average of 10.4 meals including crab per month per household).

Commercial crab sales are very irregular, usually occurring when catches exceed the basic needs of the families. The main channel of distribution is direct sale in the market of Lakatoro, at an average price of Vt20 per unit. Based on the survey results (questions 6, 7 and 12 of the household surveys), an estimated 135 000 to 250 000 crabs[9] are collected every year in Crab Bay (equivalent to 31–57 tonnes per year). This catch level represents an annual consumption of approximately 8.9 kilograms of fresh seafood per person per year.[10] Summed with reef fish consumption (approximately 26 kilograms per person per year in total), our results would be in the upper band of the annual estimates (30 kilograms per person per year in rural zones: Bell et al. 2009b; Kronen et al. 2010; Pascal 2011). Considering the level of uncertainties and approximations in these figures, as well as the fact that we worked with some studies with national figures, we consider these estimates are valid.

For mud crabs, we found an important part of the catches (60–80 per cent) in Crab Bay was sold in the local market, sold to wholesalers, or exported by plane to the Port Vila market. Even if not specifically

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[8] *Based on CPUE's estimates of the surveys (average number of fish per fishing trip) and converted to kilograms using an average weight of 0.3 kilogram per fish (Kronen 2007; Pascal 2011).*

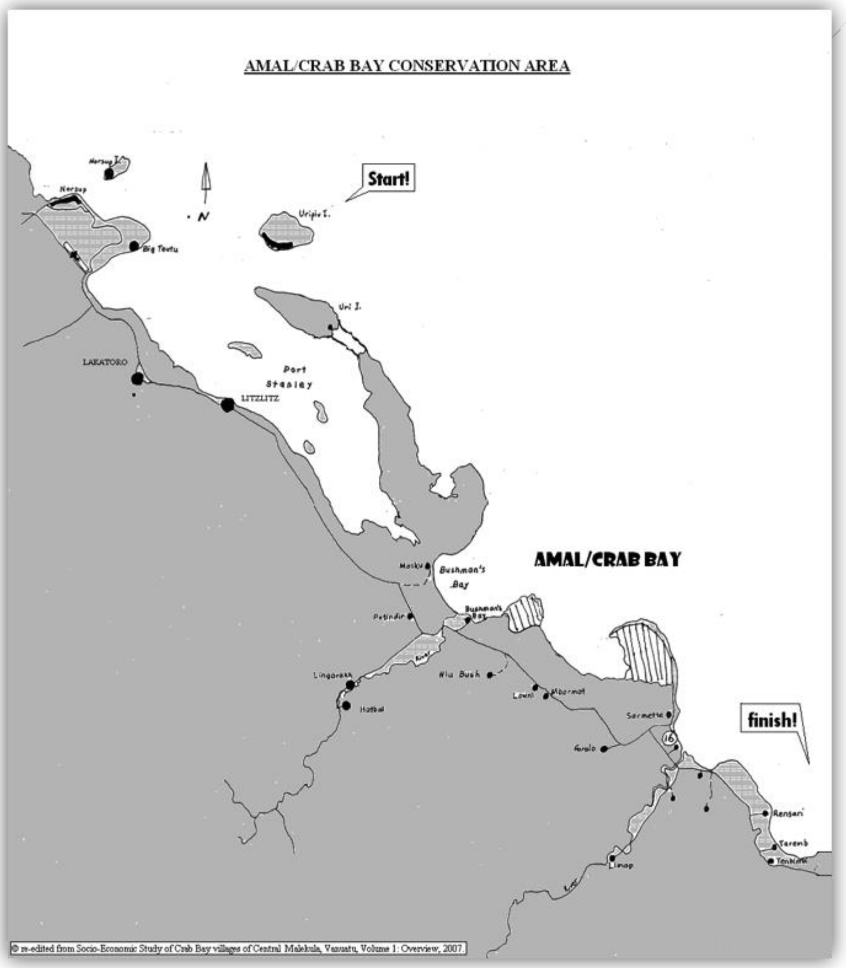
[9] *Based on declared estimated number of fishing trip during crab and non-crab season, average catches per trip and average consumption of crab per week per household.*

[10] *Based on a conversion between total weight of adult crabs (mean 230 grams per unit) and comestible part (35 per cent) (Kronen 2007).*

targeted by the surveys, almost 40 per cent of the households were involved in the fishing effort to some extent (from regular to very opportunistic fishery). No household depended on the mud crab fishery for more than 30 per cent of its weekly cash needs. Final prices varied from Vt200/kg to Vt1000/kg depending on the place of sale (Port Vila being the most expensive). The intermediary costs of this fishery are mainly transport and distribution costs (e.g. Vt200/kg to export the crabs to Vila). Based on the survey results (questions 6, 7 and 12 of the household surveys), an estimated 1900 to 3700 crabs are caught every year in Crab Bay.

The Crab Bay local people perceived a recent recovery of the crab stocks, and a stability in the fish production. By contrast, the perceptions in Eratap were more diffused, with some focus on overfishing and access conflicts due to the demographic pressure of recent settlements.

Figure 3: Crab Bay fishing grounds (dashed zones)



Source: Based on information from a focus group with fishermen in Crab Bay.

ERATAP

Reef fishing activity (see map: figure 4) is also well spread in Eratap, with 10 per cent of households doing at least three fishing trips per week and 30–50 per cent of the households doing one fishing trip per week (on average). An estimated 25–30 per cent of households made regular or sporadic sales of fish to a wholesaler or to the market in Vila. As well, sales in the villages through local bars (*nakamals*) are increasing and reflect the progressive introduction of a market economy in the villages. Prices in the *nakamals* are similar to market prices in Vila (Vt400–500 per rope, equivalent to Vt570–700/kg). In the same way, prepared meals with fish (*laplap*, rice etc.) are sold in the market. The market price per ration (Vt250–300) is very similar to that for fresh fish per kilogram.[11] The practice of fundraising is less widespread in Eratap than in Crab Bay. Based on the survey results (questions 3, 4 and 6 of the household surveys), annual catches of reef fish were estimated between 12 tonnes and 20 tonnes for the whole of Eratap. Approximately 60 per cent of the total catches were consumed, which is equivalent to an annual consumption of fresh fish of 9.6 kilograms per person (less than the estimated consumption of fresh seafood per person in Vanuatu: Bell et al. 2009b; Pascal 2011)

In Eratap, a small share of the households (10–20 per cent) collect white and black crabs (*Cardisoma carnifex and C. hirtipes*). It is an activity shared by all the members of the family but dominated by the parents (with the new generation showing less interest in crab collection). Similar to fishing, crab collection is mainly a subsistence activity (approximately 80 per cent of the catches were consumed, with an average of six meals including crab per month per household). Sales are done in the villages through the *nakamals* or during fundraising events. Based on the survey results (questions 6, 7 and 12 of the household surveys), an estimated 85 000 to 150 000 crabs are collected every year in Eratap (equivalent to 19.5–34.5 tonnes per year). This catch level represents an annual consumption of approximately 7.1 kilograms of fresh seafood per person per year.[12]

For mud crabs, we found most of the catches (80–90 per cent) were sold in the Port Vila market or to wholesalers. No household depended on the mud crab fishery for more than 20 per cent of its weekly cash needs. Final prices varied from Vt800/kg to Vt1000/kg depending on the place of sale (Port Vila being the most expensive). Based on the survey results (questions 6, 7 and 12 of the household surveys), an estimated 500 to 1400 crabs are caught every year in Eratap.

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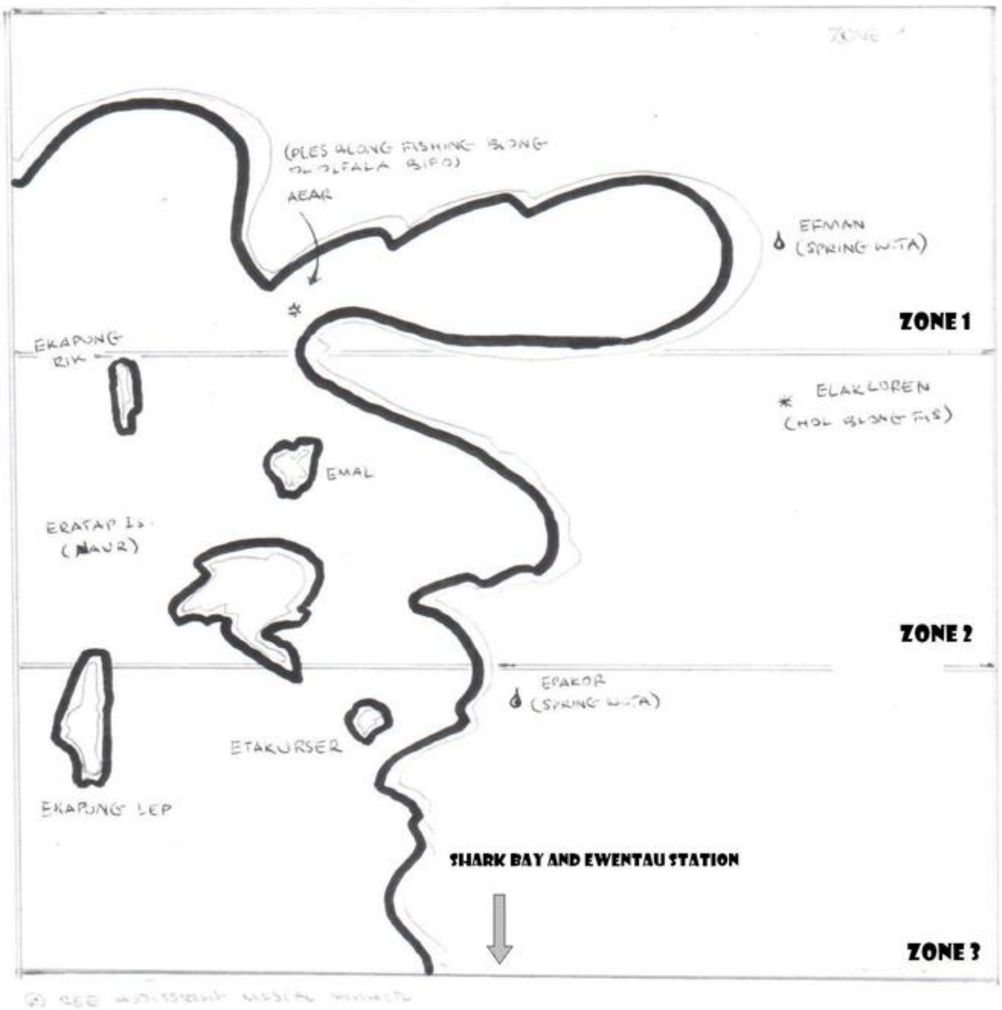
[11] *The usual ration of prepared fish with rice and complements was equivalent to an estimated 300 grams of fresh fish. Based on a Vt300 selling price, and discounting the costs of ingredients (estimated at Vt 70 per ration), the price equivalent is Vt760/kg of fresh fish.*

[12] *See previous footnote.*

Figure 4: Eratap fishing ground areas



Source: Based on information from a focus group with fishermen in Eratap.

HOW MANGROVE ECOSYSTEM PROCESSES AFFECT THE FISHERIES

We identified several ecosystem processes of the mangroves in the service of fishery production (figure 5). We distinguished mainly the process of biomass production and the maintenance of habitat complexity, nursery role and ecosystem connectivity. Two fisheries received benefits from one or several of the ecosystem processes: the crab fishery and the reef fishery.

In Crab Bay, the reef fishery occurs mainly in the part of the bay that is opened to fishing, and also outside the bay (in the barrier reef). Based on fish biological assessment (Hickey 2007), we found almost all the target species caught by the Crab Bay villages spend part of their life cycle in the mangroves (as a nursery, a spawning site, a shelter or a food supply). We applied a contributing factor of 30–40 per cent to the added value of the reef fishery. We estimated this factor from expert opinions (Planes S., Galzin R., pers. comm.) and a review of the scientific literature (Barbier 2007b; Barbier and Strand 1998; Friedlander and Cesar 2004; Harrison et al. 2012; Hixon and Beets 1993; Holmlund and Hammer 1999; Ronnback 1999; Ruitenbeek 1994; Walters et al. 2008). In particular, the results of Barbier[13] (2007b) gave us quantitative insights into the relationships between mangrove habitat and reef fish production. We based the contributing factor on a combination of selected geomorphologic factors (connectivity between ecosystems, mangrove size, reef type, mean depth, main currents) and biotic variables (fish species, mangrove species, reef complexity).

In Eratap, the reef fishery includes activities on the fringing reef and the barrier reef. The bay's configuration where the mangroves are located reduces the connectivity between reef and mangroves; connection between both ecosystems occurs in a reduced number of shallow and narrow channels. In combination with the other factors described earlier, we applied a mangrove contributing factor of 10 per cent to the added value of reef fishery.

The three species of crabs (*Cardisoma carnifex, C. hirtipes* and *Scylla serrata*) are directly related to the existence of the mangrove. *Cardisoma* use the mangrove habitats during their ontogenic migrations and during spawning. Some studies showed juveniles use the mangrove leaf litter directly as a food source (Hickey 2007). The mangroves represent the main habitat for the adult mud crab (*Scylla serrata)*.

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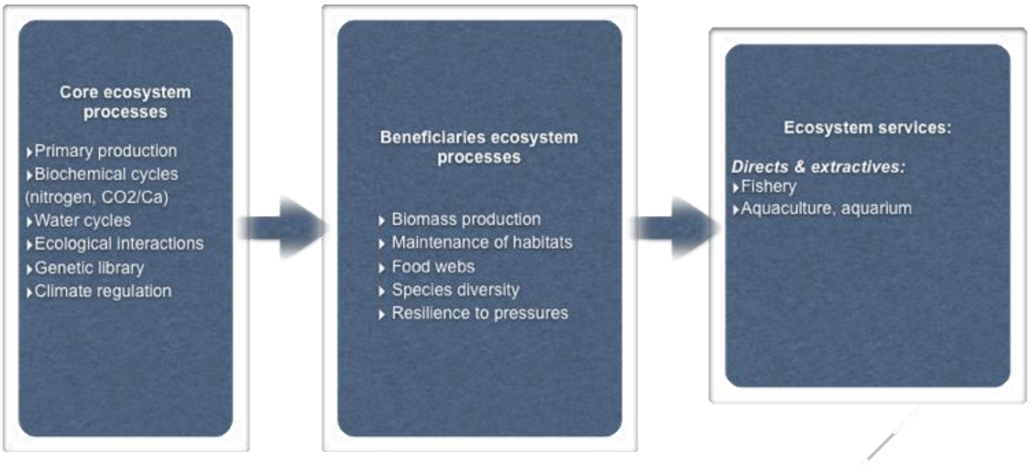
[13] *The study modelled mangrove–shrimp fishery links with a standard bioeconomic fishery model. The model accounts explicitly for the effect of a change in mangrove habitat area on carrying capacity and thus fishery production in Mexico. It found a 0.23 per cent annual reduction in mangrove habitat might have generated a 0.4 per cent loss in fishery revenues.*

Figure 5: Main ecosystem processes implicated in ES1 and ES2



SOCIAL IMPORTANCE AND ECONOMIC VALUE OF ES1 AND ES2

Approximately 800 persons were involved in crab collection and reef fishing (for subsistence mainly) in Crab Bay in 2012. In Eratap, the number was close to 400 persons. We found subsistence catches (ES1) represented a protein equivalent value[14] of between Vt6 million and Vt8 million (equivalent to between around US$68 000 and US$91 000)[15] in 2012 for Crab Bay. Protein from crab fishery represented 40 per cent of this total value. In Eratap in 2012, the economic value of ES1 was between Vt2.8 million and Vt4 million (equivalent to between around US$30 000 and US$43 000). The crab catches represented 80 per cent of this total value.

Artisanal commercial fishery (ES2) in Crab Bay produced a value of Vt3 million to Vt5.6 million in 2012 (equivalent to US$33 000 to US$62 000). Crab fishery generated 80 per cent of this total value (with 50 per cent from mud crab catches). In Eratap, the added value of ES2 was estimated between Vt0.9 million and Vt2.2 million (equivalent to US$10 000 to US$25 000) for 2012. Crab fishery represented 90 per cent of this total, with a similar distribution between *Cardisoma* and mud crab fishery.

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[14] *To convert kilograms of fresh seafood into protein content, we followed the protein table of Ramseyer 2000. We used a price equivalent to the protein price of the canned tuna (in oil) provided by the Vanuatu Statistics Office (average price of Vt 555 / kg). Results gave a price of Vt 390/kg of reef fish and Vt 132/kg of Cardisoma crabs (neither is much different from current market prices).*

[15] *Conversions of Ni-Vanuatu Vatu to US dollar were based on a 2012 average exchange rate of Vt90 for US$1.*

As described in annex 2 (and highlighted in Laurans et al. 2013), this valuation does not reflect some important advantages of subsistence and artisanal commercial coastal fishery (ES1 and ES2) for local populations:

- The fishing activity requires low investment and training (SPREP 2007).
- It can aid social cohesion in villages because it helps keep women in the villages instead of them seeking a cash income outside (Bensa and Freyss 1994).
- For some households, the protein obtained from fishing in the total diet is non-replaceable (Pollnac et al. 2000).
- Fishing is a stable food source against future uncertainties, and a way to spread alimentary risks (Johannes 2002).

To reflect these benefits of the subsistence fishery, we applied a weight correcting factor of 1.3 to the ES1 value and a similar multiplier to the ES2 value (Laurans et al. 2013). We thus determined ES1 and ES2 were equivalent to Vt9.2 million and Vt5.5 million (US$103 000 and US$61 000) in 2012 in Crab Bay, and to Vt4.3 million and Vt2.1 million (US$48 000 and US$23 000) in Eratap. Table 3 presents the main results.

Table 3: Added value of ES1 and ES2

Vatu, 2012	ES1		ES2	
	min	max	min	max
Crab Bay	7 920 000	10 600 000	3 850 000	7 210 000
Eratap	3 550 000	5 110 000	1 210 000	2 900 000

Note: Results are truncated at 10^3 for easy reading.

RECREATIONAL FISHERY (ES3) RESULTS

We observed no significant recreational fishery (commercial and noncommercial) in Eratap. Most sport fishermen and sport fishery private businesses (based in Port Vila) usually fish to the north for different reasons (currents, wind protection and proximity).

For sport fishery, only one activity was reported in 2012 in Eratap—an activity proposed by one of the resorts. Most of the resort's fishing activities occur outside the barrier reef, and the main targets are pelagic fishes (*Scombridae sp.* and *Coryphaena sp.)*. In 2012, fewer than 60 fishing trips were reported, for a total fee of Vt360 000. We applied a contributing factor comprised between 15 to 30% to reflect the role of mangrove ecosystem processes.

WOOD EXTRACTION (ES4) RESULTS

DESCRIPTION

The mangrove trees can be useful in many different ways. The trunks are used mainly for house posts, fencing, firewood[16] and, in some places, as a gardening tool. The branches are also used for firewood and small hooks that some people cut and use to capture mud crabs. The leaves are used as bait for serwok (small pointy shells) and crabs, and also for medicinal purposes (as indicated by the villagers).[17] Traditional medicine practices, however, seem to be rapidly dying out.

The majority of villages use the big stems for housing posts and rails (i.e. supports crossing each other and/or running parallel to and from the main frames of the constructed roof) more than for any other use. The wood is strong and long lasting, and does not have to be changed often.

In Crab Bay, the surveys (questions 3, 6 and 7 of the mangrove survey) found the following results:

- On average, for all the villages, most households collected mangrove dry wood for firewood. Nonetheless, the collection frequency was quite low, with trips to the mangroves to collect dry wood occurring once every 150 days (varying from once per fortnight to once per year depending on the villages). On average, five bundles of wood were collected per trip. Uri, Uripiv, Lowni and Hatbol villages showed the highest use of firewood, but the annual volumes were still low (equivalent to six bundles per month per household). Elsewhere, mangrove wood was used occasionally for firewood or not at all.
- For other uses (house and fencing posts, gardening and marking), we observed a widespread use among households of the following villages: Uri, Uripiv, Lingaharak, Tevisi (TFC), Portindir, Losarsar and Hatbo. Nonetheless, as explained, the longevity of the wood contributes to the low frequency of collection. On average, the last trip to the mangroves was 400 days earlier for house posts, 930 days earlier for fencing posts and 380 days earlier for gardening posts. The mean number of bundles in each trip was around 13. For villages reporting these uses, we calculated an average trip to the mangroves of 0.6 bundles per month per household.
- The relatively low use of mangrove wood in Crab Bay differed from another study conducted in the same area in 2004 (Vanuatu Environment Unit 2007). This difference may be explained by the

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[16] *Mangrove wood's clean burning properties make it suitable for cooking in wet weather*.

[17] *It is taboo to communicate these practices outside customary knowledge holders.*

progressive introduction of alternative sources of cooking in the past eight years (gas), changes in the family behaviour and different survey protocols.

In Eratap, the mangroves are hardly used for housing or firewood because the people have alternative, much better resources. For firewood, the settlements of Etpup, Etas, Elak and Elan are the only villages that reported regularly using mangrove wood (every two months on average, for two or three bundles per household). The other use reported was for house posts in Etpup and Nanru (every 450 days for eight bundles per household, or 6.4 bundles per month per household).

At both sites, the traditional medicine practices derived from the mangroves are rapidly dying out. The part of the tree that is used is information that is sacred to the tribe: only a few people in some of the villages have this knowledge, while others can remember only stories being told of their elders using it long ago.

SOCIAL IMPORTANCE AND ECONOMIC VALUE OF ES4

We calculated the ES4 value from an average equivalent market price and added value of Vt200 per bundle of mangrove firewood and a replacement cost of Vt850 per bundle of house and fence posts.[18]

In Crab Bay, we estimated 150 households received regular benefits from using mangrove wood for fire, with an annual value equivalent to Vt2.1 million. We found 240 households used mangrove wood or other uses (house and fence posts mainly), for an annual value of Vt1.4 million. In total for 2012, we estimated an ES4 value of between Vt2.5 million and Vt4.6 million (US$28 000 and US$51 000).

In Eratap, we estimated 45 households received regular benefits from using mangrove wood for fire, with an annual value equivalent to Vt160 000. Fewer than 25 households used mangrove wood for other uses (house and fence posts mainly), for an annual value of Vt1.3 million. In total for 2012, we estimated an ES4 value of between Vt1 million and Vt1.9 million (US$$12 000 and US$22 000).

TOURISM ACTIVITIES (ES5) RESULTS

DESCRIPTION

We observed no tourism activities in the Crab Bay villages, apart from some scientific tourism (in 2009 and 2010). The usual tourism operators and activities (day tours, snorkel tours, guesthouses) are not

[18] *Based on the market price of construction material retailers for equivalent posts in cement or other material.*

present in Malekula. Scientific tourism comprises sporadic visits from researchers, NGO members or other professionals, and it usually takes the form of payment for food and accommodation. Some visits involve long term residence in a village or in a research station (e.g. Crab Bay).

By contrast, there are two resorts in the Eratap bay: Eratap Beach Resort and Aquana Beach Resort (opened in 2011). They comprise 19 and 40 beds respectively. The main guests are from Australia and the average length of visit is 4–6 days. Local residents (mainly from the expatriate community) visit the restaurant and the beach during the weekends. The observed occupancy rates are within the tourism standard (55–65 per cent), which was equivalent to 10 300 guests in the two resorts in 2012. If we add residents coming to the restaurant and spending the day on the beach, there were 11 500 visitors in 2012.

The main attractions are the beach, natural environment, relaxation and the restaurant. Some activities are directly related to the coral reefs (snorkelling tours, boating, kayaking) and mangroves (kayaking). We did not observe any guided tours in the mangroves. There are also some day activities in Eratap; visitors come to the village from neighbouring resorts.

There are three scuba diving clubs, all based in or near Port Vila. The most frequented scuba diving sites are close to the capital (less than an hour by boat from Port Vila), but none is close to the Eratap zone.

SOCIAL IMPORTANCE AND ECONOMIC VALUE OF ES5

Based on interviews with resort managers and neighbouring villages, we estimated 5–10 per cent of guests visited the mangroves during their stay in 2012 (equivalent to 800 persons and 1100 visits in the mangroves). To determine the proportion of these visitors' expenditure that may be attributed to the mangroves, we evaluated the importance of the mangroves in the advertising strategies of both resorts.

The resort managers confirmed the presence of mangroves does not attract many visitors to the resorts. Similarly, there were very few references to the mangrove ecosystems in advertising images and the description of the resorts. One resort emphasised the area's natural environmental attributes more than the other resort, but both based their marketing strategies on comfort, tranquillity, beaches, coral reefs and village tours.

We assumed 3–5 per cent of mangrove visitors' expenditure could be attributable to the mangrove ecosystems, based on other studies about coral reef tourism (Brander et al. 2007; Ghermandi and Nunes 2011; Hampton 1998; McElroy 2003) and mangrove tourism (Bann 1997; Brander et al. 2012; Conservation International 2008; Sathirathai and Barbier 2001) (see annex 3 for a description of the mangrove contributing factor). This added value was estimated between Vt3.2 million and Vt5.3 million in 2012.

The Eratap site could develop a rural tourism market[19] if certain conditions are met (such as access, infrastructure, business capacities etc.) (Vanuatu Tourism Office (VTO)pers. comm.). The number of visitors in Eratap was expected to increase after a new main road improved access to all the villages in the study zone. The road was completed in mid-2010, but effects were not visible in our research (2012).

COASTAL PROTECTION AGAINST FLOOD (ES6) RESULTS

HOW MANGROVE ECOSYSTEM PROCESSES PROTECT AGAINST FLOOD

The mangroves are natural barriers against coastal flooding, by absorbing wave energy and lessening the damage of severe weather events (hurricanes, tropical storms etc.). Annex 4 describes how the mangroves protect against coastal flooding and the valuation method.

ECONOMIC VALUE OF ES6

Estimating the avoided damages provided by mangroves involved three steps:

A. identifying coastal areas potentially at risk from coastal flooding events

B. determining the contribution of mangroves and other coastal ecosystems in protecting vulnerable areas

C. quantifying and valuing the potential damage repair costs, based on damage avoided costs:

   C.1. characterising the assets exposed to risk (into three categories of land use)

   C.2. valuing the total repair costs of direct and indirect tangible damages based on approximate values per land use category (object oriented data) and as a function of inundation depth (relative depth damage function)

   C.3. estimating the probability of flood event per impact category.

A. IDENTIFIED ZONES AT RISK

[19] *Vanuatu's main rural tourism attractions consist of: (i) nature: volcanoes, cascades, forests, beaches, coral reefs and sites with specific attributes (for example, turtle spawning, fish biodiversity, emblematic species); (ii) culture: the different lifestyles and languages are an important tourism asset; (iii) adventure: bushwalking, treks, discovery of custom sites, dancing grounds, volcanoes, scuba diving etc (VTO pers. comm.).*

We used geographic information system (GIS) analysis to define the areas at risk of coastal flooding for both sites (figures 6 and 7). The topography of the islands (volcanic with mountains) means most people live relatively high above the sea level; the villages are situated in the hills or quite far from the sea. This means village houses and infrastructure were not at risk of coastal flooding in either Crab Bay and Eratap.

However, around 300 hectares of crop plantations (coconuts) in Crab Bay were in a potential flooding. Similarly, the Eratap resorts (which are at sea level to take advantage of sea views and beach access) were in the 5 metre flooding zone.

Figure 6: Crab Bay, zone at risk for coastal flooding (red area)

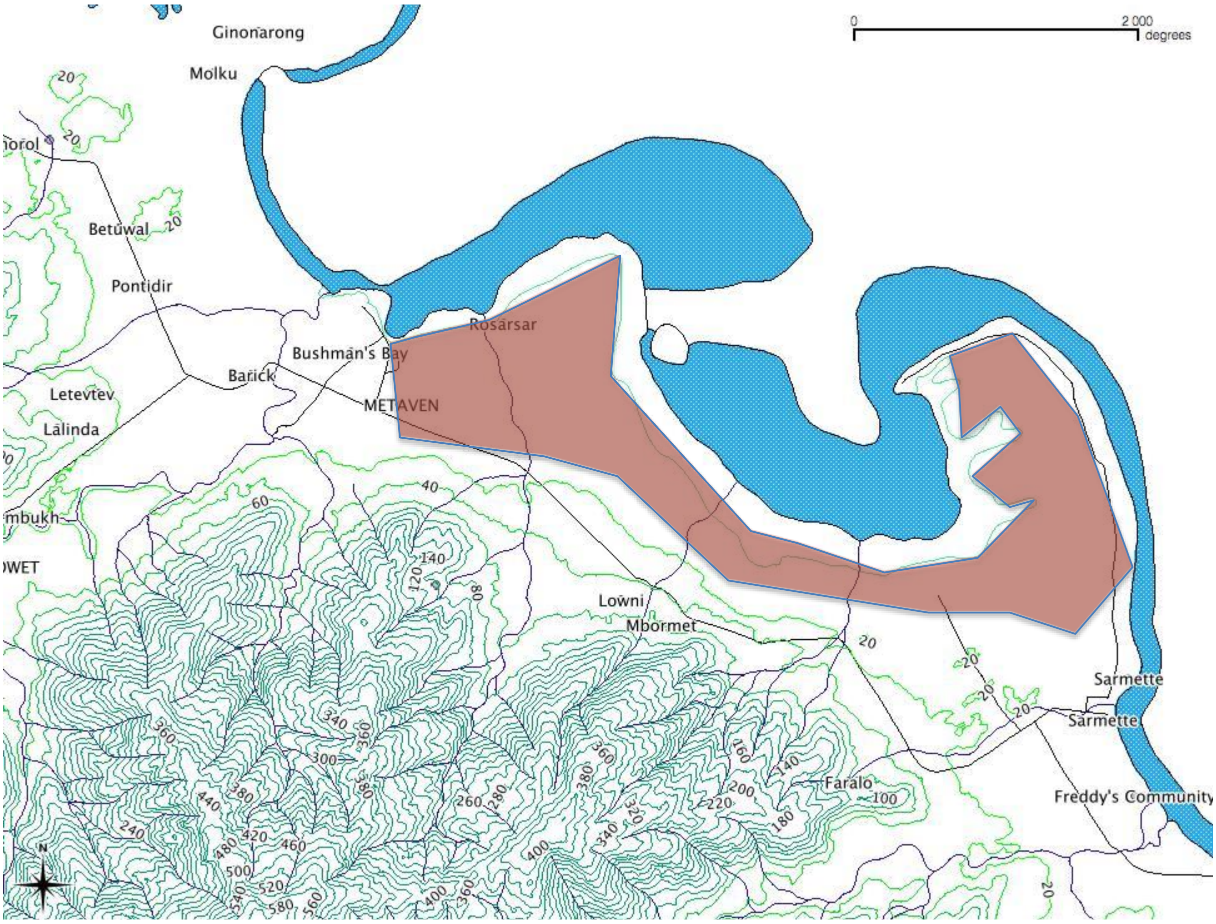


Figure 7: Eratap, zone at risk of coastal flooding (red area)

Note: Resorts are identified with a yellow star

B. CONTRIBUTION OF MANGROVES AND OTHER COASTAL ECOSYSTEMS IN PROTECTING VULNERABLE AREAS

We estimated the mangroves' contribution to the coastal protection index (CPI) for Crab Bay and Eratap, based on several mapping sources of coastal geomorphology and bathymetry (table 4).

Table 4: Calculating the coastal protection index based on coastline characteristics (developed by Allenbach and Pascal).

	Very strong	Strong	Medium	Low	None
	5	4	3	2	1
Geomorphology	Rocky shore	Mix of rocks/sediments/mangroves	Mangroves	Sediments	Beaches
Coastal exposure	Protected bay	Semi-protected bay	Artificial reefs	Low protected bay or coast	No protection
Reef morphology, area and distance to the coast	Continuous barrier (>80%) close to the coast (<1km)	Continuous barrier (>50%), patch reef, close to the coast (<1km)	Fringing reef (width >100 m)	Coral formation discontinuous	No reef
Inner slope, crest width	Very favorable conditions (gentle slope, large crest width)	Favorable conditions (slope, large crest width)	Favorable conditions (at least one component: slope, crest width)	Reduced favorable conditions (strong slope, reduced crest width)	None
Platform slope	6-10%	2.5-6%	1.1-2.5%	0.4-1.1%	< 0.4%
Mean depth (<1 km from the coastline)	> 30m	> 10 m	> 5m	< 5m	< 5m
Other ecosystems	mangroves, seagrass > 75% coastline	mangroves, seagrass > 50% coastline	mangroves, seagrass > 25% coastline	mangroves, seagrass <25% coastline, sand extraction areas	None

Table 5 summarises the results for Crab Bay and Eratap (Eratap 1 is located inside the bay and contains the Aquana resort, while Eratap 2 is located in the entrance of the bay and contains the Eratap Beach Resort). The Crab Bay and Eratap1 zones had a relatively high CPI (greater than 2.5); they are located in protected bays that provide natural barriers against winds and extreme climatic events. Crab Bay is also protected by an extended barrier reef and an inner slope and shallow depth. By contrast, the Eratap 2 zone had a low CPI (less than 2.5); it is exposed to coastal flooding and has low natural protection (mainly the platfom slope, the barrier reef and the shallow depth).

The contribution of the reef in the CPI varied from 30 per cent (for the Eratap zones) to 40 per cent (for Crab Bay). Similarly,the mangroves' contribution ranged from 24 per cent for Crab Bay, to 10 per cent for Eratap 1, and to 5 per cent for Eratap 2. Eratap 2 recorded a very low value because the mangroves are only present in a backward zone (inside the bay), which provides little protection against coastal flooding.

Table 5: Coastal protection index and relative contribution of mangroves

	Crab Bay	Eratap 1	Eratap 2
Geomorphology	3	1	1
Coastal exposure	5	5	2
Reef morphology, area and distance to the coast	5	4	3
Inner slope, crest width	5	2	2
Platform slope	3	2	3
Mean depth (<1 km from the coastline)	2	1	4
Other ecosystems	5	3	1
Coastal protection index	4.00	2.57	2.29
Reef contribution to coastal protection	40%	30%	30%
Mangrove contribution to coastal protection	30%	20%	10%
Relative importance of the mangrove in the costal protection index	**24%**	**10%**	**5%**

Please refer to: Pascal, 2010; Pascal et al., 2013

C. CHARACTERISATION OF DAMAGES AND ECONOMIC VALUATION (STAGES C.1. AND C.2.)

The economic valuation represents the value of avoided damages from coastal flooding because of the presence of mangroves. It was based on the exposure of buildings and crops to risk factors, estimates of repairing costs or production loss from damage functions, and the probability of the hazard.

In Crab Bay, the total avoided damages from protecting crops from flooding were Vt5 million. We adjusted this value by applying the annual probability of the hazard (44 per cent) and the mangrove-contributing index (24 per cent), to calculate the annual ES value (approximately Vt0.5 million per year, table 6).

In Eratap, the total avoided damages from protecting the resorts from flooding were Vt133 million. We adjusted this value by applying the annual probability of the hazard (44 per cent) and the mangrove-contributing index (10 per cent for Eratap 1 and 5 per cent for Eratap 2), to calculate the annual ES value (approximately Vt4.5 million per year, table 6).

Table 6: Economic valuation of avoided damages from coastal flooding

	Crab Bay	Eratap 1	Eratap 2
Total annual value (ES6)	534 600	3 243 240	1 235 520
Coastal protection index	4.00	2.57	2.29
Mangrove contribution to coastal protection	24%	10%	5%
Average damage costs	Vt7100 per ha of coconut plantation	Vt25 000 per m^2 of construction	
Probability of hazard event	44%	44%	44%

**Please refer to Part B of the annex on coastal protection for data & calculation*

BIOREMEDIATION OF WASTE WATER (ES7) RESULTS

Mangroves filter waste water and prevent pollutants being dispersed into deeper waters and then recirculated offshore (Herteman 2010; Tam and Wong 1993). That is, the mangroves can purify and treat domestic waste water under precise conditions (see annex 5 for a more detailed description). The Vanuatu Government has no direct legislation or regulations governing sanitation. No government authority is directly responsible for sanitation facilities. So far, mangroves play a limited role in treating waste water.

In Crab Bay, the low density of people living close to the mangroves means discharges of waste water into the mangroves were also low. Further, village houses use individual septic tanks without any connection to waste water pipes, along with ventilated improved pit and water seal type latrines. Villages do not have any waste water treatment (such as a decanter or buffer tank). The crop plantations (coconut and cacao) may be a source of additional nutrient input (from fertilizers), via water runoff and phreatic connection. However, we did not observe any direct discharges of waste water from villages or crop plantations into the mangroves or the rivers.

Eratap has a higher population density, and proximity to the streams discharging into the mangroves (see figures 8 and 9 below) may increase the potential level of waste water and contaminated waters flowing to the mangroves. However, village houses use individual septic tanks (like those in Crab Bay), while the resorts dispose of their own water treatment plant effluent. They use modern water treatment units that seem to efficiently recycle nutrients before discharging water (one into the mangroves and the other into the sea).

Precise data about stream flows and water quality were not available and we relied only on direct observations to assess the bioremediation ES. For this reason, we did not quantify the bioremediation ES.

Nonetheless, we concluded:

- The bioremediation ES seemed very low in Crab Bay, reflecting the low input of nutrients.
- In Eratap, we considered mangroves could remediate an unknown volume of nutrients. However, the reduced width and area of mangroves (two critical factors in bioremediation processes) moderated the potential importance of this service.

SEDIMENT TRAP (ES8) RESULTS

DESCRIPTION

In Crab Bay and Eratap, the ES8 is present because streams discharge into the mangroves (figures 8 and 9 respectively). GIS data (from the Department of Lands, Survey and Registry) identified three streams in Crab Bay, and three streams and one river (Teouma) in Eratap. We verified two streams in Crab Bay and one stream in Eratap during field observations.

More precise data about stream flows and sediment charges was unavailable and we relied only on local community knowledge to assess the role of ecosystem process in sediment trap.

Figure 8: Streams and rivers in the Crab Bay zone (in red)

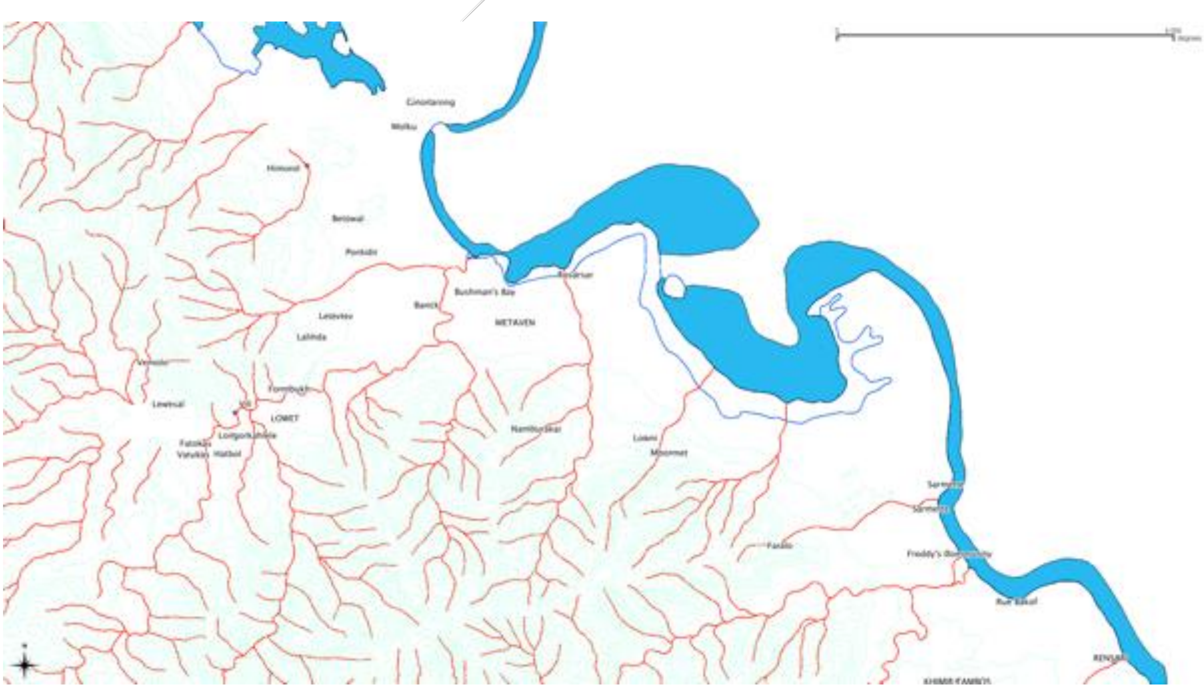
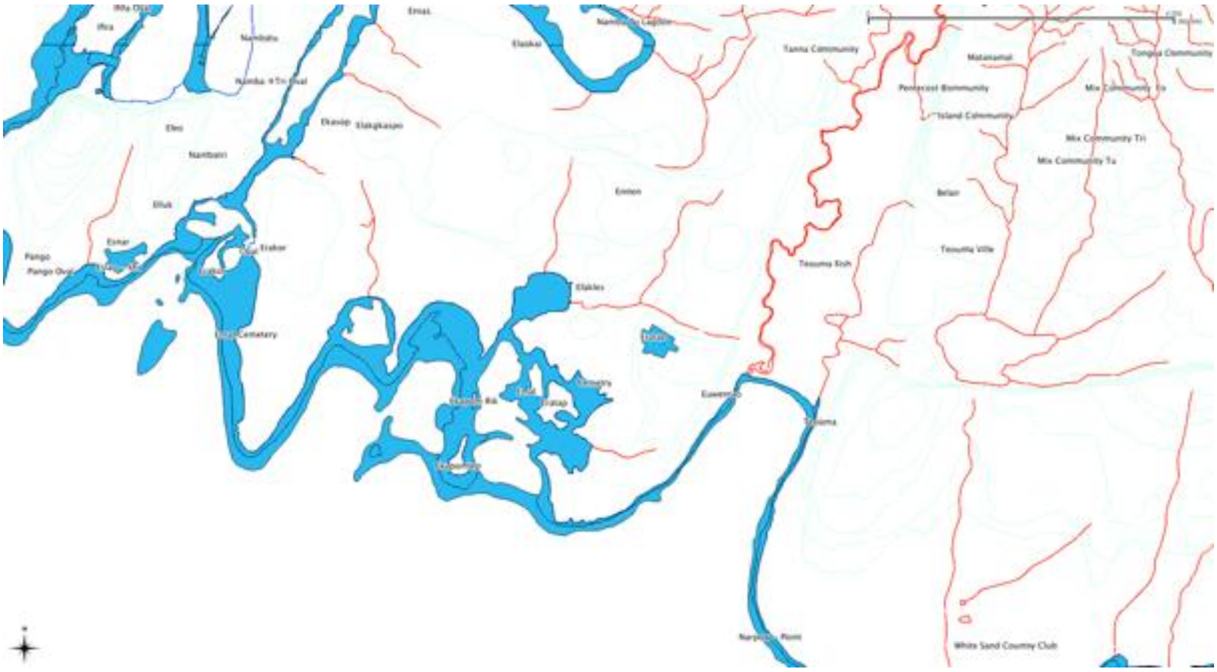


Figure 9: Streams and rivers in the Eratap zone (in red)



The streams and the river carry a lot of sediments during heavy rains and summer season. The sediment plume of the river in Eratap flows parallel to the western coast and usually penetrates in the Eratap bay (making the river the main source of sediment in the bay) (figure 9). We could not identify the direction of the sediment plume for the streams (in either Crab Bay or Eratap).

In Crab Bay, we could not identify direct beneficiaries of this ecosystem service. In Eratap, the two resorts were potential beneficiaries, by trapping sediments for recreational use by tourists (water clarification).

HOW MANGROVE ECOSYSTEM PROCESSES TRAP SEDIMENT

Mangroves can trap sediments and are an important sink of suspended sediment, which can come from river discharge, dredged material and re-suspended bottom sediment from waves and ships (Furukawa et al. 1997; Walters et al. 2008). The mangrove trees trap sediments in their complex root structure, functioning as land builders. Case studies suggested annual sedimentation rates in mangrove areas of 1–8 millimetres (Bird and Barson 1977). Mangroves reduce tidal flows and induce sedimentation of soil particles at low tide, probably due to friction force.

The efficiency of sediment trapping varies with mangrove zones and species (Kathiresan 2003; Wolanski 1995). In some estuaries, mangroves have trapped up to 40 per cent of the riverine fine sediment (Furukawa et al. 1997; Victor et al. 2004) and protect fringing coral reefs from sedimentation. See annex 6 for more information.

ECONOMIC VALUE OF ES8

We described the two resorts in Eratap earlier (in the discussion about ES5). For Eratap Beach Resort, the sediments coming from the Teouma River are firstly trapped by the beaches and then by the mangroves placed back from the beaches. For Aquana, the mangroves should retain the bulk of the sediment before it comes inside the bay, where the hotel beach is located and some marine activities occur. However, the resort has experienced turbid waters since it was built in 2011, which appears to be independent of sediments carried by the river after rainfall.

Based on the available data and community knowledge, we concluded the sediment trap service is almost nonexistent in Crab Bay and must be more isolated and quantified in Eratap.

CARBON SEQUESTRATION (ES9) RESULTS

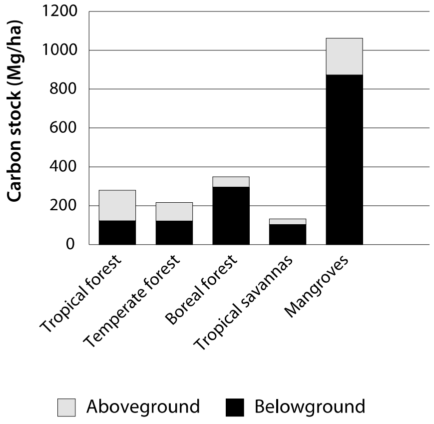
HOW MANGROVE ECOSYSTEM PROCESSES AFFECT CARBON SEQUESTRATION

Seagrass and mangrove ecosystems remove carbon dioxide (CO_2) from the atmosphere via photosynthesis, return some to the atmosphere through respiration and oxidation and, store remaining carbon in two stocks: the living biomass (which includes both above ground and underground vegetation) and as soil organic carbon (Knowlton 2000; Walters et al. 2008).

Carbon sequestration rates for mangroves can range from 6–8 tonnes of CO_2e.per hectare per year based on recent publications and the blue carbon database (Bouillon et al. 2009; Murray et al. 2010; Nicholas Institute for Environmental Policy Solutions 2011; Sifleet et al. 2011). Most of this carbon is sequestered in per hectare per yearsoil (approximately 2000 tonnes of CO_2e.per hectare for mangroves), with 20–40 per cent stored in living biomass (Murray et al. 2010).

Mangrove carbon pools are among the highest of any forest type, often more than twice the size of most upland tropical and temperate forests (figure 10). Much of this carbon is stored belowground in organic-rich soils, which can release significant volumes of greenhouse gases if disturbed by land use or climate change (Page et al. 2010; Hooijer et al. 2006).

Figure 10: Global ecosystem carbon pools, by land cover type



Source: Kauffman and Donato 2012.

We used two processes to quantify carbon volumes: the sequestration in living biomass and the carbon pools in the soils. Together, these amounts estimate the annual amount of CO_2e *avoided* being released into the atmosphere by maintaining ecosystems in their current state. Specifically, we estimated:

a. the annual rate of absorption of carbon by the ecosystem in its current state

b. carbon stocks in biomass and the basement (at a maximum depth of 1 metre even if, generally, carbon pools vulnerable to anthropogenic changes are aboveground biomass and belowground pools up to 30 centimetres). Data was based on estimates of tier 1 and tier 2 IPCC categories.[20]

c. the amount of potential emissions caused by destroying ecosystems. This evaluates how much soil carbon may potentially be exposed to the atmosphere and thereby emitted as CO_2. Metres of carbon-rich organic soils may underlie the coastal habitats, and that carbon may persist if the habitat conversion only affects the top layers and the deeper layers remain inundated.

d. the time required to release emissions into the atmosphere. In theory, following conversion, carbon in biomass is emitted to the atmosphere in the first few years. Soil organic carbon will take longer than biomass and the deeper the soil carbon, the slower its rate of release. In each case, high emission rates would be expected in the years immediately after disturbance, then dropping to lower

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[20] The IPCC (Intergovernmental Panel on Climate Change) established a tier system, reflecting the degrees of certainty or accuracy of carbon stock assessment. Tier 1 uses IPCC default values (i.e. biomass in different forest biomes etc.) and simplified assumptions; it may have an error range of +/- 50 per cent for aboveground pools and +/- 90 per cent for the variable soil carbon pool. Tier 2 requires country-specific carbon data for key factors. Tier 3 requires highly specific inventory-type data on carbon stocks in different pools, and repeated measurements of key carbon stocks through time, which may also be supported by modelling.

rates later. A decay function may approximate this physical process, and we used the concept of half-life, which denotes the time required for the carbon pool to fall to half its initial value. We assumed a half-life of five years (Murray et al. 2010).

ECONOMIC VALUE OF ES9

For Crab Bay, we assumed a deforestation rate of 0.1–0.3 per cent of the total surface per year, based on expert opinion and analysis of the existing literature about mangroves in Crab Bay (Vanuatu Environment Unit 2007). It reflected relatively low pressure on mangroves as well as efficient habitat management.

The estimated volumes of CO_2e in the soil and the biomass ranged from 33 170 tonnes to 70 025 tonnes, assuming the total area for Crab Bay was 136.5 hectares (as recently estimated by the Vanuatu Government Department of Environment Protection and Conservation). We estimated the economic value of these volumes to be between Vt24 million and Vt50 million (US$265 000 and US$563 000), using the carbon price estimates contained in annex 7 (table 7).

Table 7: Economic valuation of the carbon sequestration service in Crab Bay

	Habitat area (Ha)	Annual rate of deforestation (% of total area/y)	$t\ CO_2e\ y^{-1}\ ha^{-1}$		Soil and biomass stocks ($t\ CO_2e\ ha^{-1}$)		Potentially released (% stock)	Annual rate of decay of releasable stock (%/y)	Annual volumes of Co_2e not released (t Co2 e/y)		Value of the service of carbon sequestration ($US/y)	
			min	max	min	max			min	max	min	max
Mangrove	136.5	100.0%	0.12	23.98	900	1 900	60%	45%	33 170	70 025	265 487	563 338

For Eratap, we assumed a deforestation rate of 0.3–0.5 per cent of the total surface per year, based on expert opinion (Vanuatu Government Department of Fisheries and village stakeholders) and analysis of the present MESCAL studies on mangroves in Eratap. It reflected a relatively low pressure on mangroves.

The estimated volumes of CO_2e ranged from 7655 tonnes to 16 160 tonnes, assuming the total area for Eratap was 31.2 hectares (as recently estimated by the Vanuatu Government Department of Environment Protection and Conservation). We estimated the economic value of these volumes to be between Vt6.2 million and Vt11.7 million per year (US$ 69 000 and US$130 000), using the carbon price estimates contained in annex 7 (table 8).

Table 8: Economic valuation of the carbon sequestration service in Eratap

	Habitat area (Ha)	Annual rate of deforestation (% of total area/y)	$t\ CO_2e\ y^{-1}\ ha^{-1}$		Soil and biomass stocks ($t\ CO_2e\ ha^{-1}$)		Potentially released (% stock)	Annual rate of decay of releasable stock (%/y)	Annual volumes of Co_2e not released (t Co2 e/y)		Value of the service of carbon sequestration ($US/y)	
			min	max	min	max			min	max	min	max
Mangrove	31.2	100.0%	0.12	23.98	900	1 900	60%	45%	7 655	16 160	68 291	130 001

THE THEORY BEHIND OUR METHOD

A DEFINITION OF ECOSYSTEM SERVICES

The most common definition of ecosystem services are 'services that human populations derive, directly or indirectly from ecosystem functions' (Costanza et al. 1997) or, more simply, 'services that people obtain from ecosystems' (Boyd and Banzhaf 2007; MEA 2003). The Millennium Ecosystem Assessment defines an ecosystem as 'a dynamic complex of plant, animal, and micro-organism communities, and the non-living environment interacting as a functional unit' (MEA 2003). This report present the total economic value (TEV) results for nine ES:

- subsistence fishery (ES1)
- coastal commercial fishery (ES2), including professional and nonprofessional fishery as well as coastal and mangrove linked pelagic fishery
- recreational or sport fishery (ES3)
- other extractive uses such as wood, medicine (ES4)
- tourism activities linked to mangroves (ES5)
- coastal protection against flood (ES6)
- bioremediation of waste waters (ES7)
- sediment trapping to reduce coastal erosion (ES8)
- carbon sequestration (ES9).

A DEFINITION OF TOTAL ECONOMIC VALUE

The TEV is the sum of consumer surplus and producer surplus of all the services of direct, indirect use and non-use (Abaza 2004; Beukering et al. 2007; Defra 2008; Pagiola 2004a). Here, we present the underlying theory.

The neoclassical theories of 'value' introduce the concepts of producer surplus and consumer surplus at the microeconomic level (Azqueta and Sotelsek 2007; Diaz-Balteiro and Romero 2008; Dimand 2007). For this study, we calculated the producer surplus in the same way as the added value used in national accountancy systems[21] (Defra 2008; Farber et al. 2002). It can be estimated as the sum of profits and Ricardian rents going to factors of production (e.g. the value of a productive marine zone). Some authors

[21] *Added value is the difference between the sale price and the intermediate costs of a product (which consist of the total goods and services consumed as inputs in production).*

also call it the financial value when estimations concentrate on the cash flows with multiplier effects that are linked to the use values of the ecosystem good or service (Beukering et al. 2006).

The consumer surplus is the difference between the maximum price that a consumer is willing to pay and the actual price that they do pay. It is more complex to obtain and requires either the existence of a demand curve obtained from data (historical prices and quantities sold in the market) or the application of revealed preference analysis (e.g. travel costs) or a stated preference survey (e.g. choice experiment), (TEEB 2010). For recreational use, for example, consumer surplus is the value of an activity beyond what a user must pay to enjoy it.

The two prominent types of consumer surplus are estimated using slightly different definitions of the demand function: the Marshallian consumer surplus is based on an ordinary demand function, and the Hicksian consumer surplus is based on either a compensated demand function or hypothetical market techniques. The difference between these measures is due to the income effect. Given outdoor recreation expenditures are a relatively small percentage of total expenditures (income), the difference between the two measures is expected to be negligible.

VALUATION METHODS AND PARAMETERS

As described by various authors (Farber et al. 2002; Groot et al. 2010; Pagiola 2004a; Remoundou et al. 2009), three main methods can be identified for valuing ES absolute or marginal values (figure 11):

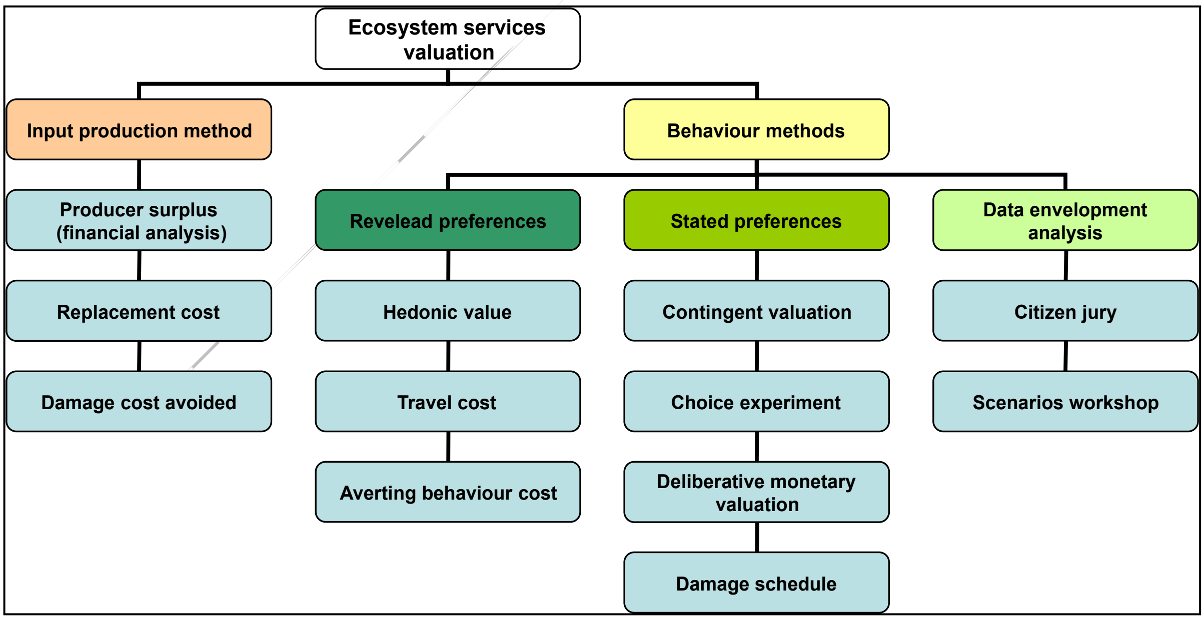
1. The production input method is based on an evaluation of physical volumes that the ecosystem generates (biomass, tourism attributes etc.) and that are an input in the production of services. This method is particularly suited to determining direct and indirect values but has rarely been applied in coral reef and mangrove valuations. Cesar (1996), Cesar et al. (2003) and Beukering et al. (2006 and 2007) used this method to estimate the 'effect on production' from an ecosystem change, through the difference in producers' output (output of fishermen, tourism businesses). The technique can be used to calculate marginal changes in production or absolute values of production. When data are based on market data added values, we refer to it as producer surplus or financial analysis. When direct market data are not available, another approach is to measure production inputs through (i) the replacement cost method, which estimates the costs of replacing ecosystem services with human-made services (e.g. an artificial reef to provide costal protection) or (ii) the cost of avoided damages method, which estimates damages avoided due to ecosystem services (e.g. the costs of avoided flood due to wave energy absorption by coral reefs).
2. The revealed preference method is based on the observation of individual behaviours, which translate into people's preferences and thus the value that people place on the environment. The most common techniques for this method are travel costings, hedonic pricing and averting behaviour. The first

technique assumes the travel costs to access a resource site indicate the value that people place on that resource. The second technique estimates the influence of ES and environment characteristics on the price of marketed goods such as real estate or tourist services. The third technique assumes people make choices to maximise their wellbeing when faced with increased health risks. Averting behaviour requires expenditures that people would not make if they were not faced with the environmental health risk (e.g. the purchase of bottled water when faced with the risk of contaminated drinking water).

3. The stated preference method surveys users about their practices and preferences. The survey techniques place the consumer in a hypothetical but realistic market context and ask them to choose between alternatives with different characteristics. From the responses, it is possible to deduce the value that people place on an ecosystem service. This value is called willingness to pay (WTP). It is interpreted as the change in consumer surplus of the individual resulting from change in the quality of services provided by an ecosystem. It is thus a method for valuing both use and non-use values. Conjoint analysis (or method of choice experiments and experimental choices or choice modelling) and contingent valuation are the two most commonly used stated preference techniques in environmental economics.

All three methods are complementary, and each has biases (Balmford et al. 2008; Beukering et al. 2007).

Figure 11: Methods of economic valuation



WHAT ARE THE SERVICE'S POTENTIAL AND SUSTAINABLE LEVELS?

The sustainability of uses and the meaning of the calculated values are legitimate questions. The estimation of a single monetary value to characterise an ecosystem service must be contextualised with information about environmental sustainability and the potential of the ecosystem service evaluated.

The economic valuation report of the Centre d'Analyse Stratégique from the French Prime Minister's office (Chevassus-au-Louis et al. 2009) refers to the 'maximum plausible use' that may be possible to determine qualitatively (e.g. based on expert opinions) or quantitatively from production functions for certain ecosystem services. The economic taskforce of the IFRECOR (the French Initiative for Coral Reef) recommended calculating potential values for the following services: fishing, underwater tourism, coastal protection and waste water treatment (direct and indirect values). The maximum plausible values may be categorised as option values of current uses.

Reef and mangrove fish populations are very sensitive to fishing effort, and overfishing is rapidly reached in these ecosystems. Nonetheless, when calculating an ecosystem service based on fisheries, coral reef and mangrove valuations rarely account for the ecological sustainability of the fishery. Defining the value based on the total fish population is inadequate because that value would be equivalent to a capital value and not a sustainable revenue. To calculate the potential fishery ES, or to project future ES flows, it is necessary to define maximum annual productivity.

In a similar way, the Sheraton paradox (Mirault 2006) describes how the valuation of coastal ecosystem services linked to tourism will provide big numbers that depend mainly on the tourism capacity. Results are independent of the future effects on the ecosystem of waste water, overcrowding of sites etc. It is thus necessary to define the limits of ecological and sociological changes that could cause some degradation but that will be allowed on site (Stankey et al. 1985).

Additional method related questions include how potential values should be calculated when a trade-off exists between ecosystem services. Fish harvest is a concern, for example, when tourism is a potential non-consumptive use of the fish stock. Another challenge is to define the trade-offs of a yield that values the diversity of fish species for tourism relative to selective fishing for consumption.

WHAT IS THE SERVICE'S SPATIAL DISTRIBUTION?

Many challenges arise in defining the spatial dimension of the valuation of ecosystem services. The first question addresses what is being assessed: the place of the ecosystem processes, the place where the human activity takes place, or the place where benefits will be transformed into money? Other challenges concern important knowledge gaps in the marine ecological processes (e.g. larval dispersion and trophic migrations) and their spatial distribution (Kendall and Picquelle 2003; Leis 2002; Sale et al. 2005).

Identifying the study perimeter for each ecosystem service being valued is not necessarily straightforward yet it can substantially affect the analysis (Mumby and Steneck 2008a). In addition, it seems to be a key variable for policy makers evaluating policy choices, who are usually influenced by the spatial distribution of beneficiaries and losers.

Considering the complexity of these processes (their variability and importance) and the technical challenge to identify some services' dispersion, especially for marine species, we relied on the most recent scientific results to reflect this parameter in the mangroves economic valuation.

WHAT IS THE COMMUNITY CONTEXT OF THE SERVICE?

The contexts of community and traditional economy pose a challenge to the neoclassical approach of individual maximisation of welfare. Although no published studies exist to our knowledge, customary tenure arrangements in the Pacific may significantly skew (constrain or enable) the influence of community in individual choice and clan/family/village resource allocation decisions (Cinner et al. 2007). If so, it presents the question of how to appropriately scale the economic valuation from the individual or household level to some broader level (group of families, clan, village etc.).

Many of the natural resources in Pacific Island territories are communally owned, often with boundaries that are not clearly defined or formally recorded. This ownership structure creates unique challenges for using and managing natural resources in a modern world. In many Pacific Islands, and mainly in Melanesia (Fiji, New Caledonia, Papua New Guinea, Solomon Islands and Vanuatu), the cash economy is still underdeveloped. So, the value that local communities attribute to money and its function may greatly differ from common economic assumptions. Island societies assign value to things that lack exchange equivalents, or relative prices, and thus cannot be included in a TEV. Three examples (Laurans et al. 2013) are:

1. the islanders' familiarity with the mangrove, which is measured by the number of places and the number of fishes named locally. These two metrics are a proxy for both the non-use value of a mangrove and its use value (because Pacific Islanders name only what they use).
2. the role of the mangrove in the identity of the village community. The highest values are attached to the place where the island's founding ancestor first landed his canoe.
3. the role of the mangrove in the social and political positioning of the community among other island communities. The highest values are found among reef fishing clans, as in New Caledonia (Leblic 1999), and among communities where the alliance relationships are built on sharing fishery products (including turtles), as on Tanna Island, Vanuatu (Bonnemaison 1986).

We know of only one study that has addressed the non-use value of coastal ecosystems for local populations in Pacific Island territories. The study was conducted in Fiji with several communities to identify the bequest value attached to the reef (O'Garra 2012). It found local communities were willing to contribute three hours of their time per week towards conservation mainly for future generations (bequest value). Several issues were raised in the study, such as time allocation conflict between communal and personal obligations, gender influence in decision making, and common property resource management by villagers.

Other studies addressing non-use values through contingent valuation or choice experiment were estimated for high-income groups from Australia or developed Pacific islands (Ahmed et al. 2007; Beukering et al. 2006; Cesar et al. 2003a; Whitten and Bennett 2004).

WHAT IS THE TIME PERIMETER FOR ANALYSIS?

Our ES valuations of direct and indirect uses focused on financial flows or economic values from the previous year of study. We undertook no time projection (e.g. no discount rate), except for carbon credits based on avoided carbon dioxide emissions for 30 years.

We used multipliers to estimate the direct and indirect impacts of the ES on the local gross domestic product, depending on data availability.

When possible, we compared the calculated use values with the previous five years, to identify potential biases and unrepresentative exceptional situations.

WHAT UNCERTAINTIES AND CONFIDENCE INTERVALS APPLY?

We highlight the calculations' degree of uncertainty by presenting the lowest and highest estimates in the results. We also specify the confidence intervals of the results and other mathematical models (production functions), and note any information on sustainability practices that should be highlighted.

WHAT IS THE DIFFERENCE BETWEEN ECOSYSTEM PROCESSES AND SERVICES?

As noted by Balmford et al (2008), it is important to distinguish between ecosystem processes and ecosystem services. Processes are physical, chemical or biological, and they help maintain the ecosystem, whereas services are the end goods and services that directly affect human welfare. Under this classification, we can identify core ecosystem processes and beneficial ecosystem processes. The core processes (such as biogeochemical cycles and the water cycle) support the beneficiaries' processes (such as biomass production and water purification), which directly help produce ecosystem services to humans.

WHAT IS THE EFFECT OF ECOSYSTEM CONNECTIVITY?

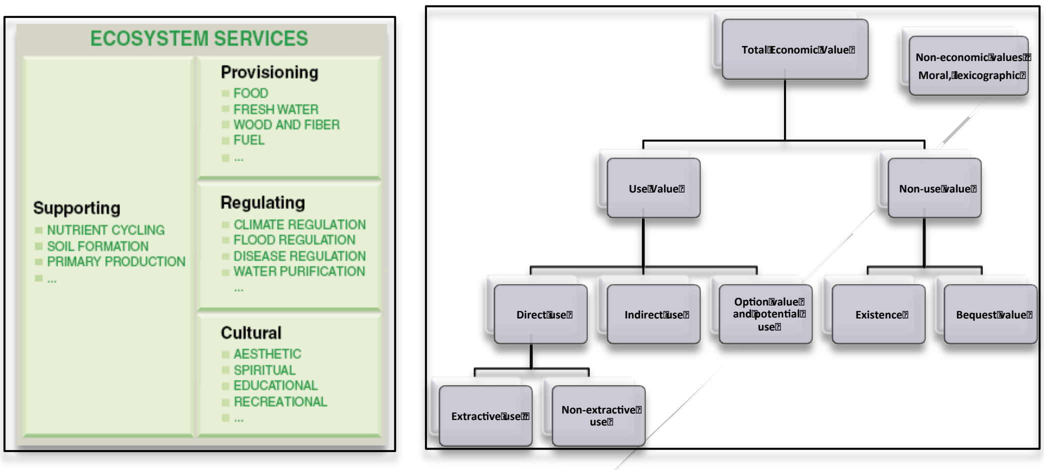
Coastal habitats (coral reef, mangroves, seagrass, saltmarshes) are linked biologically. Many fish and shellfish species use mangroves and seagrass beds as nursery grounds, and eventually migrate to coral reefs as adults, only to return to the mangroves and seagrasses to spawn (Mumby and Steneck 2008b; Ruitenbeek 1994). In addition, the high biological productivity of mangroves, marshes and seagrasses mean they produce significant amounts of organic matter that is used directly or indirectly by marine fish, shrimps, crabs and other species (Barbier et al. 2011). Consequently, interconnected seascapes significantly support fisheries via a number of ecosystem functions, including nursery and breeding habitats, trophic interactions and predator-free habitats.

Allowing for the connectivity of habitats may have important implications for how we assess the ecological functions underlying key ecosystems services, such as coastal protection, the control of erosion, and habitat–fishery links. Only recently have studies begun to assess the cumulative implications for these services, and to model this connectivity (Barbier et al. 2011).

ANNEX 1 CLASSIFICATION OF ECOSYSTEM SERVICES

There are several classifications of ecosystem services generated by mangroves (Balmford et al. 2008; Beukering et al. 2007; Cesar et al. 2003b; MEA 2003; Moberg and Folke 1999; Pascal 2010). The two most common classifications used are those of the Millennium Ecosystem Assessment (left side of figure A1) and that of the total economic value (TEV) (right side of figure A1).

Figure A1: Classification of ecosystem services



Sources: MEA 2005; adaptation of Balmford et al. 2008 and Spash 2000.

The Millennium Ecosystem Assessment (MEA) defines four main classes of ecosystem services: provisioning, regulating, supporting and cultural services. These services range from concrete harvestable goods (such as fish or shells) to more abstract regulating services such as water treatment, wave protection for flood control and biodiversity maintenance.

The Convention on Biological Diversity is using the MEA {MEA, 2003 #76} classification, but we considered it inappropriate for our case studies. Some economists, such as Balmford et al. (2008) argued it is not adequate for economic evaluation studies; it mixes processes (means) and benefits (ends), making it prone to double counting.

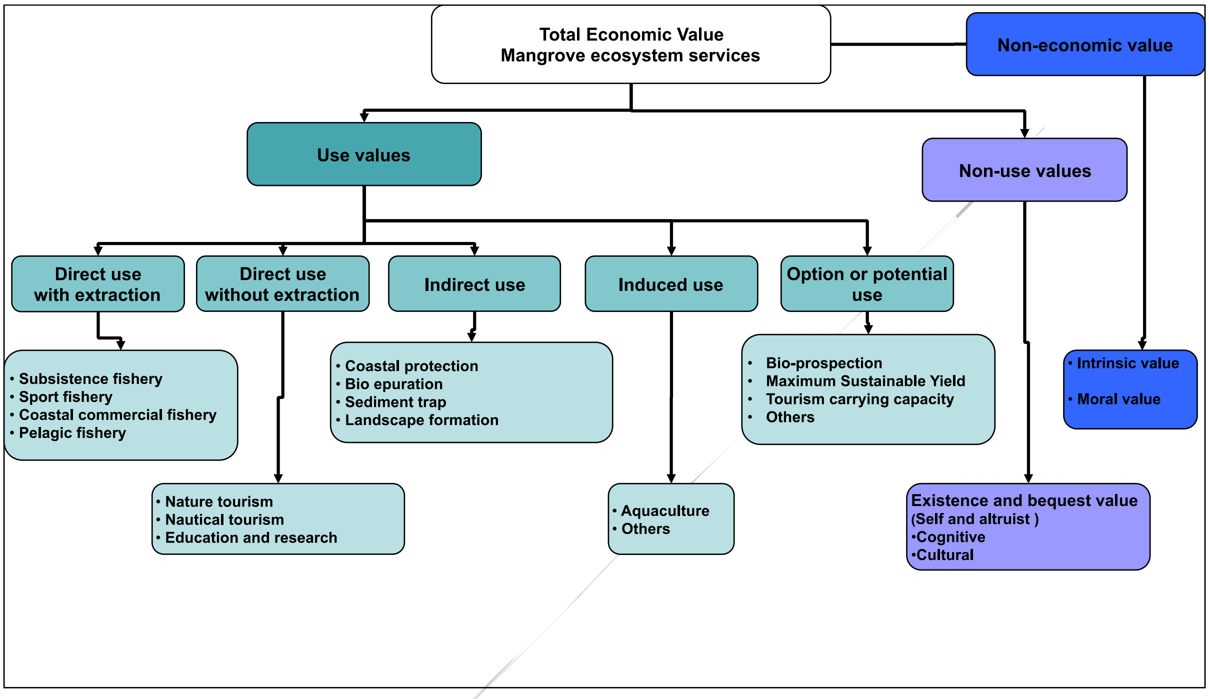
For this reason, we used the TEV classification for our case studies. Following Balmford et al. (2008) and Harborne et al. (2006), we distinguished between ecosystem processes and ecosystem services. Processes are biophysical functions, while services are the end services that directly affect the human welfare. We considered two types of ecological processes:

- core ecosystem processes—the basic ecosystem functions (e.g., nutrient cycling, biochemical processes) supporting the processes that provide benefits to humankind

- beneficial ecosystem processes—the specific ecosystem processes that directly underpin services for humankind (e.g. waste assimilation, biomass production).

The ecosystem services are the end products of these beneficial ecosystem processes (e.g., fishing). Figure A2 describes how we classified the different coral reef ecosystem services.

Figure A2: Mangrove ecosystem services classification through total economic valuation



Use values include ecosystem services from direct uses with and without extraction, indirect uses and potential uses (Groot et al. 2002). Direct uses are activities where the individual gains enjoyment directly from the resource. Some direct uses are extractive (e.g. fishery), while others are non-extractive (e.g. underwater tourism). Some direct uses (e.g. fish or a tourism service) are marketable (i.e. the market sets the price), while others are non-marketable (e.g. subsistence fishing or unorganized snorkelling activities). Other direct uses include aquaculture and the pearling industry, which incorporate ecosystem processes as inputs such as water, nutrients, etc. (Moberg and Folke 1999).

Indirect uses are ecosystem services that exist without man's intervention (Defra 2008). Mangroves can provide physical protection against waves and can contribute to waste water treatment, for example (UNEP-WCMC 2006).

Option values are future or potential uses (direct or indirect) of coral reef ecosystems. Not all known marine fish stocks will be exploited today (even sustainably), for example. Some stocks may be exploited immediately, while others are left untouched as options for the future. (Turner et al. 2003).

Non-use values, or passive use values, are all the economic values that are not related to using the ecosystem (Krutilla 1967). Often, non-use values focus only on an ecosystem's existence value and its bequest value. The existence value is the value given to the ecosystem's existence, independent of its use (Rudd 2009). The bequest value is associated with preserving the ecosystem for future generations (Nijkampa et al. 2008).

Other non-use values (such as the intrinsic value of nature, the moral value etc.) are classified as non-economic or lexicographic values (Spash 2000), and cannot be valued in a monetary way.

Recent studies about economic valuation of coastal ecosystems (Daily et al. 2009; Goldman and Tallis 2009; Laurans et al. 2013) concentrated on three ecosystem services:

1. Food production—Coastal associated fisheries are an important source of food and basis for livelihoods.
2. Recreation and tourism—Coastal recreation and tourism activities generate significant economic value depending on the quality and availability of specific marine ecosystem attributes.
3. Coastal protection—Marine ecosystems (coral reefs, mangroves, seagrasses) can buffer coastlines from storm-induced erosion and inundation. They also can help to regulate natural processes of erosion and sedimentation that are critical to maintaining beaches.

For this study, we added carbon sequestration and bioremediation of waste water.

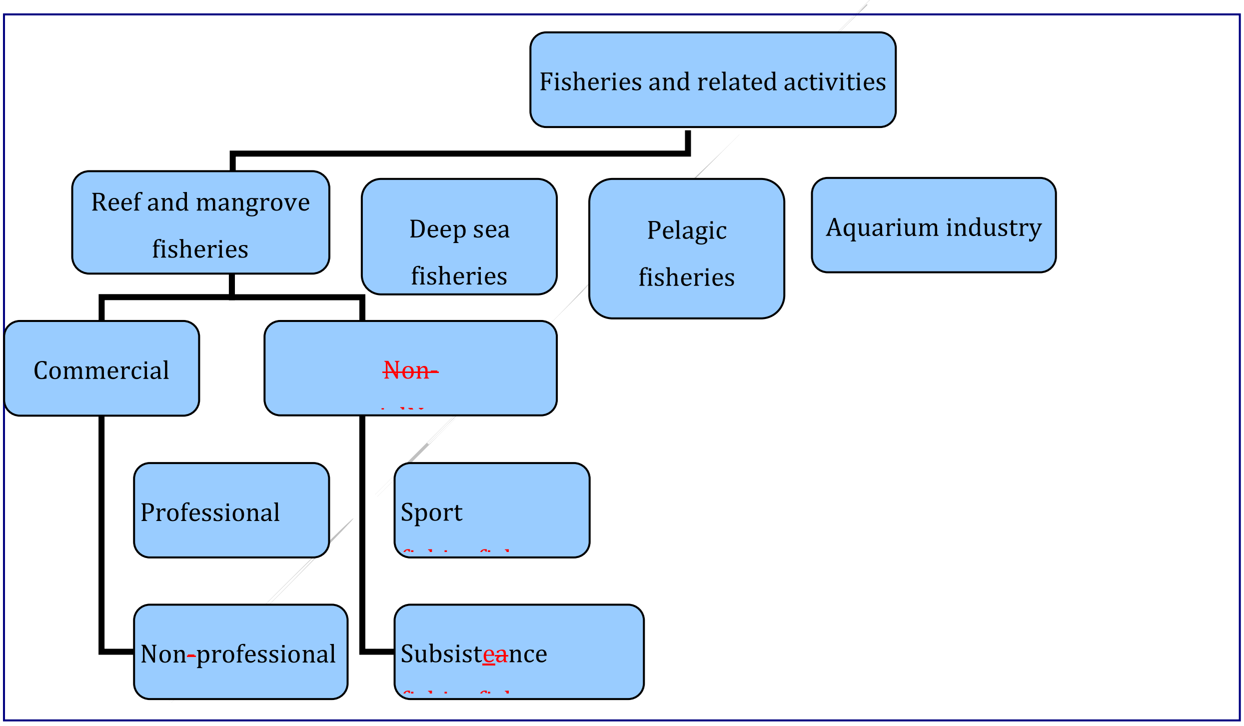
ANNEX 2 VALUATION OF DIRECT EXTRACTIVE USES (ES1, ES2, ES3 AND ES4)

This section discusses the methods for valuing direct extractive uses:

- subsistence fishery (ES1)
- coastal commercial fishery (ES2)
- recreational fishery (ES3)
- wood extraction (ES4).

Many of the direct extractive uses relate to fishing (figure A3). We can distinguish different types of fishing: if it occurs in reef and mangrove areas or in deep sea fisheries; if it is for commercial, recreational or subsistence purposes; and if it is performed by professionals nonprofessionals.

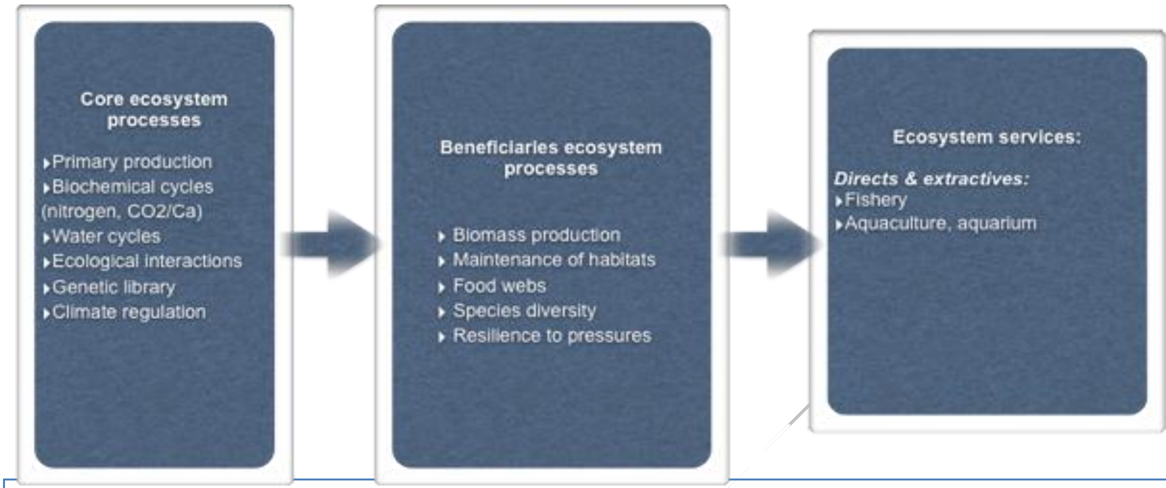
Figure A3: Direct extractive uses related to fishing



IMPLICATED ECOSYSTEM PROCESSES

Several processes are used to produce coastal fishery services (figure A4). We focused on biomass production, and maintaining habitat complexity, the nursery role and ecosystem connectivity.

Figure A4: Description of main ecosystem processes associated with reef and mangrove fisheries



BIOMASS PRODUCTION

The description of this process is based on the work of Done et al. (1996) and Pollnac (2007). A coral reef ecosystem and a healthy mangrove comprise diverse marine organisms in a highly productive environment that is low in nutrients. In this context, productivity refers to the large volume of carbon fixation that occurs in these ecosystems. Previous studies showed coral reefs and mangroves are among the most productive marine ecosystems (Done et al. 1996; Barnaud and Fustec 2007) (table A1).

Table A1: Primary production of the ecosystem

Ecosystem	Primary production (g d.m. $m^{-2}.y^{-1}$)* average values
Mangroves	2000
Coral reefs	2500
Open ocean	125
Continental platform	360
Upwelling zones	500
Estuaries	1500
Lakes and rivers	250
Tropical forests	2200
Template forests (coniferous)	1300
Agroecosystems	650

*Grams of dry matter per m^2 per year (Source: Adapted from (Barnaud and Fustec 2007).

Further, this productivity is despite the relative absence of dissolved nutrients (particularly nitrogen and phosphorus) in the surrounding oligotrophic waters. For reefs, algae and coral polyps act as a nitrogen fixer in nutrient-poor environments, much like legumes in agricultural ecosystems. Algae and phytoplankton are also autotrophs; that is, they transform nutrients in marine environments (oxygen, nitrogen etc.) into biomass for other plant and animal species (Harborne et al. 2006).

By contrast, mangroves produce a large amount of organic material, due to the structure of vegetation. This organic material is the basis of the complex food web in tropical coastal environments, so mangroves attract abundant marine life and often serve as spawning grounds. They also provide organic carbon to coral reefs. Removing mangroves interrupts the nutrient-recycling chain, depriving coral reefs of this important nutrients (Ruitenbeek 1994).

HABITAT COMPLEXITY

Science has become increasingly concerned with the relationship between coral reefs, mangroves and the abundance of fish stocks (Worm et al. 2006; Mumby and Steneck 2008). Two meta-analyses concluded half or more of the reef herbivores (including commercial species of *Scaridae sp.* and *Acanthuridae sp.*) experienced a significant decrease in stocks after a bleaching event (Wilson et al. 2006; Mumby and Steneck 2008).

This effect on the abundance and diversity of fish and invertebrates is partly explained by these species' dependence on coral reefs or mangroves for the settlement phase or larval feeding (Wilson et al. 2006). Some studies showed over 60 per cent of the fish disappear within three years of live coral cover falling by more than 10 per cent (Jones et al. 2004). The loss of habitat complexity may increase the effectiveness of predators and thus influence the density of small fish (Hixon and Beets 1993). It also influences the diversity of invertebrate species (Idjadi and Edmunds 2006). Even the stocks of fish that do not depend on live coral cover declined in degraded areas.

A unique mix of fish species inhabit the reef, mangrove and lagoon ecosystems we studied. Almost half of the species run between these ecosystems for ontogenetic trophic reasons. The nesting aerial roots of mangroves support tropical coast fauna and flora, such as algae, sponges, molluscs (oysters). The fish shelter among the roots, in the calm nutrient-rich waters. Often, schools of fry attract predators. Juvenile fish migrate from mangroves to nearby reefs as they grow (Harborne et al. 2006). Recent studies (Barbier 2012) showed mangroves on the seaward edge had significantly higher average fish density than did mangroves 30–50 metres or more inshore. There were no fish more than 50 metres inshore from the sea.

NURSERY HABITATS

Nursery habitats provide critical living space for eggs, larvae, juveniles, and sub-adults of most coastal and pelagic marine species. They provide food, shelter, space, and pathways to and from the site to other adult habitats of the species. There are many types of nursery areas. They include estuaries, shallow banks, mangroves, coastal forests and wetlands, seagrass beds, coral and rock reefs, seamounts, and even static portions of the oceans such as the Sargasso Sea.

A nursery habitat is valuable to a species only if it is accessible. Eggs, larvae, and young rely largely on currents to deposit them in nursery areas. Current flows facilitate dispersal to and from the nursery site while at the same time boundary currents allow for larval retention. Once there, young must be able to stay and grow—thus nurseries are relatively static areas able to retain larvae and young until they grow large enough to leave the site on their own. From the nursery site, organisms (such as fish, sea turtles, marine mammals and invertebrates) must also have access to adult habitats (or other nursery habitats for other non-adult life stages).

Nursery sites provide food through nutrient loading and prey availability. They must provide plant life (phytoplankton, algae, and macroalgae) for primary consumers, and supply prey carnivorous and omnivorous species. Estuaries, seagrass beds, mangroves, and other marine nurseries have high productivity. Nutrients come from outside the site via rivers, run-off, currents, and upwelling. Nursery habitats that can produce food onsite retain many nutrients through efficient recycling. The wide availability of nutrients in turn fosters blooms of copepods and other prey species.

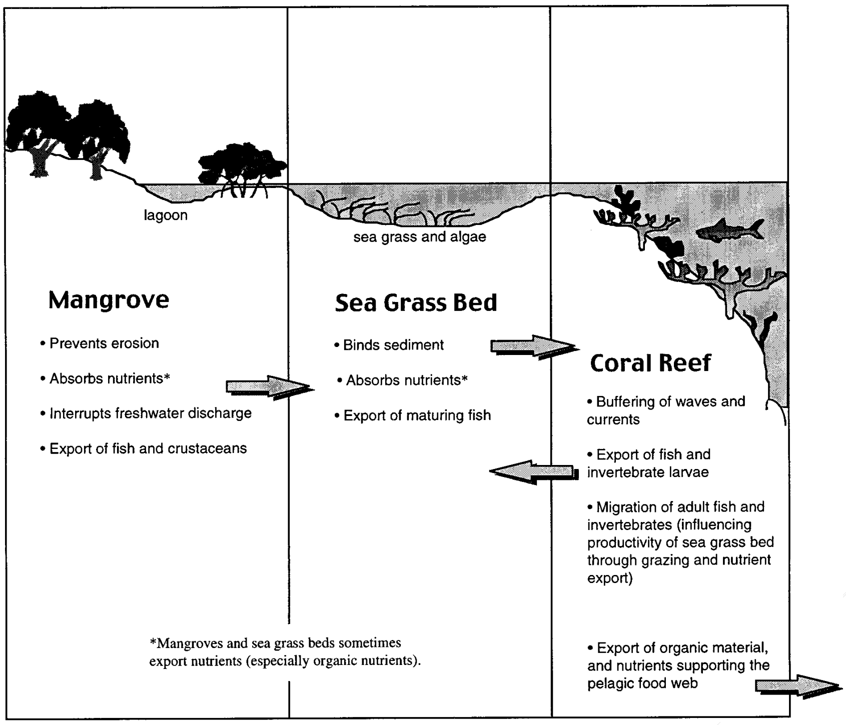
Nursery habitats are physically complex places and spacially heterogeneous. They provide many hiding places that make them suitable as refuges from predators. Survival is significantly higher in areas with reduced predation than it would be in the open ocean. Some nurseries simply provide a different habitat that predators do not generally venture into (e.g. areas with shallow, calm waters or low salinity).

Nurseries provide also the space needed for maintaining optimal densities of individuals. Most marine organisms are highly fecund—producing a lot of young to offset the natural mortality caused by predation, including human fishing pressure. Vast numbers of eggs and young from many different species find their way to nursery areas, and once there they need space to grow.

CONNECTIVITY

In the marine environment, water connects all habitats (figure A5). Currents and mobile organisms themselves link habitats such as coral reefs, nursery areas, and places organisms move to feed or breed.

Figure A5: Interactions in the tropical seascape—the connections between mangroves, seagrass beds and coral reefs



Source: Moberg and Folke 1999.

Scientific literature estimates connectivity for fishing via the production function (PF); specifically, it measures the changes in consumer and producer surpluses resulting from the marketed catch. Standard coastal habitat-fishery PF models use the wetland area as a proxy for the productivity contribution of the nursery and habitat function. It is necessary to model how changes in the stock or biological population may affect the future flow of benefits. If the natural resource stock effects are not considered significant, then the environmental changes can be modelled as affecting only current harvest, prices and consumer and producer surpluses (i.e. a 'static model'). If the stock effects are significant, then a change in an ecological service will affect both current and future harvest and market outcomes (i.e. a 'dynamic model'). The ecological and economic data requirements for each PF model usually surpass the available data. The dynamic model, for example, relies on a logistic function for biological growth and a Schaefer production process for harvesting that requires estimating many variables and coefficients.

For our study, we considered all reef, seagrass and mangrove associated species caught by the coastal fisheries benefited to varying degrees from at least one of the important ecosystem processes (habitat complexity and nursery habitats).

VALUATION OF SUBSISTENCE FISHERY (ES1)

DEFINITION

Subsistence fishery (ES1) corresponds to noncommercial fishing where all catches are auto consumed, given or exchanged but no monetary transaction occurs. This definition also applies to recreational fishery (ES3) but it was non-existent in the studied sites. The fishery ceremonies for specific events or celebrations form part of the subsistence fishery; even if monetary transactions occurred, we included fish sold in the village during fundraising activities given the low price of fish (less than 10 per cent of the normal commercial price).

FORMULA

The estimates of catch volumes were based on:

$$A_{ie} = (\sum_{ie} f_i * cpue_i)$$

where:

f_i = fishery effort per fishing métier in hours of activity

$cpue_i$ = catch per unit of effort per fishing métier (i)

Subsistence fishery added value ($VA_{f\,mpa}$) was based on :

$$VA_{f\,mpa} = ((A_{ie}*s*Pr_e*p) - \sum_i CI_i)*b$$

where:

s = proportion of catches for subsistence fishery

Pr_e = protein equivalent content per family

p = price of basic replacement protein (euro/g)

CI_i = intermediary costs per fishery métier (i)

b = weight factor to correct for resource dependency

PROTEIN CONVERSION

We calculated the monetary valuation for ES1 in two steps. First, we estimated the protein equivalent of catches for the most representative species of fish, using the database developed by Ramseyer (2000) to convert the catch of fish to protein weight. We converted the weight of the catch of the principal families into protein weight (Pr_e), which we then transformed into the equivalent weight of a basic food. We chose canned tuna (in oil) as a very common and affordable product. The Vanuatu Statistics Office uses its market price as a reference in regular macroeconomic indicators. The price was relatively stable during the observed period and converted in euros/g of protein (p).

DATA COLLECTION METHODS

Second, we estimated and valued the effort associated with fishery. We applied several methods to collect fishery effort data:

1. logbooks completed by fishermen to determine fishing effort
2. interviews with fishermen (selected individuals or with group) to complete logbooks
3. regular monitoring of fish commercialization (with transporters)
4. analysis of the results about non-monetary incomes produced by the recent Household Incomes and Expenses Survey (HIES) conducted by the Vanuatu National Statistics Office.

FISHING EFFORT

We estimated fishery effort (f_i) per métier[22] via semi-structured questionnaires (annex 8) with a sample of active fishermen, which we supplemented with direct observations. The sample came from the most active fishermen and was updated regularly to reflect the variability of the subsistence fishing (Hickey 2008). The surveys depended on recent memory to improve the reliability of answers and had a very reduced number of questions: the number of trips, the approximate duration of trips in the last month (excluding Sundays) for crab collecting, gillnet and spear fishing, and the destination of their catches (sold or consumed). We directly observed the number of boats, fishing nets, spearguns etc.).

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[22] *For fishermen, a métier is an activity characterised either by using specific gear (handline, net, speargun etc.), or by targeting a specific species, or within a specific fishing zone.*

ANNUAL CATCH ESTIMATES

We estimated annual catches by multiplying fishery effort per métier (e.g. number of trips per year of net fishing) by the average catch per unit of effort (CPUE, e.g. average number of fish caught in a fishing trip). We estimated catches of reef fish and crabs for every village and converted them to their equivalent weight based on the results of previous fishery monitoring (Amos 2007; Kronen 2007; Pascal 2011). These estimates provided a range of average weights of reef catches per fishing métier: between 0.2 and 0.35 kilograms per fish for net fishing and handline fishing; and between 0.3 and 0.5 kilograms per fish for speargun fishing.

ADDED VALUE

We estimated the intermediary costs (CI_i) associated with the three main fishery métiers via interviews with fishermen. We used the methods described by several authors (Gillett and Lightfoot 2001; Kronen 2003; Kronen 2007) to account for all cost categories for coastal fishery métiers (motorized or not).

CORRECTING FACTOR FOR SUBSISTENCE FISHERY

One of the shortcomings of the economic approach is it considers all the benefits drawn from subsistence fishery activities as replaceable. However, we measured the benefit in protein weight, leaving aside many aspects of subsistence fishery:

- Subsistence fishery activity requires very little investment and training (SPREP 2007).
- Subsistence fishery contributes to social cohesion in villages because women work in the villages instead of seeking a cash income outside (Bensa and Freyss 1994).
- In some households, the protein obtained from fishery is non-replaceable (Pollnac et al. 2000).
- Fishery is a stable food source against future uncertainties and a way to spread alimentary risks (Johannes 2002).

To account for these benefits, we applied a weight-correcting factor (b) of 1.3 to the added value estimates (Laurents et al. 2013).

VALUATION OF COASTAL COMMERCIAL FISHERY (ES2)

DEFINITION

Commercial fishery (ES2) includes all captures of reef and mangrove fish and invertebrates sold for food or for shells. Fish included all species that spend at least one ontogenic life stage or trophic migration in the reefs and mangrove ecosystems. Food could be sold fresh or as prepared food.

FORMULA

We used the same method used for subsistence fishery to calculate the economic value of commercial fishery. First, we quantified the annual catches and then applied an economic valuation to the result, using the following formula:

$$VA_{fc\ mpa} = ((A_{ie} * (1-s) * pm) - \sum_i CI_i)$$

where:

pm = average market price for commercial catches

CI_i = intermediary costs per fishing métier and other related businesses (i)

A_{ie} = fishery catch volume (same as for subsistence fishery)

s = proportion of catches for subsistence fishery

FISHERY EFFORT

We used the same data collection methods as for subsistence fishery. There was no difference in the métiers or the target species except for trochus (*Trochus sp.*), which commercial fishermen collected to sell for their shells in the capital.

PRICE

Finfish and invertebrates are sold fresh or processed as either a main dish or as a complement. Commercialized fresh or prepared foods were valued based on their market price, which covered the added value generated by the reef fishery sector. The price of reef finfish is species specific and does not seem to fluctuate with supply or demand. We used intermediaries to collect the price for crabs.

When used as a complement in prepared food, we based the commercial value of fish on the final consumer price, adjusted for the estimated weight of fish used in the preparation.

ADDED VALUE

The commercial circuit for fresh fish is short. The fishermen have two options: sell directly to consumers (in the village or in the city) or to an intermediary who will sell in the city. Sales in the city can be made informally in some neighbourhoods or through the market place. We did not observe any direct sales of reef fish or crabs to consumers such as restaurants or fish retailers.

In the studied villages, all the intermediaries belong to the same village as fishermen. This limited the distribution of fishery benefits per actor to the village level. Intermediary costs per fishing métier were the same as for subsistence fishery. We also quantified the costs related to commercialization such as ice, transport, market place and labour costs.

DETAILS OF METHOD COMMON TO BOTH FISHERIES

ANNUAL EXTRAPOLATIONS

We adjusted observed results before extrapolating an annual result, to account for seasonal variations in fishing activity during the hot and wet season (which lasts from November to April). On the one hand, the higher temperatures mean fishermen can stay longer in the water and/or take more fishing trips. On the other hand, fishing activity is often correlated with the agriculture calendar, where the wet season corresponds to a weaker crop activity (Amos 2007).

We accounted for these two potential sources of bias by adjusting spear gun catches by a factor of 1.3 and gillnet catches by a factor of 1.2. We deduced these factors from a previous study (Mees and Anderson 1999) that surveyed a full year of effort for the same types of fishing gear.

MAXIMUM SUSTAINABLE YIELD CORRECTOR

We aggregated and reported the obtained catches for the fishing grounds area (in tonnes per year per square kilometre and compared the result with a reference maximum sustainable yield (MSY) value for reef fisheries. Previous studies proposed 5 tonnes per year per square kilometre of reef as the MSY for coral reef fisheries (Armada et al. 2009; Jennings and Polunin 1995; Mumby and Steneck 2008b; Munro 1984; Newton et al. 2007). We used a maximum catch of 5000 mud crabs for the whole zone as a very approximate and almost arbitrary reference (Villasmil and Mendoza 2001). For villages with yields above the MSY, we only included the yields under this level, to limit the valuation to sustainable activities only for coral reef fisheries and mud crabs.

PELAGIC AND DEEP SEA FISHERY

We decided not to value pelagic and deep sea fisheries. MPAs have very little effect on the benthic species of the continental shelf and offshore pelagic species. The only demonstrated effects would be the trophic exchange through export of reef fish species larvae from MPAs. These reef fish species larvae make up part of the diet of some noncoastal fish species. However, studies analysing stomach contents show the contribution is relatively low (5–10 per cent of the total diet) (Allain *et al.*, 2012).

VALUATION OF RECREATIONAL FISHERY (ES3)

DEFINITION

Recreational or sport fishery (ES3) corresponds to non-commercial fishery where all catches are auto consumed, given or exchanged but no monetary transaction occurs. As noted above, this activity also describes subsistence fishery (ES1), so we had to distinguish between the two activities.

Apart from the two extremes of fishery as an important source of nutritious food and fishery as a 100 per cent recreational activity (which may not depend on catches), there are several intermediate levels that can make can make it difficult to distinguish between the two fishery types. Recent studies showed a continuum between subsistence and recreational fishery, rather than classes with distinct boundaries. Gradients can be characterized by different variables:

Low number of food sources	↔	High number of food sources
Peri-urban dwellers	↔	Urban, rural dwellers
Large boat, motor	↔	Reef gleaning, foot

We tried to identify and classify fishing effort based on these variables.

Estimating recreational fishery involved assessing the notion of leisure. Recreational fishery differs from other commercial fishery or subsistence fishery because the satisfaction of fisherman is not based only on a catch or a financial benefit, but on wellbeing generated by a leisure activity. Uncles (1997) demonstrated this difference in a study on recreational fishery in Victoria (Australia); the average cost of fish caught by sport fishers was around US$120/kg, compared with the cost of purchasing fish ($US 5/kg on average).

To calculate producer surplus for ES3, we considered two aspects: (i) the value of fish catches if they were to be replaced by purchases on the commercial circuit (estimates of demand substitutability), and (ii) the added value generated by the boating industry connected to recreational fishery.

However, this method implied all recreational catches should be substituted by purchases of similar fish in different segments of the community. But, not all recreational fishing catches can be replaced with commercial fishing catches. We estimated an elasticity of demand factor for recreational fishermen who have access to a regular market of reef fish. This factor captures the proportion of catches from recreational fishing that would disappear if these people had to buy their catch. We estimated it based on information from various experts as well as from interviews with recreational fishermen.

The added value levels are the same as those of the commercial fishery.

NAUTICAL SECTOR LINKED TO RECREATIONAL FISHING

The recreational boating industry comprises (i) the cost of the boat, motor and equipment, and (ii) the boat's running costs. We estimated the value added contribution of recreational boating using the following method:

*VA = (number of boats registered in year n * the purchase price – intermediate costs) + (number of fishing trips * annual average expenditure per trip – intermediate costs)*

We estimated the value of the boat/motor/equipment industry based on an average purchase price per ship type (size and power) and equipment. We based the number of boats on annual registrations and imports (or manufacture) of hardware. We used various sources to estimate the number of annual trips (Merchant Navy, Customs statistics, surveys with existing users etc.).

We estimated running costs using information from the 2007 study by the French Ministry of Agriculture and Fisheries on recreational fishing (recreational and sports) at sea, adapted to the local context based on PPP (Heston et al. 2009), as well as local information about the price of port fees, marinas and insurance.

VALUATION OF WOOD EXTRACTIVE USES (ES4)

Wood extractive services (ES4) corresponds to wood extracted from the mangroves. We calculated producer surplus using the following method:

*VA = volume collected * final price – intermediate costs*

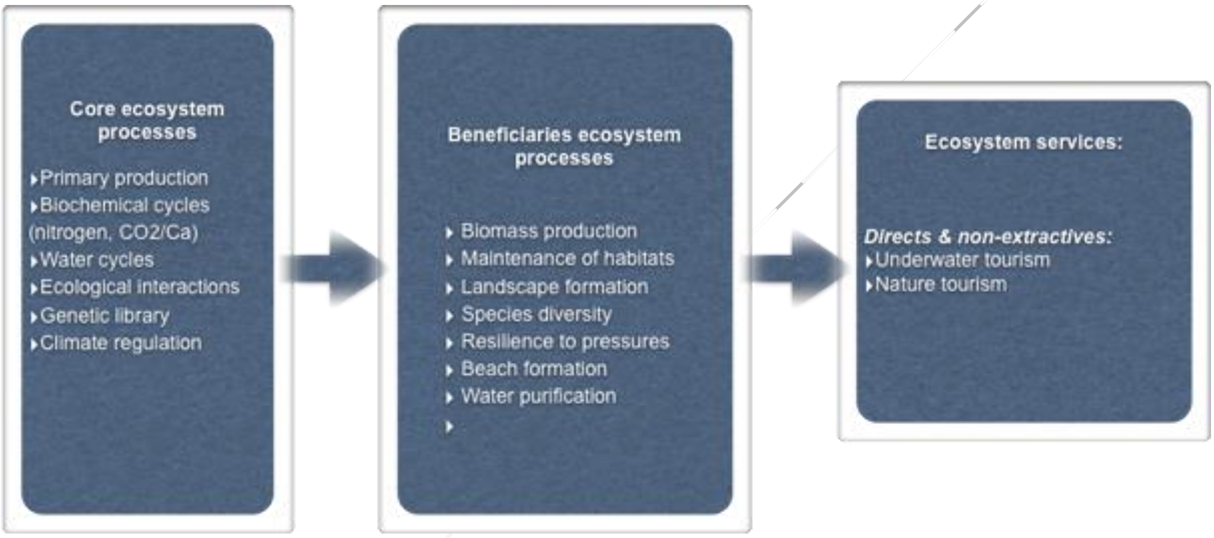
ANNEX 3 VALUATION OF TOURISM ACTIVITIES (ES5)

Tourism activities (ES5) correspond to water activities related to coral reefs and mangroves (including water taxis, day charters, guided tours, fishing charters and boat/kayak rentals), as well accommodation and food services (provided by guesthouses, resorts, restaurants etc.).

IMPLICATED ECOSYSTEM PROCESSES

Several processes are used to produce tourism services (figure A6).

Figure A6: Key ecosystem processes involved in tourism services



METHOD

We used industry producer surplus to value tourism activities.

TOURISM PRODUCER SURPLUS

To calculate the tourism producer surplus, we first valued the direct uses related to the mangroves (with or without service providers), based on information from the Business Expenditure Survey and interviews with relevant providers. Second, we valued indirect costs (accommodation, transportation, food etc.) associated with the direct uses by applying a calculated ecosystem-contributing factor.

COMMERCIAL ACTIVITIES

We quantified the value of commercial recreational activities that used one or more of the coral reef and mangrove ES, based on the fee the users paid to undertake the activity. We determined the number of visitors and then calculated the producer surplus for the activities using the following method:

*VA (by activity) = price * tourism frequentation – intermediate costs*

We included the following nautical tourism activities: water taxis, day charters, guided tours, fishing charters and boat/kayak rentals by the day or week. We interviewed business providers to understand users' motivations and practices.

We excluded uses that did not involve observations of mangrove animals or habitats.

ASSOCIATED TOURISM EXPENSES

We estimated associated tourism expenses using the following method:

*VA = contributing factor of ecosystems *associated tourism local expenditure – intermediate costs*

We identified three types of users of associated tourism local expenditures: non-resident tourists, residents and cruise passengers.

NONRESIDENT TOURISTS

We included international transport expenses and local expenditure, but excluded direct tourism expenditures (kayaking, guided tours etc.) to avoid double counting.

To meet the study's objective to isolate wealth creation for the country only, we removed all nonresident companies when calculating international transport expenses. That is, our calculations accounted for only international airlines with a locally-based parent company.

Local expenditure estimates included:

- accommodation (hotels, cottages etc.)
- restaurants, cafés and food
- local transportation (sea, air and land)
- souvenirs, gifts and other expenses (fuel, services connection etc.).

We estimated expenditures per person using:

- survey responses—We asked respondents to indicate the approximate they spent on different categories (based on a sampling protocol designed to ensure a 90 per cent and 95 per cent confidence interval according to the homogeneity of the target population). We compared the midpoint of each category to the average values to estimate the total expenditure on all categories and to avoid bias in the final estimates.
- existing studies—We used exit surveys from studies that investigated airport departures. We checked protocols and sampling to ensure the data was robust.

RESIDENT TOURISTS

Residents of the community may also undertake tourist activities in the reefs or mangroves, so we accounted for the accommodation, food and transport expenses they incurred. We used hotel occupancy studies to estimate the number of resident users and their costs. We also surveyed resident users to estimate some parameters.

CONTRIBUTION OF ECOSYSTEMS TO TOURISM

To estimate the economic impact of an ecosystem on tourism-related expenditures, we must determine the share of tourism expenditures directly attributable to the ecosystem. This is known as the contributing factor, and it reflects the importance of ecosystems in the choice of the tourism destination. However, it is not always possible to isolate a single attribute influencing tourists' destination selection process because tourists generally consider many attributes when selecting a destination (figures A7 and A8). Different authors identified almost 30 attributes involved in selecting a site, including accessibility, price, infrastructure, security, cultural atmosphere, hospitality, recreational activities proposed etc (Parry and McElroy 2009; Tourism and Transport Consult 2005).

Figure A7: Factors influencing tourism satisfaction

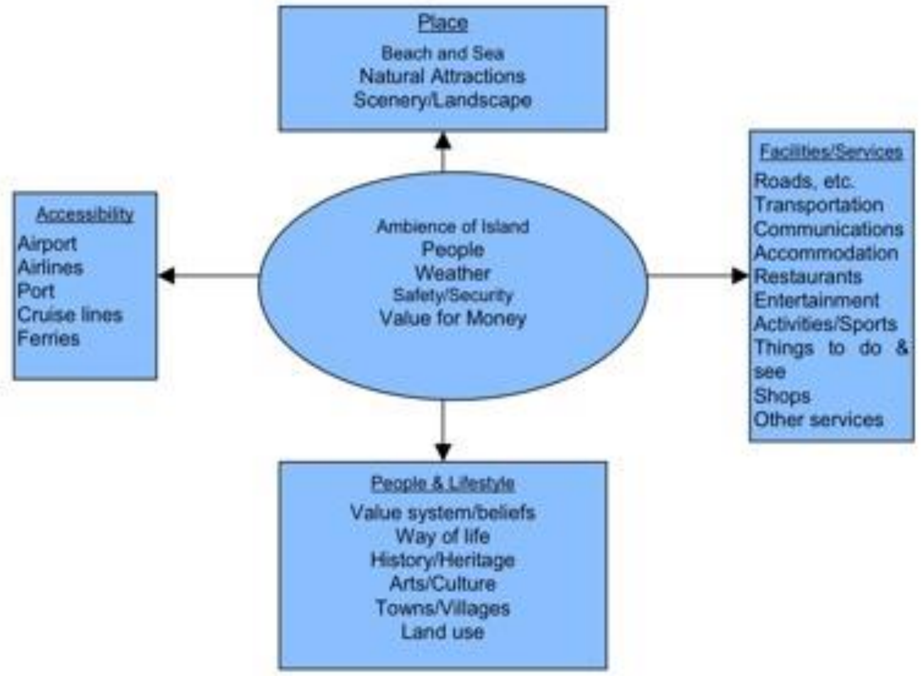
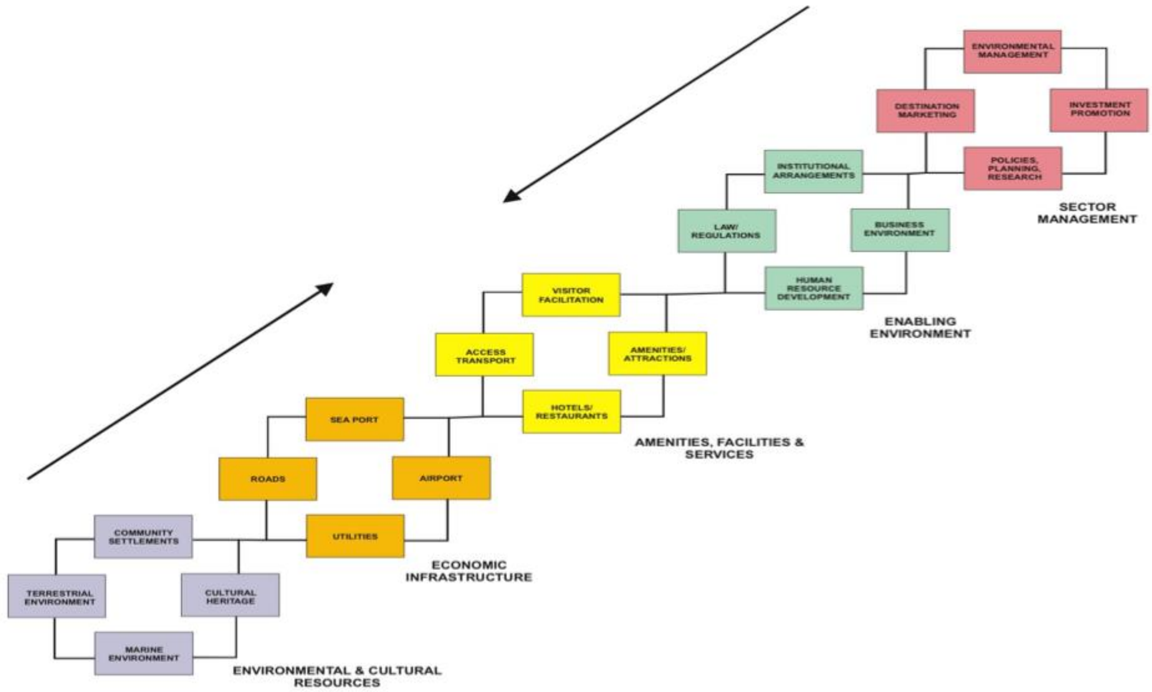


Figure A8: Factors influencing the tourism choice of destination

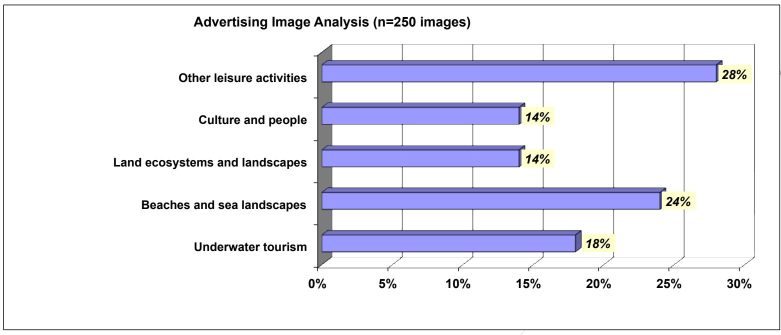


We calculated the contributing factor using the analysis of advertising images (AIA) method originally described by Hajkowicz et al. (2005). It is based on the existing tourism advertising media (mainly print and online) tourists were aware of before they arrived. The advertisements are designed with a specific target and aim to arouse the recipient's desire to acquire the service promoted.

We examined at least 200 media products to determine the proportion of images and keywords related to:

- culture and people
- ecosystems and landscapes
- beaches
- recreational underwater coral and marine biodiversity
- other forms of entertainment (figure A9).

Figure A9: Illustration of the technique of analysis of advertising images for coral reefs



VISITOR SEGMENTATION

We segmented visitors into three categories, based on annual figures. Our goal was to produce populations as homogeneous as possible so we could best apply contributing factors. We then applied AIA matrix variables of mangrove contribution to the expenditures of each category of users or tourists.

Category 1 comprised visitors (all categories combined) who would not have come to the community if ecosystems were not in their current state. Their purpose may be specialized nature trips, hunting or photography, for example. The mangrove contribution variable equalled 1 for this group, which meant we included all associated expenditures.

Category 2 comprised visitors who came to the site for several reasons, but used some mangrove ES. The mangrove contribution variable equalled XX for this group, which meant we included XX per cent of all associated expenditures.

Category 3 comprised visitors who did not use any mangrove ES. We excluded expenditures by these visitors.

ANNEX 4 VALUATION OF COASTAL PROTECTION AGAINST FLOOD (ES6)

Coastal protection against flood (ES6) corresponds to mangroves role as a natural barriers against coastal flooding.

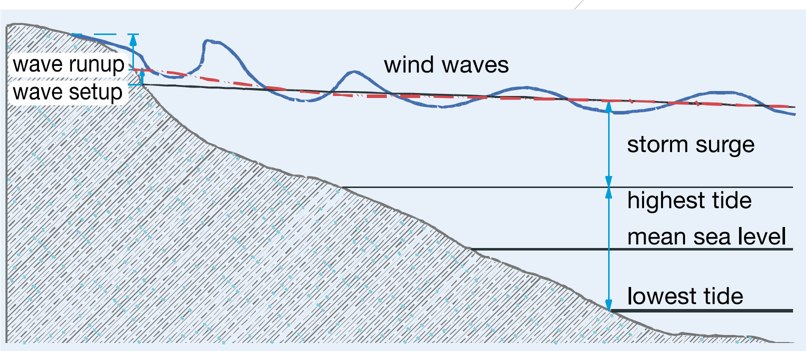
IMPLICATED ECOSYSTEM PROCESSES

WAVE ENERGY ABSORPTION

Coral reefs and mangroves limit coastal erosion by absorbing 70–90 per cent of wave energy (Kench and Brander 2009) and lessen the damage of severe weather events (hurricanes, tropical storms etc.) that cause most storm surges (UNEP-WCMC 2006). Storm surges can interact with other ocean processes such as tides and waves to further increase coastal sea levels and flooding. A storm surge will have maximum impact if it coincides with high tide (figure A10).

Breaking waves at the coast can also produce an increase in coastal sea levels, known as wave setup. Storm surges occurring on higher mean sea levels enable inundation and damaging waves to penetrate further inland. This increases flooding, erosion and damage to built infrastructure and natural ecosystems.

Figure A10: Storm surges, tides and wave setup



Source: CSIRO and Australian Bureau of Meteorology 2007.

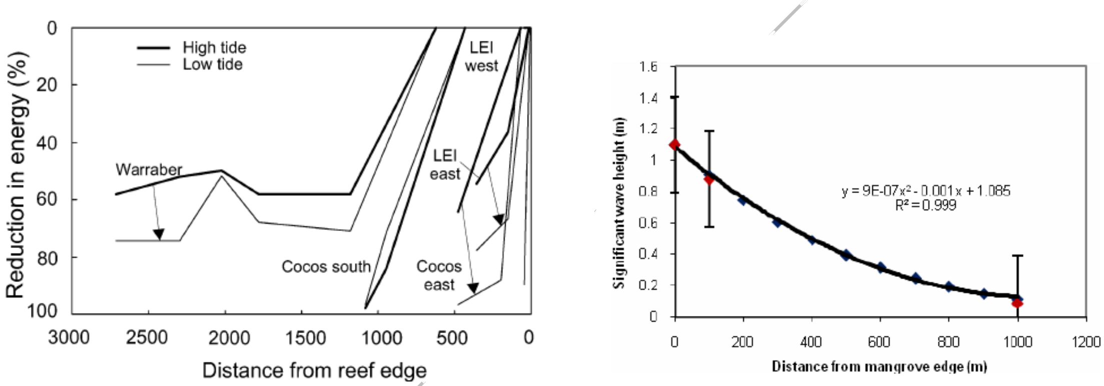
The shape of the sea floor and the proximity to bays, headlands and islands also affect the storm surge height. Wide and gently sloping continental shelves amplify the storm surge, and bays and channels can funnel and increase the storm surge height.

The climate change effect of rising mean sea levels will be felt most profoundly during extreme storm conditions.

Coral reefs and mangroves protect against waves by forming barriers along the costal line. Similarly, lagoon areas protected by barrier reefs are generally quiet areas, because the reefs act like wave breakers or shallow coast (Brander et al. 2004; Kench and Brander 2009; Lugo-Fernandez et al. 1998). They constrain ocean swell, transforming wave characteristics and attenuating wave energy. Waves formed by the wind have much of their energy at the surface. The fringing reef and the reef crest can absorb much of this force, sometimes up to 90 per cent at low tide (Lugo-Fernandez et al. 1998).

However, it is difficult to quantify this ecosystem service. First, the results for some Caribbean reefs demonstrated the level of protection varies, depending on the type of reef, the depth and the waves (Kench and Brander 2009) (figure A11). Second, it is difficult to isolate the effects of coral reefs and mangroves from other variables, such as bathymetry, geomorphology, topography and the biological cover (Burke 2004). Few studies focused on isolating the contributory role of the reef in this combination of factors (Barbier et al. 2008).

Figure A11: Reef as wave energy absorber (left) and effects of mangroves on wave height (right)



Sources: Kench and Brander 2009 (left); Barbier et al. 2008 (right).

Third, Barbier et al. (2008) found a nonlinear relationship between reef area and the absorption process. Specifically, this study found waves of 1.1metres in the sea were reduced to 0.91 metres along the mangrove forest if the forest extended 100 metres inland. The wave continued to decline, albeit at a slower rate, for each additional 100 metres the mangroves extended inland. A forest extending 1000 metres inland reduced the waves to a negligible 0.12 m.

Seagrasses, composed of four major families of plants (*Zosteraceae*, *Posidoniaceae*, *Cymodoceaceae* and *Hydrocharitacea*), also protect coastal areas, forming extensive meadows. They stabilise sedimentary substrates, their leaves slow currents by increasing the viscosity of water and they decrease the energy dissipated by the waves (by up to –40 per cent of erosive energy when meadows are dense (Barbier et al. 2011). They also increase the sedimentation rates; the roots and rhizomes capture the material they grow in (Pearson 2001).

Das and Vincent (2009) assessed the storm protection role of mangroves, using data on human casualties, damages to houses, and livestock losses suffered in the Kendrapada district in Orissa state during the super cyclone of October 1999. The analysis incorporated meteorological, geophysical and socioeconomic factors to isolate the impact of mangrove vegetation on cyclone damage. The results indicated the mangroves significantly reduced human death and seemed more effective in saving lives (both human as well as animals) than in reducing damage to static property (Vishwanathan et al. 2004). Other factors like land elevation, immovable asset holdings etc. also affected human casualties in the storm surge affected areas. Further analysis by Das (2009) revealed if the mangrove cover had remained at its 1950s' level, the area would not have suffered any fully collapsed houses. The study suggested mangrove forests provided protection benefits to houses of US$23 233 per kilometre width of forests.

Barbier (2007b) used a count data model[23] based on EM-DAT (2005) data to show a change in mangrove area significantly increased the incidence of coastal natural disasters in Thailand. Specifically, the results showed a decline in mangrove area between 1979 and 1996 increased the expected number of disasters affecting Thailand's coastal provinces. It estimated the marginal effect of a 1 km^2 loss of mangrove area increased expected storm damages by around US$585 000 per km^2.

A study estimated the average annual direct loss caused by tropical cyclones in 15 South Pacific countries varied from US$2 million to US$80 million (2009 prices) with 60 per cent of damages coming from loss on buildings, 30 per cent from cash crops and 10 per cent from infrastructure (PCRAFI 2011b).

ROLE AGAINST TSUNAMI WAVES

Tsunami waves are different from wind-originated waves; a tsunami wave is much larger and its energy is distributed throughout the water column.

Some studies suggested reefs and mangroves can protect against tsunami waves (Das and Vincent 2009; UNEP-WCMC 2006). Knott (1997) showed tsunami waves on the Great Barrier Reef travelled only through the channels. Evidence from the 12 Indian Ocean countries affected by the 2004 tsunami disaster, including Thailand, suggested coastal areas with dense and healthy mangrove forests suffered fewer losses and less damage to property than those areas where mangroves were degraded or converted to

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[23] *In economics, count data models have been used to explain a variety of phenomenon, such as explaining successful patents derived from firm R&D expenditures, accident rates, disease incidence, crime rates and recreational visits (see Barbier 2007b for more details). Count data models could be used to estimate whether the presence of an ecosystem affects the expected incidence of economically damaging storm events.*

other land uses. Tree density seems to explain how mangroves reduce tsunami threats. (See Barbier 2007a for more information.[24])

By contrast, other studies did not find clear correlations between mangrove cover and tsunami risk reduction (Done et al. 1996; Pérez-Maqueo et al. 2007; SOPAC 2008). These studies found reefs and mangroves may be not the main factors reducing damage on the coast. Rather, other factors mitigated tsunami waves; for example, areas were off the wave's main path, or they were close to deep zones that already greatly reduced the wave's effect. Other key explanatory factors were coastal bathymetry and the coast's geomorphic profile (Burke 2004).

METHOD

We used the avoided damages method[25] to estimate the value of ES5. Burke et al. (2008) and Pascal (2010) used a similar method to value coral reef ES in Caribbean and New Caledonian reefs respectively. One of the main challenges for valuing this ES is that coastal protection against waves is a complex process involving many factors such as geomorphologic patterns of the coast, the presence of other ecosystems etc. Identifying the contributing role of each factor is a challenging task and is out of the scope of this study.

The general model is:

A. Identify coastal areas potentially at risk from coastal flooding events.

B. Determine the contribution of coral reefs, mangroves and seagrass in the coastal protection of the vulnerable areas.

C. Quantify and value the potential damage repair costs using damage avoided costs:

C.1. Characterise the assets exposed to risk (into three categories of land use).

[24] *Given the overwhelming evidence of the storm protection service provided by intact and healthy mangrove systems, there has been increased emphasis on replanting degraded and deforested mangrove areas in since the 2004 tsunami disaster. The Indonesian Minister for Forestry, for example, announced plans to reforest 600 000 hectares of depleted mangrove forest throughout the nation over the next five years. The governments of Sri Lanka and Thailand also stated publicly intentions to rehabilitate and replant man- grove areas (UNEP 2005; Harakunarak and Aksornkoae 2005).*

[25] *This method assesses the damage costs avoided by the presence of the ecosystems. It is a special category of 'valuing' the environment as an 'input'; it assumes the value of an asset that yields a benefit in terms of reducing the probability and severity of some economic damage is measured by the reduction in the expected damage (Barbier 2007b).*

C.2. Value the total repair costs of direct and indirect tangible damages based on approximate values per land use category (object oriented data) and as a function of inundation depth (relative depth damage function).

C.3. Estimate the probability of flood event per impact category.

A. IDENTIFY COASTAL AREAS POTENTIALLY AT FLOOD RISK AGAINST THE REGIME OF OCEAN WAVES

Coastal flooding can occur during severe weather conditions that generate 'storm surges' (elevations in sea level in low pressure situations (hurricanes)) and cyclone swells (DEAL 2012). The European Commission issued Directive 2007/60/EC on assessing and managing flood risks (more commonly known as Directive 'Floods'), the first European directive in the field of risk prevention. It was transposed into French law via Article 212 of the Law of 12 July 2010 on the National Commitment to the Environment (known as Grenelle II). Decree No. 2011-227 of 2 March 2011 on assessing and managing flood risks complements these provisions.

We focused on the coastal land zone with an altitude of 0–5 metres above the high tide sea level because a storm surge will have maximum impact if it coincides with high tide. We used historical data showing the maximum height of non-tsunami waves in the tropical regions over the past 25 years (NOAA; Meteo France and Vanuatu Meteorological Office).

We used GIS topographic data from the following sources to project potential impacts of flood events:

- SOPAC Vanuatu and Fiji maps of infrastructure and buildings
- Government of Vanuatu 1:50 000 cartographic maps of coral reefs, mangroves, bathymetry and topography
- Vanuatu National Statement on Vulnerability and Adaptation (Rarua, *et al.,* 1998)
- Aerial photographs from PlanetObserver (satellite images), Institut National de l'Information Géographique et Forestière, Centre National d'Études Spatiales (CNES), Astrium
- SHOM (Service Hydrographique et Océanographique de la Marine) marine maps from 1:8 000 to 1:8 725 000 with bathymetry.

The areas vulnerable to the flood impacts of waves and swell were all below the maximum height relative to the sea level at low tide and up to 1 kilometre inland (Kench and Brander 2009; Das and Vincent 2009).

We used a depth damage function (discussed further below) that accounted for depth and area. These are the most frequently used parameters to evaluate flood risk and damage (Torterotot 1993). Some analyses showed depth explained little of the variation in damages, with factors such as duration, time of occurrence, velocity and the toxicological load of flooding water also potentially contributing to damages(Messner et al. 2007) (table A2). However these other flood characteristics are not routinely recorded, so it is difficult to quantify their influence.

Table A2: Damages influencing flood characteristics

		Measurement	
		Tangible	**Intangible**
Form of damage	**Direct**	Physical damage to assets: - buildings - contents - infrastructure	- Loss of life - health effects - Loss of ecological goods
	Indirect	- Loss of industrial production - Traffic disruption - emergency costs	- Inconvenience of post-flood recovery - Increased vulnerability of survivors

B. DETERMINE CONTRIBUTION OF ECOSYSTEMS TO COASTAL PROTECTION

CONTRIBUTION OF CORAL REEFS

Different working groups from the Institute of Marine Affairs (IMA) and the University of New Caledonia (UNC) developed models of factors that categorize the level of coastal protection in various contexts (Burke et al. 2008).

Coastal stability is defined as an index of coastal protection that incorporates up to 10 physical characteristics. The index estimates the erosion resistance of each segment of coastline. Physical characteristics can include:

- coastal geomorphology (a limestone cliff, beach etc.) and coastal geology (igneous, metamorphic etc.)
- exposure of the coast (protected by a breakwater or riprap, or exposed)
- characteristics of coral reefs (reef type, area and distance to the coast)
- slope of the platform (metres)
- inner slope and crest width (metres)
- mean depth between the reef and the coast
- presence of activities causing erosion, such as sand extraction
- coastal vegetation (mangroves, wetlands etc.).

We allocated these physical characteristics a value between 1 (no influence) and 5 (very strong influence) and calculated the average to produce a unique index value for each shore: the coastal protection index (CPI). We then calculated the relative contribution of reefs in the CPI.

We adapted this method to the context of each geomorphological site and available data. The UNC considered the CPI must incorporate at least five factors to ensure the results are robust (Allenbach pers. comm.). Table A3 summarises the physical characteristics we included. When local data were not available, we simplified the model.

Table A3: Physical characteristics used in the coastal protection index

	Very strong	Strong	Medium	Low	None
	5	4	3	2	1
Geomorphology	Rocky shore	Mix of rocks/sediments/mangroves	Mangroves	Sediments	Beaches
Coastal exposure	Protected bay	Semi-protected bay	Artificial reefs	Low protected bay or coast	No protection
Reef morphology, area and distance to the coast	Continuous barrier (>80%) close to the coast (<1km)	Continuous barrier (>50%), patch reef, close to the coast (<1km)	Fringing reef (width >100 m)	Coral formation discontinuous	No reef
Inner slope, crest width	Very favorable conditions (gentle slope, large crest width)	Favorable conditions (slope, large crest width)	Favorable conditions (at least one component: slope, crest width)	Reduced favorable conditions (strong slope, reduced crest width)	None
Platform slope	6-10%	2.5-6%	1.1-2.5%	0.4-1.1%	< 0.4%
Mean depth (<1 km from the coastline)	> 30m	> 10 m	> 5m	< 5m	< 5m
Other ecosystems	mangroves, seagrass > 75% coastline	mangroves, seagrass > 50% coastline	mangroves, seagrass > 25% coastline	mangroves, seagrass <25% coastline, sand extraction areas	None

Source: Developed by Allenbach and Pascal.

CONTRIBUTION OF MANGROVES

The mangrove is a unique ecosystem of the intertidal zone that can adapt to extreme conditions (Walters et al. 2008). As discussed above, mangroves reduce the effect of storm-induced waves less than 6 metres high, and the wave height decreases nonlinearly for each 100 metres that a mangrove forest extends out to sea, regardless of the mangrove species, the tide level and coastal geology (Barbier 2012; Gedan et al. 2011; Koch et al. 2009).

In cases where coral reefs were not present, we assessed the role of mangroves in a small number of settings that were accessible and quantifiable from readily available cartographic and imagery. Specifically, we identified the:

1. coastline concerned
2. mangrove area and species cover
3. width of the coastal zone concerned
4. evolution of colonized areas (stability, gain, reduction).

To estimate a monetary value, we quantified the role of mangrove protection against erosion (except from tsunamis that escape from normal quantification) schematically based on the width of the area colonized by mangroves:

- Low—less than 100 metres
- Average—100 to 500 metres
- High—more than 500 metres.

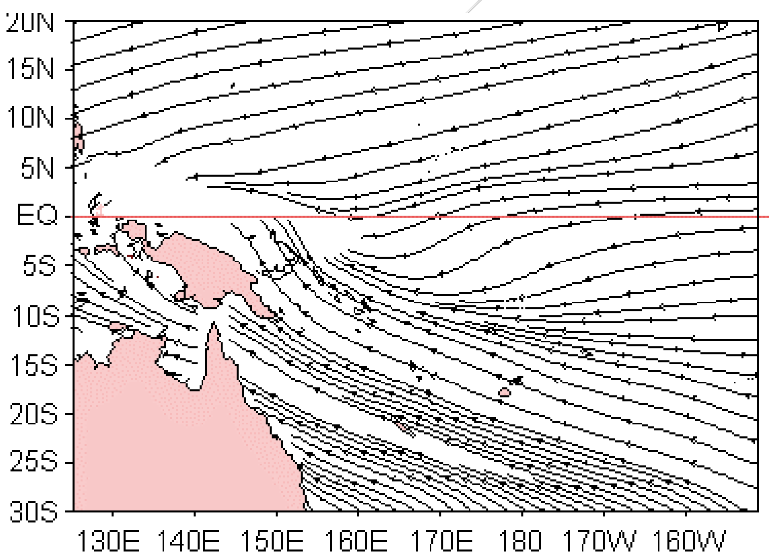
We accounted for the following factors if data were available: width of forest, slope of forest floor, forest density, tree diameter and height, proportion of aboveground biomass in the roots, soil texture, and forest location (open coast vs. lagoon) (Alongi 2008; Barbier et al. 2011).

We also accounted for the role of the other neighbour ecosystems.

MAIN CLIMATE CONTEXT

The Streamlines of Mean Surface Wind (figure A12) shows easterly trade winds dominate the region. In the southern hemisphere, the trades blow to the northwest while in the northern hemisphere they blow to the southwest. The streamlines converge, or crowd together, along the South Pacific convergence zone (SPCZ). The southeast asian monsoon also influences much of the Melanesian subregion (Siméoni and Lebot 2012).

Figure A12: Streamlines of mean surface wind



Source: SOPAC 2006.

Strength and timing varies considerably, but at Manus Island (Papua New Guinea), for example, the north west monsoon season (winds from the northwest) runs from November to March, while the south east monsoon brings wind (also known as the southeast trade winds) from May to October. Unlike many monsoon-dominated areas, rainfall is distributed evenly throughout the year (in normal years) (SOPAC 2006)

Vanuatu is located south of the equator in an area where tropical cyclones frequently occur between October and May, bringing damaging winds, rains and storm surge. In the South Pacific region from the equator to New Zealand in latitude and from Indonesia to east of Hawaii in longitude, almost 1000 tropical cyclones with hurricane-force winds spawned in the last 60 years, with an average of about 16 tropical storms per year (PCRAFI 2011a).

For Vanuatu, the report stated:

> *Since 1990 Vanuatu has been subject to at least 20 damaging tropical cyclones. The most significant cyclones in recent years were Uma in 1987 and Ivy in 2004, each affecting nearly 50 000 people and causing destruction that amounted to losses in the tens to hundreds of million USD. [Figures show] the levels of wind speed due to tropical cyclones that have about a 40 per cent chance to be exceeded at least once in the next 50 years (100-year mean return period). These wind speeds, if they were to occur, are capable of generating severe damage to buildings, infrastructure and crops with consequent large economic losses. A number of destructive tropical cyclones have passed near Vanuatu in the last 25 years. Three in particular have come close enough to Port Vila to be recorded as very low pressures. TC Prema on 29 March 1993, TC Paula (Category 3) on 2 March 2001 and TC Ivy (Category 4) on 26 February 2004 have all caused considerable damage.*

McKenzie et al. (2005) documented the extent of cyclone damage in Vanuatu:

> *Disaster impact assessments in Vanuatu principally focus on the impacts of cyclones, and related flooding and landslides. The most comprehensive impact assessment in Vanuatu was conducted for Cyclone Ivy, which struck the country in February 2004. The total cost of Cyclone Ivy was estimated at Vt427.6 million. Cyclone Ivy affected 50 000 people, and caused one fatality. In the affected communities, 90 per cent of the water sources and water supply systems, 70 per cent of roads, 60 per cent of health infrastructure, 112 schools, and over 80 per cent of food crops were damaged.*

Table A4 shows the number of extreme events since 1940 per category. Figure A13 tracks the category and course of tropical storms and cyclones around Fiji and Vanuatu over the past 70 years.

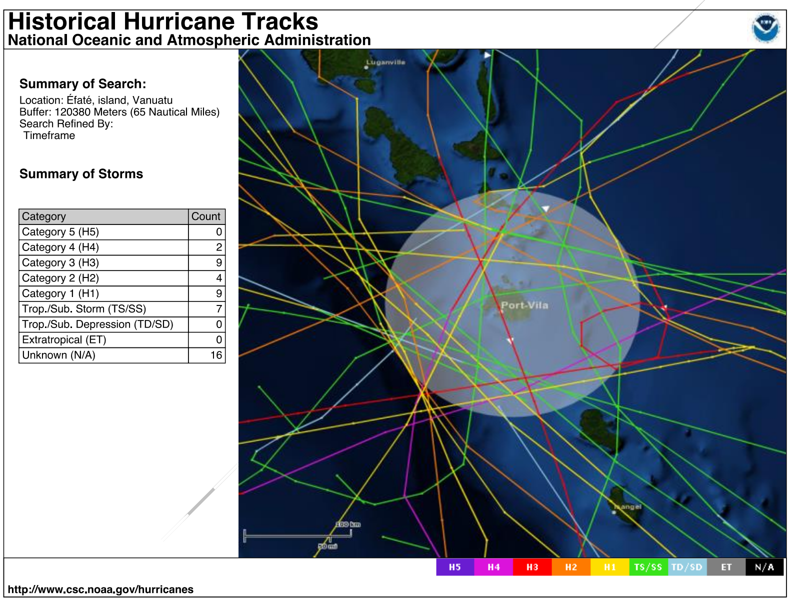
Table A4: Count of extreme climatic events in Fiji and Vanuatu since 1940

Vanuatu

Category	Count
Category 5 (H5)	0
Category 4 (H4)	2
Category 3 (H3)	9
Category 2 (H2)	4
Category 1 (H1)	9
Trop./Sub. Storm (TS/SS)	7
Trop./Sub. Depression (TD/SD)	0
Extratropical (ET)	0
Unknown (N/A)	

Source: National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center , Historical Hurricane Tracks.

Figure A13: Historical hurricane tracks for Efate, Vanuatu over 70 years



Source: National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center , Historical Hurricane Tracks.

C. VALUE THE POTENTIAL COSTS

After defining the hazard by flood characteristics it is necessary to find out who or what is exposed to this hazard. More precisely, we needed information about the number, location and type of elements at risk, as well as their value and their susceptibility against flooding.

Valuing potential costs comprised three steps, based on the method used in several reports (PCRAFI 2011b; Bolt et al. 2005; Messner et al. 2007; Pagiola 2004a, 2004b):

- Characterise the assets exposed to risk (into three categories of land use)
- Value the total repair costs of direct and indirect tangible damages based on approximate values per land use category
- Apply the relative depth damage function showing the damaged share of the total value as a function of inundation depth.

The approaches produce approximate estimates, mostly for examining large areas or for developing quick overviews.

C.1. EXPOSURE TO RISK

First, we characterised the assets and the distribution of population exposed to flood risk[26]. We identified several categories of damages from flood events (table A5).

Table A5: Typology of flood damages

Inundation characteristics	Relevance
Area	Determines which elements at risk will be affected
Depth	Has perhaps the strongest influence on the amount of damage
Duration	Special influence on damages to building fabric
Velocity	Only high velocities will lead to increased damages; therefore mainly relevant in flash flood areas or areas near dike breaches
Rise rate	Influence on damage reducing effects of warnings and evacuation
Time of occurrence	Especially important for agricultural products
Contaminations	Contaminations and loads may increase damages significantly
Salt-/freshwater	Saltwater may increase damages; relevant in coastal areas

Source: Messner et al. 2007.

Given the macro scale of our study and our purpose of reflecting a minimum valuation, we focused on direct damages[27] (buildings, infrastructure and crops) and indirect tangible damages (emergency costs and the loss of tourism industry revenues). Direct damages are described below.

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[26] *Direct damage from direct contact with water.*

[27] *Direct tangible damage can include more categories (inventories, cars etc.). However, some damage categories—especially buildings—usually dominate the total amount of damage. Therefore, it can be reasonable to include only the most important damage categories to reduce the effort of the study.*

Buildings—The building exposure included residential, commercial, public, and industrial buildings. We created a database with building quantification, replacement cost and simplified structural characteristics that affect the vulnerability to natural perils for the zone at risk. Data resolution and accuracy varied, especially in urban areas. We used a mix of object oriented data and aggregated land use data. The first uses data about single properties or buildings to estimate damage via property-by-property valuation techniques (Penning-Rowsell et al. 2003). The second aggregates properties and buildings in areas of more or less homogeneous land use. Most data was secondary: address-point data (where each property is represented by a point in a map) and cadastral map data (which also gives information on ground floor area of properties). We verified some data via field observations, generally in in areas that had a variety of building types and usage with more costly structures.

Infrastructure—We estimated the infrastructure exposure using similar techniques as those used for buildings. Infrastructure comprised a detailed and extensive inventory of major assets, such as airports, ports, power plants, dams, major roads and bridges.

Crops—We derived the spatial distribution of major commercial crops from medium resolution satellite imagery. We validated results by ground 'truthing' to the extent possible. We also validated data against agricultural census data and feedback from local experts.

We analysed a GIS-based population database (when available) to geographically identify the population most at risk in each site. This database, compiled from data sets from the Vanuatu National Statistics Office and the World Bank, provided population counts within the main administrative boundaries.

C.2 VALUATION OF REPAIR COSTS

Repair costs reflect the construction costs needed to repair or replace the damaged assets. We collected the repair cost values for different buildings and infrastructure from a variety of sources, including construction cost management firms, government reports, interviews with local experts and historical disaster reports. We measured the potential damages on the constructed areas using average construction costs to replace damages assets. We estimated average surface per house from official and real estate sources, based on three types of structures: single-storey timber, masonry/concrete, and traditional-style buildings. For infrastructure assets, we derived construction costs from official statistics, special publications and the responsible offices.

Using repair costs to value storm damage ensures the estimates are not influenced by site-specific costs (such as real estate price fluctuations), which can affect valuations based on asset appraisals. Further, asset appraisals overestimate the economic costs of damage, because they do not account for depreciation and they assume replacement with a new asset. Ideally, asset appraisals should use depreciated values to reflect the value of a good at the time it is damaged by a flood.

We derived the damages for cash crops from the loss in gross profit from crop production. Data came from local governments and/or official annual rental costs of croplands. What is lost is the real economic value of the crops minus the variable costs avoided because the crop was destroyed e.g. harvesting, drying the crop. We did not consider any permanent reduction in the value of agricultural output.

We categorised all buildings, infrastructure and crop assets into groups of similar vulnerability to tropical cyclones.

We also estimated costs for the following:

- Population impacts—We estimated population impacts using models developed to estimate the number of casualties caused by each type of event. The tropical cyclone model for the South Pacific, for example, predicts the number of casualties as a function of the total economic losses, which are used as a proxy for the number of damaged buildings.
- Indirect tangible damage—When data were available, we estimated the damage from:
  - Loss of tourism revenues—We tested earnings per room (a common ratio in the hotel industry) as a reference value for lost earnings over a two-year time period.
  - Emergency costs—These included removing debris, setting up shelters for those made homeless and supplying medicine and food (Messner et al. 2007; PCRAFI 2011b). We estimated these emergency costs as a fraction of direct losses. Previous studies showed 'average' emergency costs were 23 per cent of the direct losses suffered by residential dwellings, commercial establishments, public buildings, schools, and hospitals from tropical cyclones and flood (Bolt et al. 2005; Pagiola 2004a; PCRAFI 2011b).

DAMAGE FUNCTIONS

We derived the vulnerability of different types of buildings, infrastructure assets, and crops from damage functions. Damage functions estimate the loss that is expected when an asset is subject to different levels of storm intensity; the loss is usually expressed as a percentage of the asset's replacement cost. They show either the damaged share (referred to as relative damage functions) or the absolute monetary amount of damages per property or square metre (referred to as absolute damage functions) of elements at risk, as a function of the magnitude of inundation. As noted above, most models use depth damage functions, which are based on inundation depth. Models rarely account for other parameters like velocity, duration and time of occurrence (Messner et al. 2007).

We used two prominent damage databases: the UK Flood Hazard Research Centre database and the German HOWAS database. HOWAS 21 is a property-specific flood damage database for Germany. In addition to the monetary damage incurred for residential buildings, furnishings, businesses and other premises, HOWAS 21 contains data on the impact of an event on a property, on the damaged property itself and on damage minimisation. The database was developed in cooperation with the Helmholtz EOS networking platform for natural disasters (NaDiNe). Our data fairly represented the typical damage that might be expected for selected flood events. Attempts to improve the database of properties in other locations did not noticeably change the weighted distribution function (DEAL 2012; Eleuterio et al. 2011; Messner et al. 2007).

In summary, our model assumed:

- a damage function of 35 per cent for villages, which comprised a mix of houses with traditional materials and houses with concrete walls
- each household comprised five persons
- the average cost of a traditional house was US$6000
- the average cost of a cement house ranged from US$15 000 to US$19 000
- a damage function of 20 per cent for resort buildings (pers. obsev.).

C.3. PROBABILITY OF THE HAZARD EVENT

The last step is to calculate the probability of the hazard event (storm, cyclones). Tropical cyclone activity and intensity varies on the intraseasonal, interannual, interdecadal and multi-decadal timescales. Variations in the number of tropical cyclones from year to year are strongly correlated with local sea surface temperature before and near the start of the cyclone season (CSIRO and Australian Bureau of Meteorology 2007). Tropical cyclone numbers are also correlated with indices of the El Niño Southern Oscillation (ENSO), indicating a remote effect on tropical cyclone numbers through the Walker Circulation (CSIRO and Australian Bureau of Meteorology 2007).

Further, there is theoretical and experimental evidence that greenhouse warming is changing the large-scale environment where tropical cyclones form and evolve. Projected changes in tropical cyclones are subject to the sources of uncertainty inherent in climate change projections. These include errors in the modelled tropical cyclone climatology and regional patterns and magnitude of change for various fields and climate patterns such as ENSO (PWA and SAIC 2009).

Consequently there is large uncertainty in the tropical cyclone frequency projected by climate models:

> *There is some evidence that regional frequencies of tropical cyclones may change. There is also evidence that the peak intensity may increase by 5–10 per cent and precipitation rates may increase*

by 20–30 per cent. There is a need for much more work in this area to provide more robust results (IPCC 2000).

We calculated the probability of events by reviewing existing models for the study region including global climate models and higher resolution regional models. We found the spatial and temporal occurrence and severity of past events was often used as a guide to predict potential tropical cyclones and earthquakes that may affect the study zone. The simulated events were not necessarily identical to those that occurred in the past but were statistically consistent. In the South Pacific, for example, the catalogue of simulated events contains more than 400 000 tropical cyclones, grouped in 10 000 potential realizations of what may happen in the next year. Mathematical models were then used to estimate the intensity of the simulated events in the affected region, measuring effects such as wind speed, precipitation, and coastal surge for tropical cyclones, and ground shaking for earthquakes. If the earthquakes produced a tsunami, wave height and velocity were estimated as well. The models were based on empirical data and on the underlying physics of the phenomena (CSIRO and Australian Bureau of Meteorology 2007).

When no models were available, we analysed the tracks of historical tropical cyclones. We assembled the catalogue of historical storms starting from the dataset of the International Best Tracks Archive for Climate Stewardship project, the NOAA Historical Hurricane Tracks, the Joint Typhoon Warning Center (JTWC), the Australia Bureau of Meteorology, the France Météo and other countries' meteorological services.

We used the spatial and temporal occurrence and severity of past events as a guide to determine potential tropical cyclones and earthquakes that may affect the study zone in the future. We applied the probability of the occurrence of climatic events to annualise the calculations and reflect the probability of avoided damages. We deduced a probability annual event of 44 per cent from historical storm events analysis (over the past 70 years).

ANNEX 5 VALUATION OF BIOREMEDIATION (ES7)

Bioremediation of waste water (ES7) corresponds to the mangroves' ability to purify and treat domestic waste water, under certain conditions.

METHOD

We used the following method to assess this ES.

Step 1: Calculation of the production function

We based the biophysical production function of water bioremediation by mangroves and seagrasses on literature references and field observations. We accounted for the following variables to calculate the denitrification capacity and particle deposition of mangroves and seagrasses:

- facies
- cover surface of living biomass and density
- state of nutrient load discharged into water mangroves and seagrass, water residence time, and general hydrodynamic conditions.

We expressed results in terms of denitrification capacity (kilograms Nitrogen per hectare per year) and particle retention capacity (milligrams per litre) of dissolved or suspended solids).

Step 2: Economic valuation of bioremediation

There are four potential benefits of using natural systems to treat waste water rather than other conventional methods:

1. reduced costs to attain the same level of treatment as alternative methods
2. effluent discharges may enhance the quality and integrity of the receiving wetlands
3. levels of treatment by wetlands may exceed levels attainable by other methods
4. surface waters previously receiving effluent from conventional treatment methods may experience water quality improvements (Breaux et al. 1995).

Waste water treatment requires both capital investment and operating costs. Treatment levels are typically specified so that a discharge exhibits certain water quality characteristics, such as biological and chemical oxygen demand, suspended solids, acidity etc. These levels are met under conventional treatment with physical, chemical, and biological processes (such as settling ponds and aerators), and chemical additives (such as chlorine and lime). These treatments may be avoided, or can be undertaken at reduced rates if mangrove treatment replaces any of these processes.

According to Breaux et al. (1995), cost savings can be estimated simply. In the literature, values of water treatment or bioremediation are generally calculated using replacement costs (Bann 1997; TEEB 2009). Specifically, the value is estimated from comparing (i) the cost of installing and maintaining a biodisc waste water treatment with (ii) a decanter and a buffer tank with discharge of water in the mangroves (Herteman 2010; Liénard et al. 2001). The costs of engineering and annual maintenance serve as a replacement cost for valuing this service (Molle et al. 2005; Yang et al. 2008). Initial investment costs are amortised over the expectancy life of the asset.

Most experts recognise bioremediation by mangroves seems to be restricted to water discharges from 200–300 habitants (Marchand, Riegel, pers. comm.). This substantially reduces the potential of this ES, which maybe restricted to some specific sites.

We estimated replacement values based on actual costs in the study area. We interviewed local water treatment industries to clarify costs. We supplemented this data with data from literature or other IFRECOR (Initiative Francaise pour les Recifs Corelliens) valuations, adjusted to the economic environment of the study area (based on PPP) (Heston et al. 2009).

Shabman and Batie (1978) suggested the replacement cost approach can reliably value this ES under the following conditions:

1. the alternative technology provides the same services
2. the alternative identified for cost comparison is the least-cost alternative
3. there is substantial evidence that society would demand the service if it were provided by that least-cost alternative.

Similarly, our discussions with experts identified two complications (Riegel, pers. comm.). First, cost comparisons must be based on identical treatment standards for mangrove and non-mangrove systems. Second, mangrove costs must be compared against the least-cost alternative. This comparison may be simple when the alternative is another type of treatment. However, it is more complicated if discharge standards could be met by more pervasive, but less costly means, such as changing consumer habits.

OTHER APPROACHES

Another approach to explore is the avoidance of human health and morbidity effects downstream from organic pollutants retained in great quantities by the mangrove system (Bann 1997). One option is to estimate the potential loss of earnings from the health effects that would occur if the pollutants were released downstream. Another option is be to estimate the medical and other preventive expenditures required to compensate for this pollution.

ANNEX 6 VALUATION OF SEDIMENT TRAP (ES8)

Sediment trap services (ES8) correspond to the mangroves' ability to build land by trapping sediment and acting as a sink for suspended sediment (Furukawa et al. 1997; Walters et al., 2008).

IMPLICATED ECOSYSTEM PROCESSES

The mangrove trees catch sediment via their complex aerial root structure. Studies showed an annual sedimentation rate in mangrove areas of 1–8 millimetres (Bird and Barson 1977). Mangroves reduce tidal flows and induce sedimentation of soil particles at low tide, probably due to friction force.

The suspended sediment is introduced into coastal areas by river discharge, dumping of dredged material and re-suspension of bottom sediment by waves and ships. Based on a bibliographic review by Kathiresan (2003), Wolanski (1995) found sediment transport in mangrove waters was mostly the result of hydrodynamic process rather than biological processes. The hydrodynamic processes include tidal currents, baroclinic circulation and shear-induced destruction of flocs. The mangroves trap the suspended sediments during their transport based on tidal flows. This can lead to land accretion buffering against potential sea level rise in the future (Victor et al. 2004).

The efficiency of sediment trapping varies with mangrove zones and species (Kathiresan 2003; Wolanski 1995). The high efficiency of trapping suspended sediment in *Avicennia-Rhizophora* interphase may be attributed to wide spread occurrence of numerous aerial respiratory roots (pneumatophores) in *Avicennia* and to compactly arching, stilt roots of *Rhizophora* (Kathiresan 2003).

Dune systems and seagrasses also play an important role in trapping sediments (acting as sediment reserves) and stabilising shorelines (Ruitenbeek 1994; Victor et al. 2004).

Some estuaries mangroves can trap up to 40 per cent of the riverine fine sediment (Furukawa et al. 1997; Victor et al. 2004) and protect fringing coral reefs from sedimentation. Sediment stabilisation by seagrass roots and rhizomes, as well as by their beach-casted debris, helps control coastal erosion (Barbier et al. 2011). Some studies suggested the sediment trapping efficiency of mangroves may be explained as a function of tidal dynamics independent of riverine suspended sediment concentration (Victor et al, 2004).

METHOD

The sediment retention function of mangroves may protect downstream economic activities and property from sedimentation (Walters et al. 2008). Evaluating the effects on slowing downstream sedimentation requires estimating the amount of sediment restrained by the mangroves and determining what economic activities and structures would be affected if this extra sediment had been released downstream. The damage costs avoided and replacement cost approaches can be used to value this function (Bann 1997).

Different case studies around the world identified the following options for valuing ES8 (Bann 1997; Barbier 2007b; Furukawa et al. 1997; Hussain and Badola 2008; Kathiresan 2003; Victor et al. 2004; Wolanski 1995):

- the additional costs of dredging to clear for uses such as shipping and navigation
- the damage costs avoided of extra sedimentation to downstream irrigation, turbines, and dam reservoirs, etc.
- the costs of building sediment 'traps' to replace the mangrove function.

For this study, we identified the potential benefits of sediment trapping ES to downstream activities. We used GIS analysis (river flows, watershed characterisation, urbanisation, human uses etc.) and interviews with local experts for the biophysical valuation. We adapted the economic valuation to the type of service identified, using damage costs avoided or replacement costs.

ANOTHER APPROACH—VALUING THE SERVICE OF NUTRIENT ENRICHMENT

IMPLICATED ECOSYSTEM PROCESSES

Another approach valuing sediment trap ES is to examine the nutrient enrichment for agriculture uses (Hussain and Badola 2008). These authors examined the nutrient contents in mangrove and non-mangrove soils in and around the Bhitarkanika National Park, India. They assessed whether the local agricultural producers were aware of this contribution of mangrove forests in enhancing agroecosystem productivity. They analysed soil samples from both mangrove and non-mangrove areas to derive the quantities of organic carbon, total nitrogen, available phosphorus and potassium. They used the replacement cost method to estimate the value of nutrients in mangrove soils. Each hectare of mangrove contained additional nutrients worth US$232.49, compared with non-mangrove areas. They valued the nutrients in 145 $kilometers^2$ of mangrove forests at US$3.37 million. The agricultural producers were aware mangrove forests act as a source of nutrients and were willing to pay a higher price for the land adjoining mangrove forests.

METHOD

This method involved valuing either the increase in crop productivity or the avoided costs (less intensive use of artificial fertilisers). Scientific literature contains productivity increase data for some crops such as palm oil or coconuts (Jack Snaddon, Oxford University and Alain Rival, CIRAD, pers. comm.).

ANOTHER APPROACH—VALUING THE SERVICE OF LAND ACCRETION

IMPLICATED ECOSYSTEM PROCESSES

Mangroves, by retaining sediment, can build riverine habitats downstream, which reduces erosion and loss of riverine habitats (Vishwanathan et al. 2004) In the Sundarbans, Bangladesh, planting 150 000 hectares of mixed mangrove species enhanced the deposition of sediments to such an extent that the elevation of 60 000 hectares is no longer suitable for mangroves, and can be used for agriculture worth US$800 per hectare per year (Saenger and Siddiqi 1993).

METHOD

The value of the land accretion service requires determining the rate of land accretion and then the value of any extra agricultural production generated annually (Bann 1997). We used land appraisal techniques based on local data (lease values, database etc.) and data from experts.

ANNEX 7 VALUATION OF CARBON SEQUESTRATION (ES9)

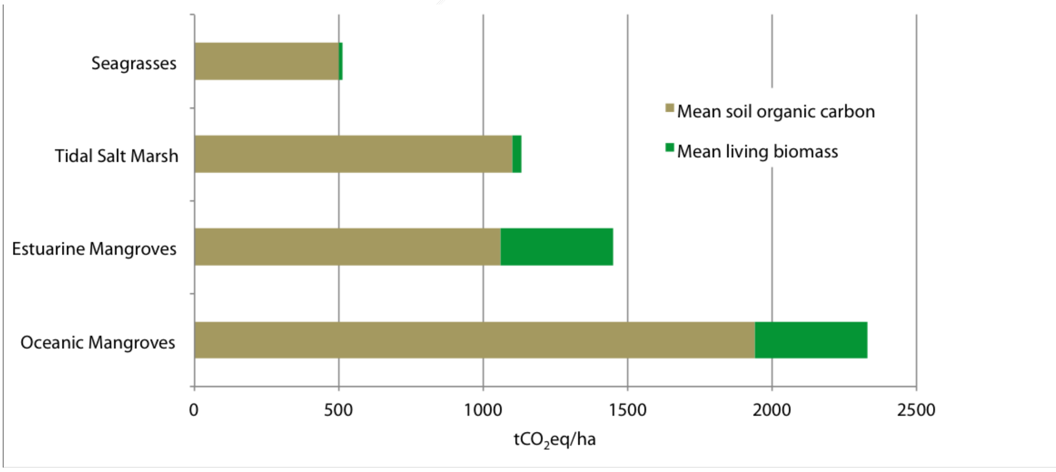
Carbon sequestration services (ES9) corresponds to the carbon mangroves store. They remove carbon dioxide (CO_2) from the atmosphere via photosynthesis, return some to the atmosphere through respiration and oxidation and store the remainder in two stocks: living biomass (which includes both ground and underground vegetation) and soil organic carbon (Knowlton 2000; Walters et al. 2008).

IMPLICATED ECOSYSTEM PROCESSES

The rate of carbon sequestration quantifies the carbon added to the biomass and carbon pools in the soil each year. For intact ecosystems, mature vegetation maintains a constant live biomass, and the soil stocks almost all sequestration. This rate is assumed to be constant over time (Duarte and Middleburg 2005; Jennerjahn and Ittekkot 2002; Suzuki and Kawahata 2004).

Based on recent publications and the blue carbon database (Bouillon et al. 2009; Murray et al. 2010; Nicholas Institute for Environmental Policy Solutions 2011; Sifleet et al. 2011), we estimated the average ranges of carbon sequestration by mangroves and seagrass ecosystems. Mangroves varied from 6–8 tonnes of CO_2e.per hectare per year, while seagrasses retained around 4 tonnes of CO_2e.per hectare per year. However, soil carbon is the main carbon stock (500 tonnes of CO_2e.per hectare for seagrasses and approximately 2000 tonnes of CO_2e. for mangroves) (figure A14). Seagrasses store only 5 per cent of carbon in living biomass while mangroves store 20–40 per cent (Murray et al. 2010).

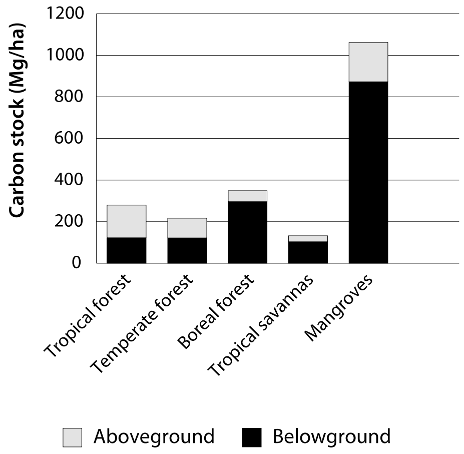
Figure A14: Global averages for carbon pools, by coastal habitat



Source: Sifleet et al. 2011.

Mangrove carbon pools are among the highest of any forest type; for example, ecosystem carbon pools of mangroves are more than twice those of most upland tropical and temperate forests (figure A15). A great proportion of this pool is below ground in organic-rich soils, which can release significant volumes of greenhouse gases if disturbed by land use or climate change (Page et al. 2010; Hooijer et al. 2006).

Figure A15: Global ecosystem carbon pools, by land cover type



Source: Kauffman and Donato 2012.

Mangroves vary greatly in structure and function, largely as a result of topography, substrate, latitude and hydrology (Kauffman and Donato 2012). Dominants in mature mangroves may range from trees with trunk diameters greater than 1 metre to shrub-like stands less than 1 metre high. Aboveground biomass may range from more than 500 milligrams per hectare in riverine and fringe mangroves of the Indo-Pacific region to about 8 milligrams per hectare for dwarf mangroves.

Mangroves are classified into four major associations of differing structure, corresponding to physical, climatic and hydrologic features of the environment in which they exist: fringe or coastal mangroves; riverine or estuarine mangroves; basin mangroves; and dwarf or scrub (or chaparro) mangroves (Mitch and Gosselink 2007).

METHOD

STEP 1: PRODUCTION FUNCTION

To define the production function, we adapted the method developed by the Nicholas Institute for Environmental Policy Solutions of the Duke University (Murray et al., 2010) to our context and data availability. The function used two processes to quantify carbon volumes: the sequestration in living biomass and the carbon pools in the soils. The result was the annual amount of CO_2e *avoided* being released into the atmosphere by maintaining ecosystems in their current state.

We estimated the following parameters:

a. the annual rate of absorption of carbon by the ecosystem in its current state
b. carbon stocks in biomass and the basement (at a maximum depth of 1 metre even if, generally, carbon pools vulnerable to anthropogenic changes are aboveground biomass and belowground pools up to 30 centimetres). Data was based on estimates of tier 1 and tier 2 IPCC categories.[28]
c. the amount of potential emissions caused by destroying ecosystems. This evaluates how much soil carbon may potentially be exposed to the atmosphere and thereby emitted as CO_2. Metres of carbon-rich organic soils may underlie the coastal habitats, and that carbon may persist if the habitat conversion only affects the top layers and the deeper layers remain inundated.
d. the time required to release emissions into the atmosphere. In theory, following conversion, carbon in biomass is emitted to the atmosphere in the first few years. Soil organic carbon will take longer than biomass and the deeper the soil carbon, the slower its rate of release. In each case, high emission rates would be expected in the years immediately after disturbance, then dropping to lower rates later. A decay function may approximate this physical process, and we used the concept of half-life, which denotes the time required for the carbon pool to fall to half its initial value. We assumed a half-life of five years (Murray et al. 2010).

STEP 2: MONETARY VALUATION

CLEAN DEVELOPMENT MECHANISM (CDM) AND THE CARBON PRICE

To include an estimate of the price of carbon that can be considered valid for a certain period of time, it is necessary to be clear about how to generate such price and in which market it will be traded. The Clean Development Mechanism (CDM) is an agreement of the Kyoto Protocol; governments and companies in industrialised countries can engage in emission reduction projects in developing countries to earn certified emission reductions (CERs), so they can meet emission targets set in the Protocol. Each certificate, equivalent to 1 tonne CO_2e, can be traded and sold in international financial markets. CERs are

[28] *The IPCC (Intergovernmental Panel on Climate Change) established a tier system, reflecting the degrees of certainty or accuracy of carbon stock assessment. Tier 1 uses IPCC default values (i.e. biomass in different forest biomes etc.) and simplified assumptions; it may have an error range of +/- 50 per cent for aboveground pools and +/- 90 per cent for the variable soil carbon pool. Tier 2 requires country-specific carbon data for key factors. Tier 3 requires highly specific inventory-type data on carbon stocks in different pools, and repeated measurements of key carbon stocks through time, which may also be supported by modelling.*

obtained by driving projects to mitigate greenhouse gases through actions promoting clean energy or reducing consumption (brown credit), afforestation and reforestation (green credits).

This mechanism is one of the most successful because it was selected as the model designated by the United Nations Framework Convention on Climate Change (UNFCCC). This convention gave rise to the global carbon market, which currently constitutes one of the most important mechanisms and incentives to mitigate greenhouse gases emissions. It is the primary tool for protocol countries to meet agreed targets for reducing emissions (Nellemann et al. 2009a).

Currently there are two types of carbon markets: compliance regulated markets and voluntary markets. The first market is used by companies and governments that are obliged by law to meet a 'quota' of emissions of greenhouse gases for carbon credits through CERs, which are traded in the market to meet emission reduction obligations. It was the base of our price valuation.

The second market can be used by any country, institution or company wishing to carry out projects for different reasons (reputation, certifications etc.). They receive credits called verified emission reductions (VERs)[29] or verified carbon standards (VCSs)[30].

Although credits from initiatives such as reducing emissions from deforestation and forest degradation (REDD+), afforestation/reforestation[31] (A/R) and improved forest management (IFM) are best suited to

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[29] *The most popular type of carbon credit used to offset emissions around the world voluntarily is a VER, a verified or voluntary emission reduction unit and there are many different types. Before CDMs deliver credits used for compliance purposes such as CERs, they can produce VERs. These credits can be verified to a number of specific standards, including the Gold Standard. Not all projects go on to register within the CDM, often due to the size of the project and the inhibitive costs associated with compliance registration, so their choice of one or more of these voluntary standards is made based on its overall viability and compatibility to them.*

[30] *VCS credits or voluntary carbon units (VCUs) must be real; the abatement must have occurred; they must go beyond business-as-usual activities; they must be measurable, permanent, not temporarily displace emissions;, and the findings must be independently verified and unique so they cannot be used more than once to offset emissions. The VCS is the most widely known and chosen standard in the voluntary market given its Kyoto compatibility as well as its ability to manage a wide range of project types and methodologies. (www.carbonplanet.com)*

[31] *Afforestation: The direct human-induced conversion of land that has not been forested for a period of at least 50 years to forested land through planting, seeding and/or human-induced promotion of natural seed sources. Reforestation: The direct human-induced conversion of non-forested land to forested land through planting, seeding and/or the human-induced promotion of natural seed sources, on land that was forested but has been converted to non-forested land (CDM-EB07-A04-GLOS).*

the characteristics of the mangrove ecosystems, they have still not have been included in the regulated market as CERs (Gordon et al. 2011). Because compliance standards do not yet account for the offsets of these initiatives, mangrove and seagrass carbon finance through VERs must come through the voluntary market. Although major voluntary offset creditors such as the VCS and Climate Action Reserve have yet to approve any blue carbon projects, future projects could occur based on current REDD+ standards.

Additionally, the most recent version of the VCS Agriculture, Forestry and Other Land Use (AFOLU) requirements include peat land rewetting and conservation (VCS 2011a). Coastal lands with peat soils could be eligible for voluntary credits through these peat land requirements. Moreover, VCS is in the process of approving wetland mitigation standards that will likely include coastal habitats.

The future of coastal habitat protection through the voluntary carbon market will rest, for now, on two factors: (i) the extent to which REDD+ projects in the voluntary markets can incorporate blue carbon, and (ii) the development of blue carbon standards in the voluntary market. According to REDD methodology in VCS, project areas may include forested wetlands (including mangroves) as long as these wetlands contain no peat, which is dealt with separately (VCS 2011b).

Therefore, we used REDD+ credits as a proxy for blue carbon credits from mangroves. These have only been traded on the voluntary market; in 2010 the voluntary market purchased approximately 131.2 megatonnes of CO_2e (Gordon et al., 2011). Of this, 30.1 megatonnes came from forest carbon projects (with a market value of US$178 million). Depending on the study, REDD+ credits supplied 17.8–19.5 megatonnes of CO_2e to the voluntary market (Idem 2011). The average price for a REDD+ credit in 2010 was US$5 per tonne of CO_2e; the average forest credit price was US$5.50, and the average voluntary credit price was US$6.90. The price range of all voluntary credits (including forest credits) remains extremely high; prices range from US$.01 to US$136.3 per tonne of CO_2e. Forest carbon credits in the voluntary market have a smaller range, with a high price of approximately US$34 per tonne of CO_2e.

VCS credits accounted for most voluntary credits in the market, with an average price of US$4per tonne of CO_2e. Latin America provided almost all (89 per cent) of the REDD+ voluntary credits (Murray et al. 2010).

Demand for REDD+ carbon credits is difficult to predict and remains subject to pending regulations (post-2012 UNFCCC protocol and California's Global Warming Solutions Act (AB32)). Several studies considered estimates of REDD+ carbon credits' future demand for blue carbon credits as highly speculative (Gordon et al.,2011; Murray et al. 2010; Point Carbon 2010). Therefore, the comparative analysis of CERs should be useful (Sifleet et al. 2011).

The CER price is volatile and it depends on agents' expectations, the success of the projects and the global economic situation, among other factors (figure A16). The cost for biomass carbon credits fell from US$12 to US$10 between 2009 and 2010. Over the same period, agroforestry carbon credits doubled in value—

from US$5 to US$10. In 2010 The most expensive carbon credits (at US$18.10) were produced by offset projects in Oceania. In Europe, 2010 prices were a little over US$11 per credit, while, US-produced credits were transacted at the lowest value among regions(US$4.9 per credit).

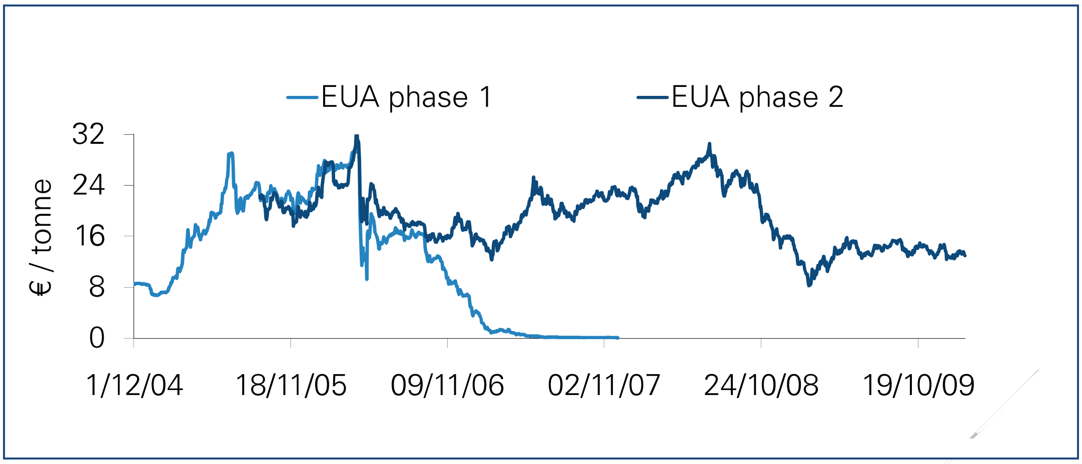
Figure A16: Price simulations of carbon emission reductions

Source: JP Morgan report.

The estimated price per unit of emission reduction is based on the analysis of historical transactions of European Union Allowances (EUAs) on the European marketplace European Climate Exchange (EXC). Transactions in the EU Emissions Trading System or the Kyoto CER in 2010 represented more than 80 per cent of transactions in global carbon markets (12 000 megatonnes of CO_2e since 2006) (figure A17).

We estimated an average price for the study period based on the results of different surveys (Gordon et al. 2011; Point Carbon 2010; Sifleet et al. 2011).

Figure A17: Market prices on the European Union Emissions Trading System (price at 30/12/11: 6,70€/t)



Source: Point Carbon 2011.

FORMULA

We used the following formula to value ES9:

$$SC_e = \sum_{e,t} \left((T_e + Q_{e,t}) * Prix_t\ (tCo_2eq) \right)$$

where

SC_e = annual value of carbon sequestration (tonnes of CO_2e) per ecosystem (e)

Te = annual absorption rate per ecosystem (e)

$Q_{e,t}$ = quantity of potential release of pool stocks of CO_2 per ecosystem (e) per year (t) with decay rate

Prixt (tCo_2eq) = price projection of avoided tonne of CO_2e

We monetised the carbon flows by multiplying the annual avoided carbon quantities during the year of the valuation by expected carbon prices (US$/tonne CO_2e).

ANNEX 8 DESCRIPTION OF THE SURVEYS

We used three questionnaires in the socioeconomic survey of each village. One focused on crabs, one on mangroves and one on reef fishes.

SURVEY 1: HOUSEHOLD CRABS

This survey collected information about:

- general information on the interviewee (status, age, gender, marriage, island, religion, household members)
- basic questions on common type crabs the interviewee caught, preferably species found in the mangroves
- language name of the interviewee's commonly caught or preferred crab type, information on the common area the crabs were caught (zones of the areas devised by the MESCAL team), transport means of getting there, how many people in the household hunt crabs, the quantity caught per person in a week or per trip, harvesting techniques used, how long a usual crab hunting trip takes, purpose of catching crabs (consumption or sale), number of crabs the family consumes after a catch, quantity of crab sold weekly/ monthly
- any taboo/management systems in place in the village that aim to preserve or conserve any resources or ecosystems, with follow up questions about efficacy.

SURVEY 2: MANGROVES

This survey collected information about:

- general information on the interviewee (status, age, gender, marriage, island, religion, household members)
- income earning activities the family does, how much the household earns each month
- if and how the family uses/used mangroves (including details about the activity, what is collected and the species type of mangrove used)
- what the mangroves used for, how often they are cut (weekly, monthly etc.), how many are cut (number of posts or bundles), who usually cuts the mangroves
- alternatives for firewood and house posts used, whether the family buys firewood (sometimes or never)
- statements about mangrove ecosystems.

SURVEY 3: REEF FISH

This survey collected information about:

- general information on the interviewee (status, age, gender, marriage, island, religion, household members)
- the types of fish the family normally catches, some common fishing techniques the family uses, weekly fishing trips for the different techniques, fish caught per trip
- common fishing grounds, some information on last catch (was it consumed or sold), market information (buyers, means of selling, transportation, middlemen, price of fish per kilo or rope)
- number of different types of fishing gear in the village.

SAMPLING DETAILS

The team used random sampling in the villages, accounting for factors such as distance from the mangroves (houses near the mangroves and those further away), fishing and non-fishing households, different religious beliefs (such as Seventh Day Adventists not selling eating crab to Presbyterians etc.). Some villagers did not want to be interviewed. We collected 482 valid surveys (table A6).

Table A6: Total number of completed questionnaires

Questionnaires (no.)	Eratap	Amal/Crab Bay
Household crab	29	130
Mangroves	29	137
Reef fish	29	128
Total	**87**	**395**

In Crab Bay, surveying began on 4 September and ended on 12 September 2012 with the help of seven locals, an officer from the Vanuatu Government Department of Environment Protection and Conservation and a contracted resource environmental assistant (table A7). Overall, 15 villages hosted the team and its socioeconomic agenda.

Table A7: Survey team

Name	Status/*Village*
Molu Hango Bulu	Resource Environmental Economic Assistant
Primrose Malosu	DEPC, Administrative Officer (with first-hand experience in field workshops)
Kalmasing Peter	Hatbol Community Chief—Amal/Crab Bay Committee member, *Hatbol village*
Numa Fred	Vanuatu Cultural Centre field worker, *Uripiv*
Spetly Jonah	Amal/Crab Bay committee member, *Hatbol village*
Ritson Josen	*Uripiv*
Leonie Mark	*Lingharak village*
Susan Tahi	*Lowni village*
Morry Ruben	*Tautu village*

There were some difficulties in the field including responsible committee members having other commitments on the day we were supposed to visit their village, slight program changes to include overlooked issues, and the team being unable to locate on interviewee who recently built his home using mangroves. Overall the survey was successful and the villagers were very helpful.

In Eratap, surveying commenced on 24 September and ended on 10 October 2012. The community had many issues, which made data collection lengthy.

QUALITATIVE ANALYSIS OF SURVEYS (BY MOLU BULU)

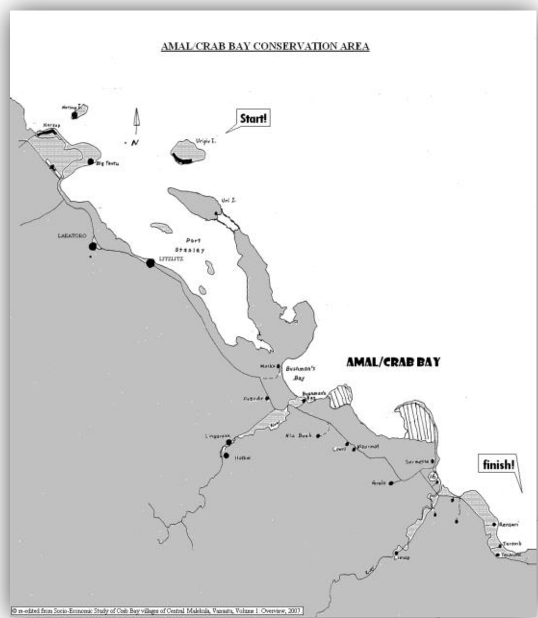
AMAL/CRAB BAY

All 15 villages are original members of the conservation area committee of Amal/Crab Bay. Only a few are located within a reasonable walking distance (the nearest 5 minutes' walk away; the furthest 15–20 minutes' walk), but all are members due to land related issues. The villages are diverse in both their cultures and people. Most villages have people from other villages and/or islands. *Tevaiout* and *Niu Bush* for example, were settled by Paamese people when the tribal landowners granted their ancestors the right to settle. Malekula has a varied range of cultural practices and customs, although there are similarities. People speak four different languages in the member villages of the conservation area, for example.

Agriculture was the mainstay for many centuries and it continues today. Economic pressures have made it difficult for people in the villages. Some families have members with jobs in other areas (Lakatoro, Luganville and/or Port Vila) or have access to education (including attending university. Manoa of *Lowni*, for example, works at the Public Works Department in Lakatoro but his family still depends on resources from the gardens and conservation area for food and other necessities.

The urban centre of Malakula, Lakatoro, is around 90 minutes' drive from the conservation area of Amal/Crab Bay (figure A18). The START and FINISH labels show the span of villages that are members of the conservation area committee.

Figure A18: Amal/Crab Bay



CRABS EXTRACTION

Not all villages are located within walking distance of the conservation area (figure A19). But despite the distance, results showed one in three households in every village had crab hunters. Trip frequencies varied for every family member, so average travel range was 0.2–3.0 kilometres and less mostly for these villages.

Consumption levels varied for each village. Young girls in the house consumed more of the recorded crab catch than any other family member, on average consuming 55 crabs in crab season, and 30 crabs when it wasn't crab season.

Around 80 per cent of households interviewed collected crabs for subsistence use only; 15 per cent collected crabs for both sale and consumption, while 5 per cent only caught crabs to sell for income. These differences in consumption patterns reflected two factors: distance from the village to the mangroves and alternative resources available. Those living near the mangroves collected more crabs than those in other villages. We concluded these villages had few alternative resources and they depended on the mangrove ecosystems to meet immediate needs.

Overall, villages caught an average of 363 000 crabs a year (with catches some years as high as 363 129). More than 50 per cent of the annual crab catch was consumed in the homes, while a smaller percentage was sold for money at the main market, roadside markets, or shops in Lakatoro.

Each village has its own allocated access area provided by the conservation area committee; villagers cannot access another village's area.

WOOD EXTRACTION

Villagers use mangrove trees in several ways. The trunks can be used for house posts, fencing, firewood and in some places as a gardening tool. The branches are also used for firewood and small hooks that some people cut and use to capture mud crabs. Leaves are used as bait for *serwok* (small pointy shells) and crabs, and for medicinal purposes.

The most common use is for housing posts and rails (i.e. villagers use large stems as supports crossing each other and/or running parallel to and from the main frames of the constructed roof). Unlike other trees, mangrove wood is strong and long lasting (often lasting for 10 years or more).

Details about traditional medicine practices are taboo and only revealed to particular people. However, these practices are rapidly dying out. Only a few people in some villages know these practices, while others have faint recollections from old stories.

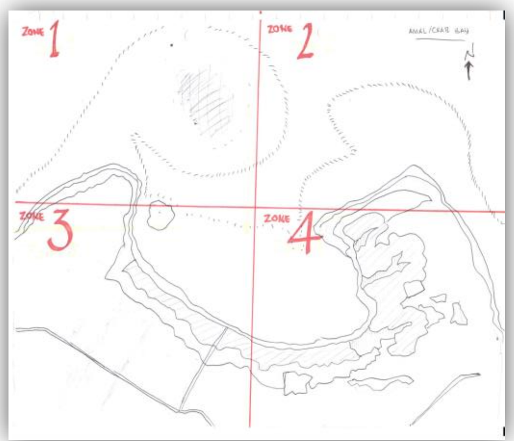
FISHERY

Locals use many fishery techniques, but the most common ones were the reef net and the handline, followed by the cast net and then other techniques. Reef nets, which can reap a large number of fish in a short time were used on more than 90 per cent of fishing trips.

Each household takes one fishing trip a week on average. Occasionally a household will take more than one trip a week, but this generally only happens over one month. Occasions requiring a huge stock of fish include village fundraising events, big village meetings, and sometimes community held workshops, such as the MESCAL socioeconomic visit.

Each fisherman or fisherwoman catches around 15–20 fish on average. Not all fishery is done around the mangrove areas; some people go deep sea fishing, outside the conservation areas towards the reefs. Figures 18 and 19 show the fishing grounds and zones.

Figure 19: Amal fishing zones



The conservation area committee allocates each village an area; only people from that village can extract resources from that area. Open fishing is allowed in areas inside the bay and outside, away from the two headlands (Amal/Crab Bay).

Village residents consumer most of the fishing catch, with some sold for income. Fish that are sold are taken immediately to the Lakatoro market, fish market, or Rina store in Litzlitz via any available means of transport, or they are sold in the village. Prices fluctuate, but usually around Vt300 per kilogram. The men usually bring in the large catches and then sell them in the semi-urban centre; the women usually sell in the village.

The annual catch per household ranged from 74 for *Tevif* to 2174 for *Barrick*. This significant difference reflects many factors, such as the availability of alternative resources, time, means of fishing, distance to fishing grounds and the reasons for fishing (for example, to pay school fees, for a feast, to pay for groceries etc.).

The annual value of fish caught for both subsistence and commercial purposes ranged from Vt6 875 645 to Vt10 239 424 for all the villages.

PERCEPTION OF TABOO AND MANAGEMENT

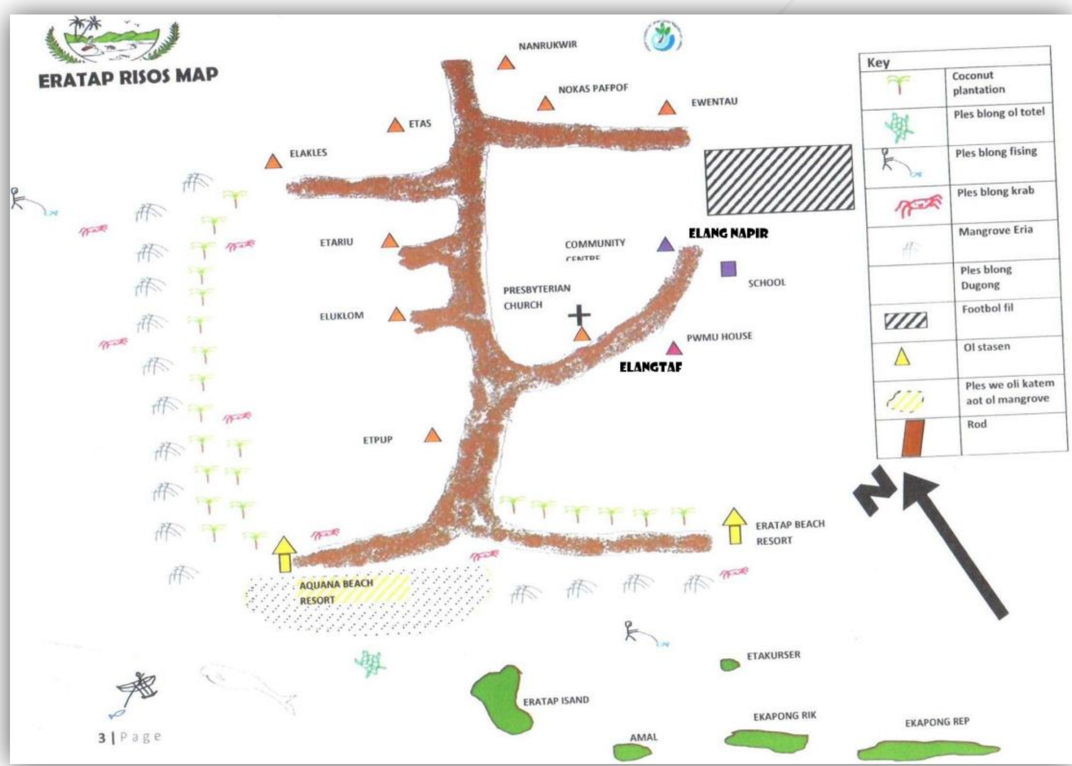
Managing the area is difficult even with the management plans set up by the conservation area committee and the respective stakeholders. The villages understand what the *taboo* aims to achieve for them and their children and generally support it. However, there are some issues that make it hard for them to abide by the rules: the resources are their main source for food and income, they incur unexpected expenses, while others simply refuse to abide by the rules. These factors create tensions with neighbours who follow the rules and depend on the resources more than others. A committee member suspected some people in his own village of not following the rules, for example, and was quietly conducting his own investigation during our stay.

There is no traditionally set means of managing the mangroves themselves but there have been cases for the fishes and crabs.

ERATAP

Eratap is much smaller than Malekula, but surveying took longer than expected (figure A20). As a multicultural community with many different beliefs, backgrounds and life goals, it was difficult to organise a workshop everyone could attend.

Figure A20: Eratap resource map



ERATAP IS DIVIDED INTO 10 STATIONS. THE SMALL STATIONS HAD 15–50 HOUSEHOLDS, WITH POPULATIONS BETWEEN 50 AND 200 PEOPLE; THE TWO MAIN STATIONS HAD A COMBINED POPULATION OF 300 PEOPLE. THE SMALLEST STATION IS ROUGHLY 50 M^2 ROUGHLY, WHILE THE MAIN VILLAGE (COMBINING TWO STATIONS) IS THE SIZE OF 12 SOCCER FIELDS. THE STATIONS CONTAIN PEOPLE WITH DIFFERENT ETHNIC BACKGROUNDS FROM DIFFERENT ISLANDS OF VANUATU THAT HAVE SETTLED HERE TO BE CLOSE TO THE PORT VILA, THE URBAN CENTRE. MUCH OF THIS SETTLEMENT WAS THE RESULT OF UNORTHODOX LAND SALES BETWEEN CUSTOMARY LANDOWNERS, WHICH CAUSED DISPUTES THAT HAVE BEEN RUNNING FOR MANY YEARS. CRABS EXTRACTION

Middle-aged men hunted crab more than the other household members in Eratap, although very few people hunted. Most households caught an average of 50 crabs in a month, although the lowest number recorded was 10. This was only for mangrove *white* crabs; mud crabs were rarely hunted because chances of catching any are small. Most hunting occurs in crab season.

About 50 per cent of interviewees hunted crabs to feed the family; 40 per cent of interviewees did not hunt crabs because of religious beliefs (SDA), because they had other more easily accessible resources, or because they had other more stable means of income generating.

Up to 150,000 crabs were caught annually. More than 90 per cent of crabs caught annually were consumed at home.

Eratap's mangroves are not managed as a conservation area with a management mechanism. People freely overuse the resources, which are now being depleted and destroyed without any care for future generations.

WOOD EXTRACTION

Eratap's mangroves were rarely used for housing or firewood because people had alternative and more easily accessible resources. The mangroves were last used 2–3 months before the survey period (June/July 2012).

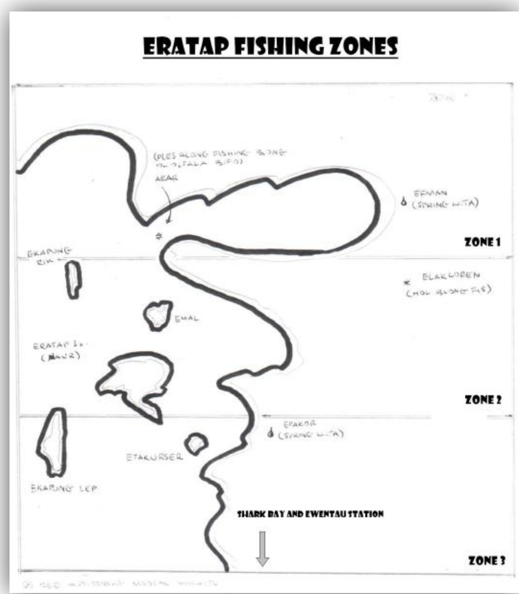
Some people understand how important mangroves are and are trying to preserve the ecosystem. However, cultural and historical differences mean villagers find it hard to work together.

FISHERY

People in Eratap used a variety of fishing techniques, but the handline was the most common technique (and had been for some time). The stations near the sea and river fished more often, so they had more fishing equipment. The station of *Ewentau* had eight canoes, the most of any station (even though it had a population of 120 people).

Fishery occurs a few times monthly but not all the time. The average catch varied from 15 fish to 30 fish per trip. Fishery areas ranged from shorelines to around the mangroves as well as outwards on the reefs (figure 21). There were no patterns to people's trips; they often based decisions on their willingness to go out on the reef to fish. A fisherman may follow the coast past the resort, go towards the river and Shark Bay or borrow a canoe to go out for example. There are no motorboats in the villages; the only motorboats are owned by the two resorts, Aquana and Eratap Beach Resort.

Figure 21: Eratap fishing zones



The typical household in Eratap caught no more than 200 fish a year for home consumption and sale. Most fish was consumed, but people did fish occasionally for recreation and/or to earn some money. Fish was only sold in *nakamals* to relatives and friends outside who made arrangements, and each arrangement was different. Fish were sold by the rope (not the kilogram), and prices range from Vt300 to Vt500 for a rope of fish, depending who caught them.

As noted above, there is no taboo or traditional management system for the Eratap mangroves. Further, tribal differences, ongoing land disputes and personal issues prevent the people working together.

GENERAL OBSERVATION

We experienced some issues that hindered our field work, including transportation difficulties between villages (for Malekula); poor attendance and little cooperation at group discussions (in Eratap); and financial problems. Most villages or stations we visited were not always interested in learning about the importance of mangroves, but expected to be compensated for helping the team (especially for accommodation and lunch), which put pressure on the team's limited budget.

Socioeconomic observations showed Malekula earned must of its income from agricultural products, fish and handicrafts. The resources found in the mangroves provided the majority of services such as food security, shelter and housing means, and financial support. For the people of Eratap, the mangroves generated very little income; the urban centre of Port Vila is on the same island, so people had other means of generating income. Most resources were used for residential consumption while a lesser percentage was sold for income.

Overall, people depend on the mangrove ecosystem to ensure a certain proportion of their sustainable livelihood; its resources are abundant and satisfy the most basic needs like food and shelter. The abundance of crabs, shells and fishes ensures food security for the villages, especially the majority of villages without stable salary paid incomes. Most people rely on agricultural products for income, whose market prices fluctuate unreliably.

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