SPREP

# Background Paper Number 2:
# The Potential for Ecosystem-based Adaptation(EbA) in the Pacific Islands

Final

CONSERVATION INTERNATIONAL

# 1 - Executive Summary

There is an increasing level of interest in the capacity of ecosystems to help buffer human development from climate change, particularly in developing countries where natural capital forms a larger proportion of wealth. The objective of this report is to explore the technical feasibility of improving the uptake of Ecosystem Based Adaptation (EbA) within adaptation planning and projects in the Pacific Island Countries and Territories to ensure that the full suite of adaptation options are available for adaptation decision-makers in the Pacific.

The uptake of EbA depends heavily upon the framework that is used to guide decision-making on adaptation planning and projects. This report explores frameworks that are capable of internalizing the range of EbA benefits in such decisions, focusing heavily on the potential of economic and resilience-based approaches.

This analysis also involves an exploration of the current knowledge of key ecosystem service relationships that are relevant to the specific climate change exposures in the Pacific Island Countries. For example, what do we really know about the capacity of mangrove ecosystems to act as a 'bioshield' to protect human settlements from cyclones and associated storm surge?

Based on the local climate exposures, and the spectrum of social, economic and ecological contexts in the Pacific Islands, the following EbA relationships were identified and examined as a part of this report:

- Coastal vegetation and protection from storm surge
- Floodplain/riverine vegetation and reduced flood damage
- Mangroves and accommodation of sea level rise
- Seagrass and reduced sedimentation from floods
- Slope vegetation and landslide risk reduction
- Agroforestry and agricultural yield stability

Based on the existing knowledge of these relationships, it can be argued that ecosystem management is a legitimate part of the solution to climate change vulnerability of the people of the Pacific Islands, and there is a need to ensure that decision-makers in Pacific Island Communities have access to information and skills that enables the identification of EbA opportunities, and the design and implementation of EbA options within adaptation planning. As a starting point this report recommends that available information on the 6relationships outlined above are presented within the proposed Climate Change, Ecosystems and Biodiversity in the Pacific Toolbox to help guide decision-makers on the introduction of EbA within their adaptation planning. More specifically, it is recommended that the EbA components of the toolbox includes information on:

- Current knowledge of the EbA relationship (including uncertainties, limitations and risks)
- Guidance for consideration within cost-benefit analyses
- Capacity requirements for application
- Generalized guidance/'rules of thumb'
- Access to more specific resources.

This is the second volume of the *Biodiversity, Ecosystems and Climate Change in the Pacific - Analysis and Needs Assessment Project* (The Project) being undertaken by SPREP and Conservation International to identify priority options for better consideration of biodiversity conservation and ecosystem services within adaptation planning in the Pacific.

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# 2 - Scope, Objectives and Audience

This report examines the role of the ecosystem services in reducing the vulnerability of the people of the Pacific Islands to climate change. Specifically, it describes the decision-making frameworks and the current state of knowledge of specific ecosystem-service/development relationships that are relevant to EbA.

The primary objective of this work will inform broader recommendations on improving the integration of ecosystems, biodiversity and climate change adaptation under the *Biodiversity, Ecosystems and Climate Change in the Pacific - Analysis and Needs Assessment Project(The Project)* which is part of a collaboration between the Secretariat for the Pacific Regional Environment Programme (SPREP) and Conservation International and was undertaken from January to July 2011.

This report should be considered as a companion volume to the other 3 background reports produced under the Project:

- Climate Change Adaptation Options for Species and Ecosystems in the Pacific: Background Paper #1;
- Need Analysis for Information on Ecosystem, Biodiversity and Climate Change Adaptation in the Pacific Island Countries and Territories: Background Paper #3;
- Report on the Results Workshop from Nadi, 12-13 May 2011: Background Paper #4.

The findings of each of these reports will be synthesized into a single, shorter volume that targets decision-makers in planning, agriculture, environment, fisheries and disaster management institutions in the Pacific. However, the audience for this EbA report (Background Paper #2) is technical staff in these institutions as it explores the next level of detail on EbA potential and practicalities of implementation.

# 3 - Introduction: What is Ecosystem-based Adaptation?

There is an increasing level of interest in the capacity of ecosystems to help buffer human development from climate change, particularly in developing countries where natural capital forms a larger proportion of wealth[1]. However, there is also a lot of rhetoric on the specific benefits of ecosystem-based adaptation(EbA) and the conditions under which those benefits are likely to be received. For example, in its 2010 report 'Natural Hazards, Unnatural Disasters ' while the World Bank recommends that the 3 top spending areas for disaster prevention are early warning systems, critical infrastructure and environmental buffers, it also adds that "*some who seek to protect the environment may have also exaggerated the benefits in cost-benefit analysis*"(p18).

The concept of ecosystem-based adaptation is not embedded within the discussions under the United Nationals Framework for Climate Change(UNFCC) but with the Convention on Biological Diversity(CBD), as follows: "*Adaptation that integrates the use of biodiversity and ecosystem services into an overall strategy to help people adapt to the adverse impacts of climate change*. (CBD AHTEG)". Hence, the primary beneficiaries of EbA are people rather than the local ecosystems and biodiversity. While there is overlap between these two groups of beneficiaries and there is an increasing amount work that considers integrated socio-ecological systems, these tasks have been separated as a) the relationship between biodiversity and ecosystem services is complex and b) the institutions and objectives of the conservation community and the development community have often been viewed as inherently different.

The concept of ecosystem services is defined in the Millenium Ecosystem Assessment(MEA) as : *'the benefits that people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as regulation of floods, drought, land degradation and disease; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious and other non-material benefits'* (World Resources Institute, 2003)

Some coastal ecosystem services that are relevant to climate change adaptation in the Pacific context include :

- *Roots of mangrove plants help to hold sediment in place (Orth et al., 2006)*
- *Coastal vegetation can prevent saltwater intrusion during storms (Semesi 1998; Badola and Hussain, 2005)*
- *Seagrasses can help prevent resuspension of sediment (Gilbert and Janssen, 1998; Spaninks& van Beukering 1997).*
- *Mangroves can serve as "natural barriers" to protect life and property of coastal communities (Badola and Hussain, 2005)*
- *Vegetation can protect water quality (Aburto-Oropeza et al. 2008)*
- *Coral reef structures buffer shorelines against waves, storms and floods (Moberg and Folke, 1999; Done et al., 1996; Adger et al., 2005)*
- *Some ecosystem structures can provide a significant barrier to storm surges (UNEP-WCMC, 2006)*

Based on such examples, there is a growing consensus that using natural capital is in important part of 'climate proofing' human development. However, compared to the other forms of capital, investment in these areas of adaptation represents a low proportion of adaptation activity, in the Pacific and elsewhere(Pramova, 2010).

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[1] This World Bank report (2006) suggests that in comparisons of total wealth based on income group that low income countries have a much higher proportion of their capital as natural capital than medium and high income countries (ie compared to intangible and produced capital). Specifically, natural capital representing about a quarter of the national wealth in low income countries.

Hence, there is a clear need to identify and remove 'the blockages' to EbAdelivering on this potential in the Pacific Islands. Based on the needs analysis conducted as part of the Project (Background Paper #3) one of the key blockages is awareness of practical EbA options which are suited to the local development and climate context.

There is a significant amount of knowledge on the role of particular ecosystem services within a specific development contexts scattered across the academic literature, but it is difficult to find central resources that pull information together into a single volume, and even more difficult to find such resources that would be suited to the specific development and climate context of the Pacific Island Countries.

# 4 - Approaches that Support Decision-making on EbA

Based on the results of the needs analysis (Background paper #3), decision-makers in non-environment institutions in the Pacific are not generally convinced that 'environmental infrastructure' is capable of meeting some of their adaptation objectives through EbA. Hence, the ability to effectively communicate the relative advantages of EbA against alternatives will be a critical step in improving uptake within the Pacific Island context. This will require the application of approaches that are frank about the applicability, value, limitations and risks of EbA options against the 'hard' infrastructure alternatives so that direct comparisons can be fairly made.

The information in this document has been framed to enable consideration of EbA against a suite of other alternatives, and comes with an acknowledgement that EbA is not the best adaptation solution in all contexts, but has a lot more potential to be used as part of the solution to climate change vulnerability in the Pacific than is currently reflected within adaptation planning and action.

The approaches that are examined in this study for their relevance to decision-makingon EbAare economic methods (both cost-benefit analysis and economic valuation methods) and resilience-based approaches. Note that these 3 categories of approaches are not necessarily mutually exclusive and can be used together as needed.

## 4.1 - Cost-Benefit Analysis forEbA

An important part of communication of EbA benefits in the context of the audience for this volume (technical officersfrom planning, agriculture, fisheries and disaster management institutions) will be through economic instruments, and more specifically, through cost benefit analysis.

In the context of climate change adaptation, a cost-benefit analysis aims to quantify the total expected costs of one or more adaptation options implemented in response to an observed or projected climate change impact, together with the total expected benefits so that alternative adaptation solutions can be directly compared. However, to accurately compare EbA approaches with alternatives, the cost-benefit methodology must be able to A) consider ecosystem service values in the local context (ie rather than use generic $ values for mangrove) and also B) set the boundaries of the system so that full costs can be considered of all alternatives (ie to ensure that the full impacts of each adaptation option can be internalized/costed).

On (A), there are a number of characteristics which guide the effectiveness of EbA in a given context, all of which have implications for cost benefit analysis. These characteristics include the size, location and species composition of the ecosystem, as well as the socio-economic characteristics and infrastructure. Table 1 illustrates the generalized characteristics of EbA in the coastal context.

Table 1 - Generalized Characteristics of EbA and Implications for Cost Benefit Analysis in the Coastal Context

| Factors | Effects | Implications for Cost Analysis |
|---|---|---|
| **Size of Ecosystem** | The relationship between ecosystem extent (or size) and provision of a service is a matter of debate. Researchers have assumed a linear relationship between size and ecosystem service provision,butBarbier et al (2008) argue that this leads to the "misrepresentation of economic values inherent in ecosystem service, particularly at their endpoints." Density of the vegetation might be as important as size for certain storm events, and the density and size affect both wave attenuation and the storm surge, with a larger area of low density mangroves being needed to achieve the same level of 'bioshield' protection as a small area of high density mangroves (Mazda et al., 1997; Massel et al., 1999; Komiyama et al. 2008). The economic implication here is that choices can be made regarding the area of conservation possible, based on the funds available to decision-makers. | Consideration can either be based on size of the ecosystem or density of vegetation in the ecosystem. There are also time issues involved for this and how might this play into designing an effective incentive scheme. For example, the short and long term costs and benefits of conservation for related ecosystem services (which would be provided at all times, not just during storm events). |
| **Location of Ecosystem** | For certain ecosystems, the location of the ecosystem effects the service it provides, and the value that can be measured represents important aspects in effectiveness of service delivery. For example, major differences in plant biomass are associated with major differences in wave attenuation; hence coastal protection likely varies with latitude. For mangroves, the highest wave attenuation is near the equator (Komiyama et al. 2008); for seagrasses, wave attenuation varies non-linearly with latitude, lowest at the equator (Duarte and Chiscano 1999). Hence valuation and planning based on the valuation must be based on sound quantification of the ecosystem service benefits with specific respect to location. | The cost of EbA will vary with the location of the ecosystem and the community served by that fringing ecosystem. In order to assess any costs of replanting, restoration, conservation and zoning/planning, the location where this would be effective would have to be determined, to make an accurate assessment. |
| **Species/ Habitat Composition** | Few studies have compared the wave attenuation functions of different species of mangroves, marsh plants, or seagrasses (Bouma et al. 2005). It remains unclear from research whether it is the structure of the barrier or the type of barrier that is key. Likewise, the "health" of the habitat and the capacity of the habitat to mitigate storms may or may not be closely linked. | The key question here is what species should be used, and the cost implications. From an economic point of view for shoreline protection, the species which have the greatest capacity for storm protection should be used for restoration. However there are issues with invasive species and fisheries which suggest the bundled nature of coastal ecosystem services must be taken into account. |
| **Activities in Coastal Area** | The management of activities in the coastal zone and associated catchments is an area of study that can be also called "ridge to reef" management. The management within this area, from the area that is nearest to the fringing habitat to several kilometers inland, can affect the value of the ecosystem service that is being considered. Depending on the methods used for valuation exercises (see Table 2), the ecosystem service values would likely differ. This issue is closely tied to the issue of size. | With only a few exceptions, urban areas in the Pacific Island Countries are located on the coast which makes them particularly susceptible to storm surges and potentially, flooding. These areas might experience higher property damage or higher mortality. In terms of estimating the costs, it is important to establish whether property damage or human mortality is being considered, even if it cannot be totally explained by economics. |
| **Socio-economic Factors** | Non-environmental factors affecting ecosystems and their capacity to provide ecosystem services are extremely important to examine. Issues such as population density, poverty levels, resilience of a community following a storm, governance issues (stability, federal to township issues, distribution of aid), population trends, land tenure etc. Demographic issues are important within the area served by the ecosystem, economic activities affected by the system, or shocks to the system will be important to estimate. | Socio economic factors drive people to live in certain places rather than others, and the coasts are especially affected by the influx of people. When planning for enhancing or protecting ecosystems which are natural buffers it is important to look at the factors driving this distribution. One main issue is that in poorer areas with less expensive housing, the natural barriers protect less valuable housing, which yields low estimates of ecosystem service value. However, many lives are affected and can be lost in these areas, and this is not possible(or morally acceptable) to quantify these losses economically. Socioeconomic factors also vary over time, respond to political events and other outside shocks, like climate. Hence, time series forEbA planning as well as scenario projections are crucial in order to prepare for different sorts of scenarios. Additionally, when |

| | | |
|---|---|---|
| | | calculating future values for ecosystems and their services, although this seems to be controversial amongst economists. |
| **Infrastructure** | Built infrastructure within the landscape can cause important linkages between ecosystems to be destroyed, resulting in higher damages after storm events, due to decreased adaptive capacity. | Infrastructure isgenerally expensive to replace so the durability and maintenance costs across the full design life must be considered, and ties into issues of spatial planning and zoning. Combined economic and spatial analysis, using land use, land cover, road and development data, can make estimating the costs of EbA plans clear. This will also help regional planners and municipalities anticipate some of the damage that infrastructure might undergo in a storm event, as well as help to plan out future development in areas not critical to mitigating the effects of storms. |

## 4.2 - Ecosystem Service Valuation forEbA

In terms of selection of the most appropriate method for ecosystem valuation exercises, there are a range of options, all of which can be classified as either 'direct market methods', 'revealed preference methods' or 'stated preference methods'. The merits and limitation of approaches under these categories were described under The Economics of Ecosystems and Biodiversity(TEEB) project - see Table 2. It is worth noting that the different valuation methods usually elicit different results, and that few studies make use of more than one method due to methodological issues. However, there is a more recent trend in the utilization of "mixed methods" which use both the valuation methods and qualitative research such as in-depth interviews or focus groups with stakeholders.

### Table 2 - Economic Methods Used to Value Ecosystem Services (from TEEB)

| **Direct Market Methods** | |
|---|---|
| Market price based approaches | The market price can be taken as an accurate reflection on the value of commodities. |
| Cost based approaches | These are based on estimations of the costs expected to be incurred if the ecosystem service benefits were recreated artificially (Garrod and Willis, 1999). |
| Production function based approach | Estimate how much a given ecosystem service contributes to the delivery of another service/commodity which is traded on an existing market. 2 steps: 1) determine the physical effects of changes in the resource/ecosystem service on an economic activity and 2) impact of these changes is valued in terms of the corresponding change in marketed output of the traded activity. This is the approach of the Natural Capital project. |
| **Revealed Preference Methods** | |
| Travel Cost | Estimate the demand for the resource based on the fact that recreational activities are associated with a cost. |
| Hedonic Pricing | Uses information about the implicit demand for an environmental attribute of marketed commodities. Value of a change in ecosystem service will be reflected in the change in the value of the property (house, etc.). Then "by estimating a demand function for property, the analyst can infer the value of change in the non-marketed environmental benefits generated by the environmental good." |
| **Stated Preference Methods** | |
| Contingent Valuation | Uses surveys to ask people to state their willingness to pay to increase the provision of an ecosystem good or service. (Or willingness to accept.) |
| Choice Modeling | Models the decision process of an individual, given alternatives, with and without shared attributes of ecosystem services |
| Group Valuation | Combines the above two methods with a deliberative process (from political science) which can account for pluralism, incommensurability, non-human values or social justice (Spash 2008). |

The appropriateness of applying these economic methods in an EbA context will be dependent on the current knowledge of the specific EbA relationship (ie the ability of an ecosystem type to attenuate specific impacts from climate change based on the characteristics in Table 1). Relationships for ecosystem types and their adaptation-relevant ecosystem function is further explored in section 5.

## Table 3 - Quantification Approaches for Ecosystem Services

| Research Effort | Description | Findings |
|---|---|---|
| **The Economics of Ecosystems and Biodiversity (TEEB)** | This study was undertaken to determine the "economic significance of the global loss of biological diversity. In terms of the research, much of it is conceptual, presenting different research frameworks. Appendices in the book detail the literature review exercise and the ranges of values were reported. | This research found that significant global and local economic costs and human welfare impacts were attributable to the ongoing losses of biodiversity and degradation of ecosystems. The TEEB products are designed to help policymakers, private sector and governments make decisions using an economic framework of analysis when determining ecosystem service value. |
| **Site level studies** | These arestudies done in a specific site, and use one of the various methods described in the previous page. | The findings of these studies vary widely, depending on geographic and physical factors. |
| **Meta-analytic Regressions** | Based on site level studies, which measure the value of the ecosystem services using various valuation techniques, we can try to understand what variables affect the value of the ecosystem service. This may help us determine how to achieve EbA in a least-cost way. This approach is to 1) do a literature review for studies 2) get the data from the literature regarding the ecosystem service value and standardize this value 3) collect a set of study, site and context variables that you think might influence the ecosystem service value 4) regress the dollar value of the ecosystem service on this set of explanatory variables 5) then finally do a benefit transfer(where estimates for one context are based on benefits from another context) from these study sites to policy sites (areas where the study has not been done) and estimate the accuracy. | The ecosystem service values ($ /ha/yr), taken from site-based ecosystem service value studies, are regressed on a series of explanatory variables. These variables are site characteristics (includes ecosystem size and type), study characteristics (includes year of the study, ecosystem service, valuation method), and context variables (includes level of development, biodiversity indices derived from Ocean Biographic Information System(OBIS) data, population density, etc. ). The ones which so far seem to affect significantly the ecosystem service value are size, type of ecosystem service, development index and region/geographic characteristics. After determining the regression, we use a benefit transfer to estimate the value of the ecosystem service in areas where the particular ecosystem exist. This paper covers only coral reef, mangrove and coastal wetland ecosystems. |

There are a number of studies which aim to value ecosystems, and such studies can be instructive in understanding the relative value of these systems. For example, mangroves are critically important as breeding and nursery areas for many important species of fish and prawn and represent an important source of timber. For example, In Matang, West Malaysia, 40,000 hectares of managed mangrove forest in yield $10 million in timber and charcoal and over $100 million in fish and prawns every year to the local economy(Talbot and Wilkinson 2001). In Southern Thailand, mangrove forests provide an estimated $3,679 NPV of coastline protection and stabilization service per hectare (Suthawan and Barbier 2001).

Coral reefs also play an important role in protecting the coastline and providing a buffering capacity (i.e. acting as breakwaters). The role of this service varies, depending upon the activity it is protecting along the coast. For example, in Indonesia reefs have been valued at US$829/km, based on the value of agricultural production that would be lost if there was no protection, and US$50,000/km in areas of high population density, and $US1 million/km in areas of tourism with the associated cost of maintaining the sandy beaches (Wells et al. 2006).

While there is less awareness of the ecological functions associated with seagrasses than with coral reefs and mangroves, their functions are no less important, and have been estimated to be worth $1.9 trillion in the form of nutrient cycling (Waycott, 2009). Other relevant ecosystem services provided by seagrasses and seagrass meadows that are relevant to food production include resource provision for coastal food webs, increased oxygen content of waters and sediments, prevention of sediment resuspension, wave attenuation and shoreline protection (Duarte, 2002).

However, the methods under which the $ figures specified above were derived need to be considered against the local context to have any practical influence over planning and development agencies; the real value of a mangrove ecosystem needs to be expressed in terms of specific contributions to the local economy. For example a mangrove ecosystem would be more valuable in an area that is adjacent to a highly populated human settlement, and less valuable in an area that is not prone to cyclones and storm surge (eg the Galapagos Islands).

## 4.3 - Resilience Frameworks for EbA

The concept of resilience is embedded within many discussions on climate change adaptation, and can be defined as follows:

> *Resilience is the capacity of a social-ecolocial system to absorb a spectrum of shocks of perturbations and to sustain and develop its fundamental function, structure, identity and feedbacks through either recovery or reorganization in a new context(Chapin et al, 2009)*

For example, a resilient watershed will be able to return to its original function following a flooding event, or a resilient person will be able to recover quickly following an illness.

One of the most important characteristics of resilience is the recognition that complex adaptive systems are constantly changing in a ways that cannot be fully predicted or controlled*(Chapin et al, 2009).* This differentiates resilience-based approaches from vulnerability-assessment/downscaling approaches to climate change adaptation in which efforts focus heavily on trying to characterize the future climate and the impacts of the future climate on the local system. Rather, resilience-based approaches will establish a 'robust' system configuration that capable of maintaining function across the broadest range of climate futures(Wilby and Dessai, 2010). Hence, resilience is particularly relevant concept when working in areas with low quality of historical climate data(with which to validate projections) and high climate variability.

The comparison of engineering resilience and ecological resilience is also an important consideration forEbA. One definition of engineering resilience suggests that it is: '*the rate at which a system returns to a single steady state following a distrurbance*', while a definition of ecological resilience is'*the amount of distrurbance a system can withstand before it changes to a new set of reinforcing systems of structures*'(Freitag, 2009). Hence engineering resilience aims to establish a fail-safe system(ie there is enough redundancy so that the system will not fail), whereas a ecologically resilient system will be more likely to fail, but less likely to result in catastrophe when this failure occurs. Freitag goes on to compare the characteristics of engineering and ecological resilience in the context of flooding (see table 4)

**Table 4 - A Comparison of Engineering and Ecological Resilience (adapted from Freitag, 2009)**

| Engineering Resilience | Ecological Resilience |
|---|---|
| • Seeks stability | • Accepts inevitability of change |
| • Resists disturbance | • Absorbs and recovers from disturbance |
| • Single acceptable outcome | • Multiple acceptable outcomes |
| • Predictability | • Unpredictability |
| • Fail-safe | • Safe-fail |
| • Rigid boundaries and edges | • Flexible boundaries and edges |
| • Efficiency of function | • Persistence of function |
| • Redundancy of structure | • Redundancy of function |

Alternative approaches that focus on 'resilience' include tools that enable decision makers to consider as many of the intended and unintended consequences as possible, but are still intuitive and enable quantitative comparisons between engineering and ecological resilience. Mechler (2005) suggested that ‘fragility curves’ are a useful tool to identify changes in direct and indirect losses to different classes of assets in relation to hazard parameters such as flood depth or earthquake intensity. These curves are presented in the context of hard and soft resilience[2] in the case of disaster risk reduction, which are concepts that are analogous to engineering and ecological resilience.

The curves typically include a damage ratio (in percentage) on the y axis and event intensity (e.g. flood depth) on the x axis, enabling 'ideal' points of investment to be identified and direct comparisons to be made – see figure 1. This example from Semarang in Indonesia estimates the degree of direct and indirect damage for different sectors as damage increases with flood depth. While there are limitations to this approach, mostly due to data availability, it offers a conceptual entry point of a broad range of alternatives, which would need to be followed by more detailed analysis.

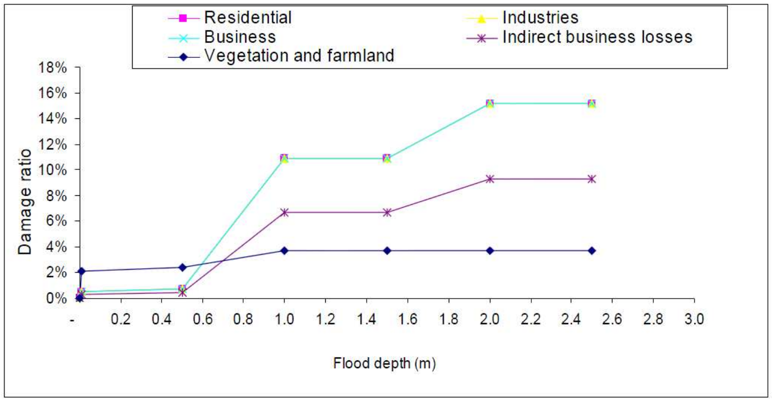

Figure 1- Fragility Functions for Semarang, Indonesia (Mechler, 2005)

The following 3 figures (adapted from Moench, 2009) illustrates how these fragility curves can be used to inform decisions that compare the relative merits of soft versus hard resilience-building measures for adaptation. Figure 2 illustrates a typical pre-adaptation example, Figure 3 illustrates a hard resilience solution (note the 'inflection point' or point of 'structural failure' at flood depth of 2.5m) and figure 4 offers a soft/ecological resilience solution.

While real systems are more complex, these examples illustrate the key concepts, including the inflection point: the point of structural failure designed into the 'hard resilience' options.

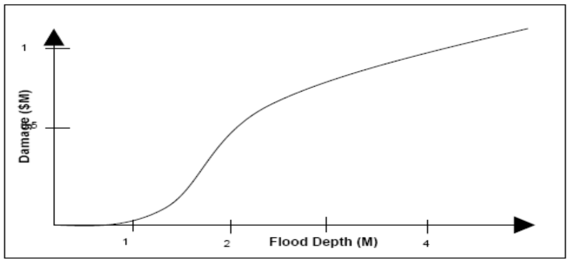

Figure 2 - Example of an Unprotected System (i.e prior to adaptation)

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[2] In this case 'hard resilience' refers to the direct strength of structures or institutions when placed under pressure, and 'soft resilience' is the ability of systems to absorb and recover from the impact of disruptive events without fundamental changes to structure. This differs slightly from the engineering vs ecological resilience

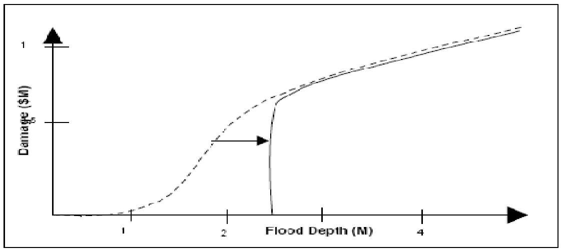

Figure 3 - Example of a Hard Resilience Solution for Adaptation (eg river levees)

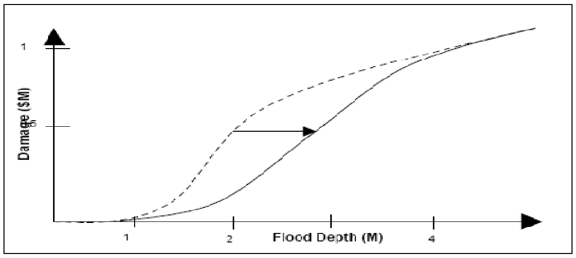

Figure 4 -Example of a Soft Resilience  Solution for Adaptation (eg restoration of riverine vegetation)

The key conclusion for this assessment tool is that with greater uncertainty, making an engineering decision on an acceptable point of inflection/failure becomes more difficult, and soft options become more appropriate.

# 5 - Potential EbA Options in the Pacific Context

Based on the range of development, ecosystem and climate change contexts across the Pacific Island countries, a set of EbA options is offered, within which generalized information is presented on the current state of knowledge, advantages and disadvantages when compared with alternatives, and wherever possible information from case studies and indicative cost ranges.  As conceptualization of the role of EbA in the development context was identified as a challenge in the survey feedback (See Background Paper #3), introductory illustrations have been established and are presented along with the description of each relationship to aid with this conceptualization.

An important factor to note in many of these relationships is the existence of a 'threshold point' - ie where environmental stress is such that the EbA service essentially ceases ie  the environmental stress is greater than the assimilative and regenerative capacity of the ecosystem. For example, while seagrasses are able to remove a certain quantity of additional sediment loading associated with changes in precipitation regimes (due to, for example,a longer dry season and shorter, more intense wet season) high levels of sediment, above a particular threshold will kill the seagrass communities.A major knowledge gap in the field of EbA is quantifying what these thresholds are, since they vary by ecosystem, stressor and by service.

## 5.1 - Coastal Vegetation and Storm Surge/Cyclone Protection

In order to understand the potential role of ecosystems in protecting coastal areas from surge resulting from cyclones in comparison to 'hard resilience' alternatives, it is firstly necessary to examine the objectives of the many different forms of coastal defenses. One of the most common typologies for coastal adaptation approaches was proposed by the Intergovernmental Panel for Climate Change's(IPCC) Coastal Zone Management Subgroup(1990), as follows:

**1 - Protect(P):** defend vulnerable areas, especially population centres, economic activities and natural resources

**2 - Accommodate(A):** continue to occupy vulnerable areas, but accept the greater degree of flooding by changing land use, construction methods and/or improving preparedness

**3 - Retreat(R):** abandon structures in currently developed areas, resettle inhabitants and require that new development is set back from the shore, as appropriate. Unplanned retreat is not considered.

The selection of appropriate technologies that sit under these three categories needs to be guided by the local objectives(likely to be defined by adaptation planning in this case) and available resources across the full life cycle of the technology. The following table outlines the objectives of some of the most popular technologies that sit under these three categories, and provides broad cost estimates for construction and maintenance:

### Table 5 - Objectives and Costs of Coastal Protection Technology Options

(Adapted from Zhu, 2010, TEEB, 2010)

| Type | Technology | Objective (Primary and Secondary) | Construction (USD low) | Construction (USD high) | Maintenance USD/annum |
|---|---|---|---|---|---|
| P | Sea Walls | Erosion reduction + coastal flood defense | $0.4/km | $27.5M/km | High |
| P | Sea Dikes | Protect low-lying coastal areas from inundation from the sea under extreme conditions | $0.9/km | $29.2M/km | $0.03M-$0.14M |
| P | Closure Dams | Preventing extreme water levels from penetrating and estuary | $0.7/m | $3.5M/m | 5-10% |
| A | Wetland Restoration | Reduce coastal flooding + new habitats + environmental benefits | $41/ha | Unknown | $41/ha[3] |
| A | Flood Proofing | Reduce or avoid the impacts of flooding on structures | $2.2/ft2 | $17/ft2 | Low |
| R | Managed Realignment | Reduce both coastal flooding and erosion | Unknown | $97,000/ha | Low |
| R | Coastal Setbacks | Establish a prescribed distance within which all development is prohibited | Land cost | Land cost | Enforce ment |

As the financial figures provided are from a range of contexts in developing and developed countries and cover a wide span of cost and associated quality, caution should be exercised in including lower end budgets in planning. Note that there are other coastal technologies that are not included in this list as they do not appear in developing countries due to the significant capital and maintenance expense, such as the storm surge barriers used in the River Thames in London, UK.

In addition to the figures presented in this table, the full environmental impacts of the specific design under each technology needs to be properly considered. For example, many of the hard structures, such as seawalls, are likely to cause significant 'downstream' damage/erosion due to changes in sediment dynamics, and local issues caused by 'overtopping' of waves.

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[3] Maintenance is based on thinning, from year 6 onwards.

The effectiveness of each of these technologies in meeting their objectives is the subject of some debate, with the lowest level of confidence commonly being placed in the protective function of wetland protection or restoration - often referred to as a 'bioshield'. As noted by Feagin (2010) '*coastal vegetation has been widely promoted for the purpose of reducing the impact of large storm surges and tsunami' but also observes that a UNEP study found that vegetation had no effect on Tsunami inundation at 52 sites across the Indian Ocean'.* Following the analysis of the protective function of vegetation against the Indian Ocean Tsunami of 2004 and given the structural similarities between tsunami and storm surge (both being long period waves) there are suggestions that the impacts of these extreme events are significantly more dependent on other physical factors like topography, near-shore bathymetry and distance from the shore(Mukherjee, 2010).

However, there are other compelling arguments for a viable protective function for climate-related phenomenon. *(Das et al 2009)* argued that through restoration of mangroves the average opportunity cost per life saved (based on mangroves hurricane protection function) in Orissa, Indiais 11.7 million rupees - see figure 5. In a developed country context, Costanza(2008) use meta-analytic regression techniques to argue that annual value of coastal wetlands for hurricane protection in the USA amounts to US$ 8,240 per ha per year - see figure 6.

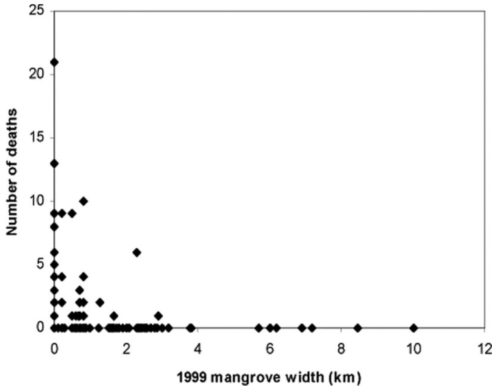


**Figure 5- Average Opportunity Cost of Saving a Life by Retaining Mangroves in Orissa, India (Das, 2009)**

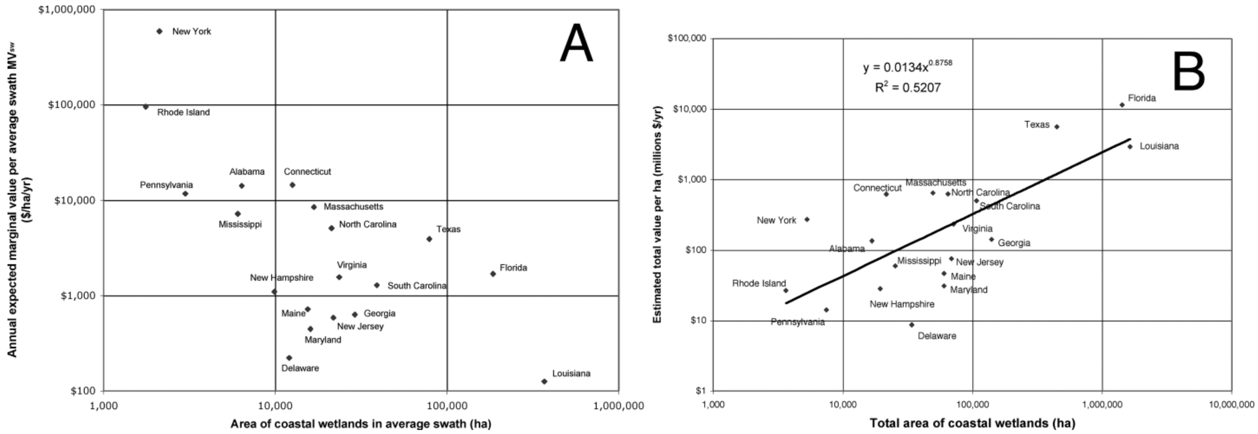


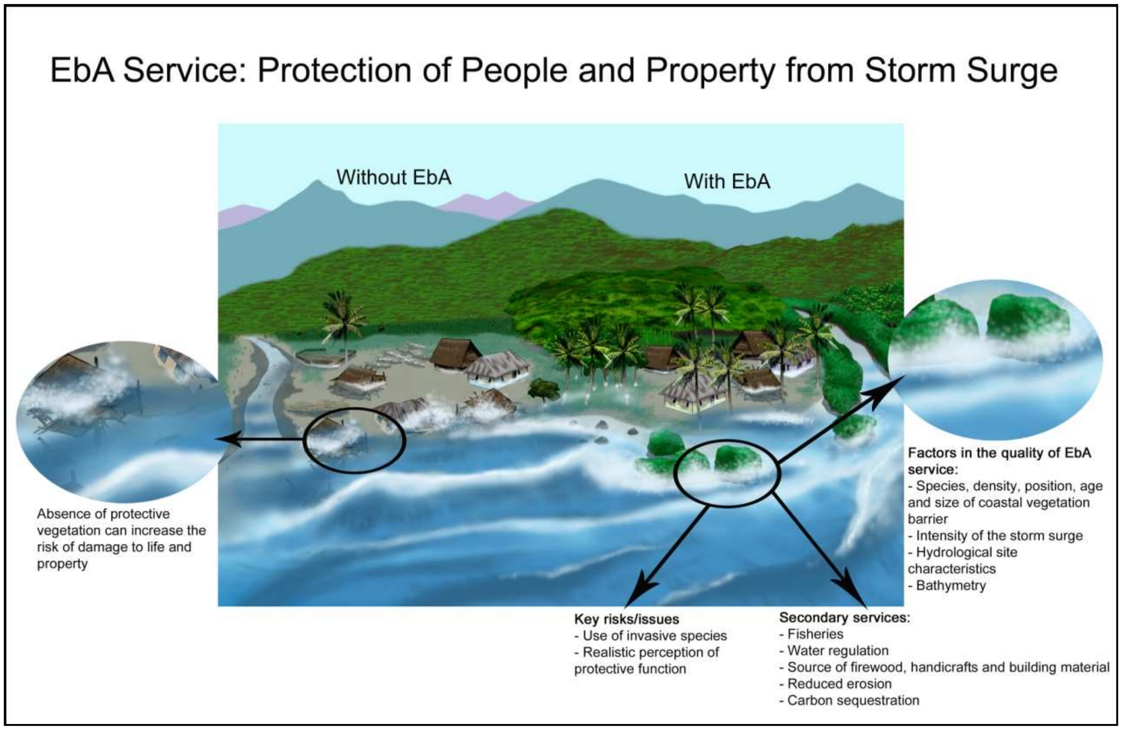
**Figure 6 - Annual Value of Coastal Wetlands for Hurricane Protection in the USA (Costanza, 2008)**

Cleary, there is a role for rehabilitation or restoration of mangrove systems in areas of risk of extreme climate events but in such cases the precautionary principle should be applied and also vegetation should be a part of a broader DRR strategy. Also, the expectation of strong protective function across the higher end of extrem events needs to be carefully managed. For example, looking at the Saffir-Simpson Scale in Table 6, it is unlikely that mangrove systems could provide significant protection against category 4 or 5 events given the scale of storm surge.

**Table 6 - Saffir Simpson Scale for Hurricanes (Ewing, 2010)**

| Category | Wind Speed (km/h) | Storm Surge (m) |
|---|---|---|
| 1 | 119-153 | 1.2-1.5 |
| 2 | 154-177 | 1.8-2.4 |
| 3 | 178-209 | 2.7-3.7 |
| 4 | 210-249 | 4.0-5.5 |
| 5 | >250 | >5.5 |

In the case of design of restoration programs, the emphasis of such programs should be on the restoration of ecosystem function in the local hydrological context, rather than getting the seedlings 'in the ground'. While such programs are more complex to design and implement, this is preferable given the large failure rate in restoration programs due to planting of inappropriate species, and in inappropriate locations (MAP, 2011) and in light of the additional livelihood benefits of a more rigorous approach in terms of primary and secondary productivity. The 6-step program to the ecological restoration of mangroves outlined by the Mangrove Action Project (www.map.org) provides guidance on avoiding the 'pitfalls' in mangrove restoration programs, including species selection, hydrological considerations and rehabilitation design.



However, the role of bioshields in coastal protection also has the potential to illustrate the differences between ecosystem services and biodiversity, and the tradeoffs between the two. As Feagin et al (2010) notes, there are instances in which bioshield plantations have displaced native vegetated ecosystems. In some locations, exotic *Casuarina* plantations have been promoted as a better alternative to native vegetation species. They further note that in some areas in India, "*sand dunes have been flattened to make way for these plantations, destroying sea turtle nesting habitat and reducing the natural effectiveness of coastal dune topography to provide protection from storms*" and also highlight the displacement of indigenous peoples within bioshield plantation areas. In order to avoid the potentially negative impacts of bioshield policies and emphasize their positive roles, Feagin introduced the use of a decision tree for policy-makers(Figure 7). At each branch within this decision tree, policy-makers ascertain that the policies produce realistic and sustainable outcomes. Such decisions are related to site selection, and support decisions that place native species in appropriate locations.

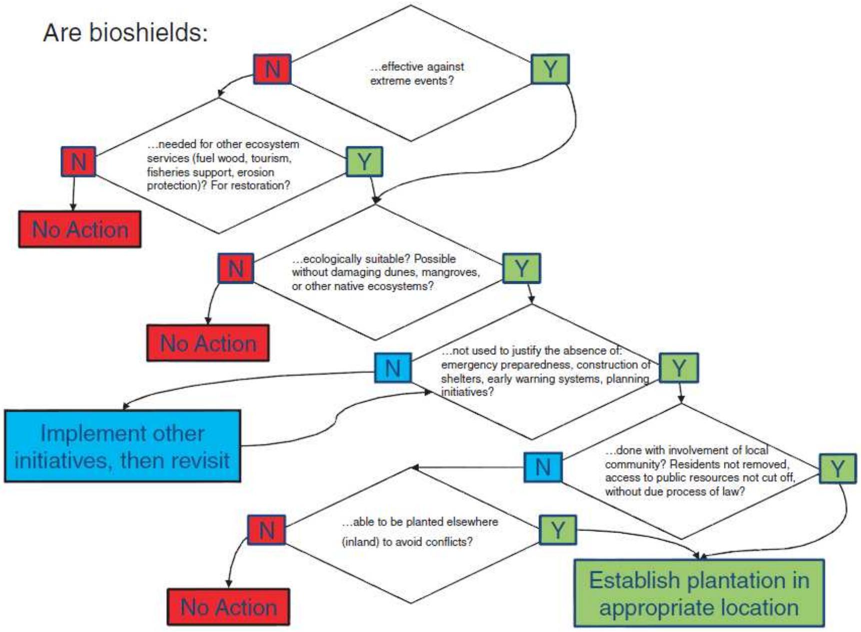
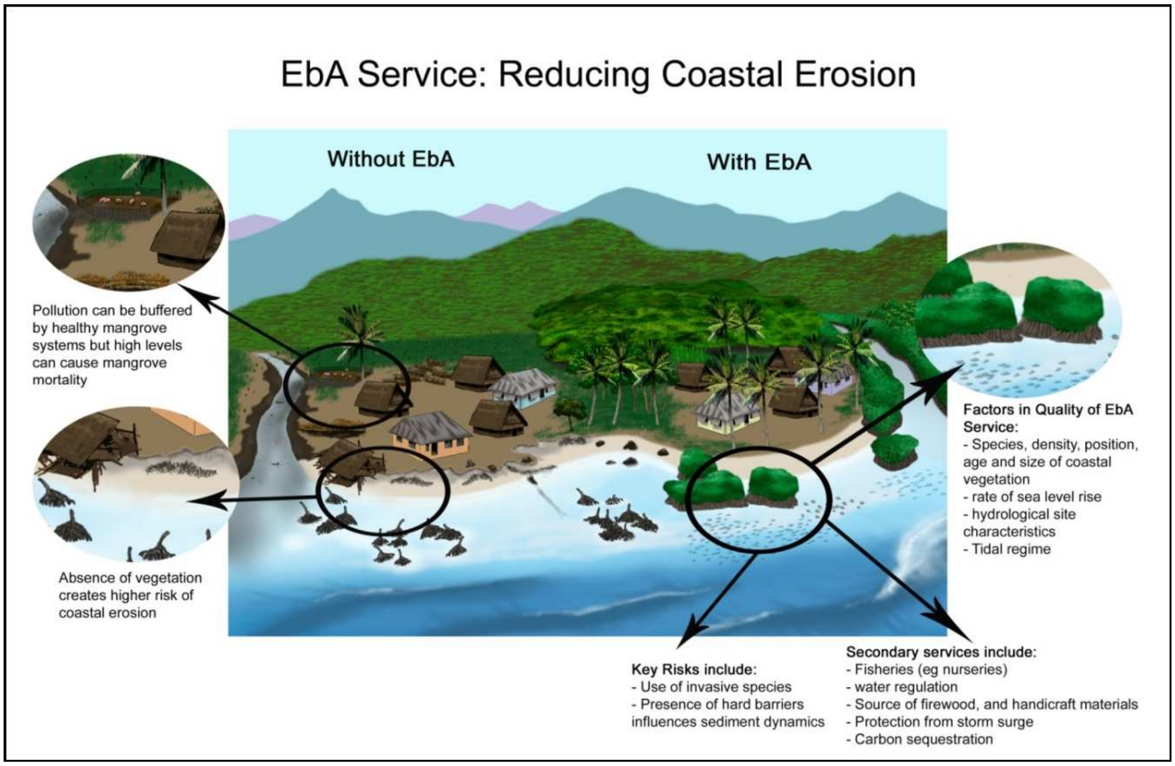


Figure 7 - Decision tree for the establishment of bioshields in appropriate locations (Feagin, 2010)

**Case Study** : Following the tsunami in Samoa in 2008, a campaign was established by Conservation International and the Kulunani Urban and Community Forest Program to encourage the establishment of 'bioshields'. This was an awareness raising program that encouraged communities to both avoid cutting down coastal trees and forests, and also plant native and useful trees and shrubs at the coast. Importantly, the guidance suggested the use of specific buffer species (i.e.in planting the first 10 metres) and secondary species to plant from 10-50 metres. Such resources are a strong example of low cost community education in areas where there is a extremely strong awareness of coastal vulnerability. The challenge for EbA in the disaster context is to encourage such activity without the additional incentive of a recent disaster event.



## Summary for Adaptation Planners: Coastal Vegetation and Storm Surge/Cyclone Protection

### Key Issues:

-No ecosystem or any hard solution can guarantee full protection to people in the face of an extreme climate vent, such as a category 5 cyclone or major tsunami.

- Mangroves and other coastal vegetation can provide some protection from storm surge and cyclone damage, but should be considered as part of a broader disaster risk reduction strategy
- There is a high level of confidence in the ability of mangroves to stabilize erosion when compared to hard structures
- The selection of appropriate species as a bio-shield is critical

### Considerations for Cost-Benefit Analysis:

- With careful attention to species selection and placement, hydrology and storm levels expected/projected, coastal vegetation has a high potential to be a desirable mechanism to reduce the impact of storm surge. To determine what approach to take, the planner can examine whether vegetation restoration is feasible in the area, the costs of restoration, the time scale over which the restoration will become effective. If due to hydrological reasons mangrove restoration will be more expensive and less effective than a different bioshield or built infrastructure, then alternative or combination approaches should be considered.
- Include planning and design costs. Consider using a combination of hard and soft solutions in order to protect the coastline and communities effectively. Note that conventional elements of Disaster Risk Reduction (DRR) such as early warning systems should be a key component of an adaptation strategy because higher intensity storms coupled with degraded habitats, could lead to ineffective protection.
- Note also the additional economic benefits (i.e. the co-benefits) of multiple ecosystem services that are protected/generated along with the coastal vegetation conservation/restoration, such as subsistence activities (e.g. improved fisheries) and cultural amenities, such as recreation.

## 5.2 - Slope Vegetation and Landslide Risk Reduction

Likely changes in the intensity of precipitation and/or changes in the timing or duration of the rainy season under new climate regimes creates an increased potential for landslides in areas with steep slopes, particularly where vegetation has been removed. A number of studies have been undertaken to assess the nature of this relationship, and the results from these studies present several EbA opportunities for areas already affected by landslides as well as those that are likely to be affected in the future. One example is based on field investigations in various areas of the Pacific Rim which found that landslide rates increased by 2 to more than 10 times during the period of 3 to 15 years after clearcut timber harvesting(Bishop and Stevens, 1964). Clearly, the information on this important relationship is not new, but has only more recently been placed in the context of climate change adaptation in developing countries.

Landslides are shearing displacements between two masses of material along along a surface or within a thin zone of failure(Kehew, 2006). There are a number of other processes that change the safety factor (a ratio of resisting to driving forces) relating to a landslide, the most simple of which is to remove material from the base of the slope. Other processes include addition of weight to the slope, including from the presence of water(Kehew, 2006).

The two key characteristics of vegetation that can change the safety factor are 1) the ability of the vegetation to modify the soil moisture regime through evapotranspiration processes, and 2) the ability of the vegetation to provide root cohesion to the soil mantle (Siddle, 2008). For the first function, when large and high intensity storms occur - deep roots of woody vegetation candry the soil at greater depths compared to shallow-rooted vegetation (McNaughton and Jarvis, 1983). The second function (related to root strength) makes a more significant contribution to slope stability in 2 different ways: in shallow soils, tree roots may penetrate the entire soil mantle and anchor the soil into more stable substrate. Secondly, dense lateral root systems in the upper soil horizons form a membrane that stabilizes the soil and larger tree roots can provide reinforcement across planes of weakness. (Siddle, 2008).

Borja-Baeza (2006) undertook an analysis of landslides distribution resulting from extraordinary precipitation events in terms of their likely relationship with vegetation cover density following the rainfall induced landslides of October 1999 which devastated communities of the Sierra Norte, Puebla, resulting in more than 250 victims and economic losses greater than $ 450 million. This analysis (see figure 8) was aided by the use of spatial tools, and went on to produce a map of potential areas of mass movement based on the combination of a socio-economic vulnerability index, geologic and geomorphological maps and the spatial landslide distribution.

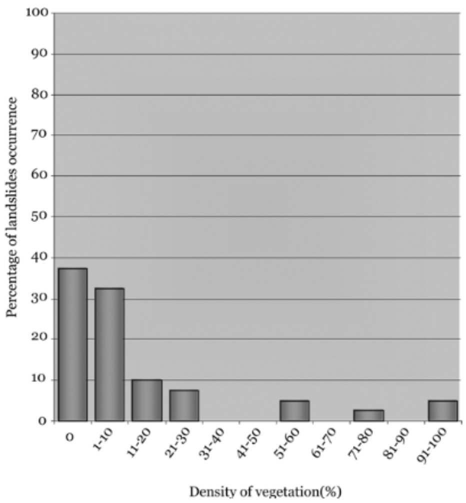


**Figure 8 - landslide occurrence as a function of vegetation density**

Both of the evapotranspiration and soil cohesionfunctions havea particular implications in cases where woody vegetation on sleep slopes is removed for the purposes of agricultural production, where such risks are likely considered, but the short term benefits associated with land conversion commonly outweigh the risks of erosion.

There are some limitations to this function, with studies suggesting that root strength contributes to the reinforcement of shallow soil mantles, (1-2m) but does not affect deeper (>5m slides) (Siddle, 2008)

This relationship also has implications for agriculture: Philpott et al (2008) found that at the farm scale, increasing management intensity (i.e. reduction in vegetation complexity) correlated with increased proportion of farm area affected by landslides and that reduction in vegetation complexity was correlated with increased number and volume of roadside landslides at the landscape level. This suggests that mono-cropping operations with typically low complexity will translate to a higher risk of landslide. The policy and management implications of this are that more diverse agricultural regimes should be applied to reduce risk in areas of agricultural production that are vulnerable to increased severe weather events, In Pacific landscapes, practical steps could include the integration of native and agroforestry operations to reduce the risk of landslides in agricultural areas where increased high intensity rainfall events are expected.

Additionally, this relationship also has important implications for restoration activities for purposes of EbA. In a Japanese case study that examines data in a forestry catchment over a period of 40 years it is suggested that landslide, erosion and sediment delivery to streams is reduced by 4 to 5 times compared to young forests with little root structure, see Figure 9. This suggest that the time periods associated with restoring functionality are reasonably long, and that rapid benefits (ie<10 years) should not be expected(Siddle, 2008).

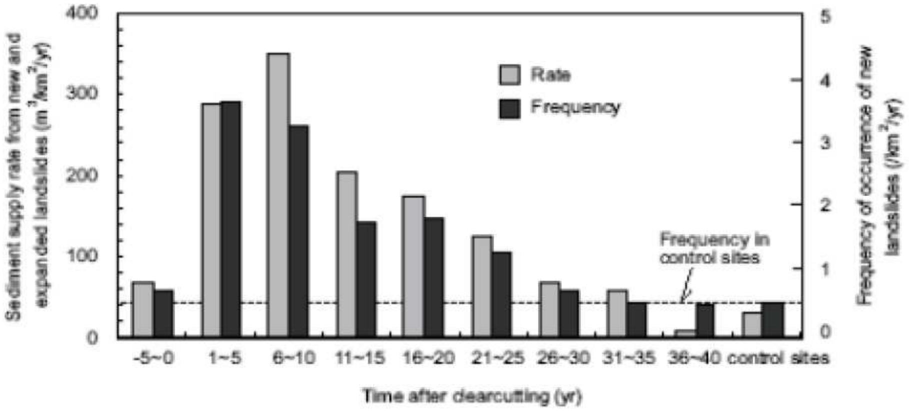
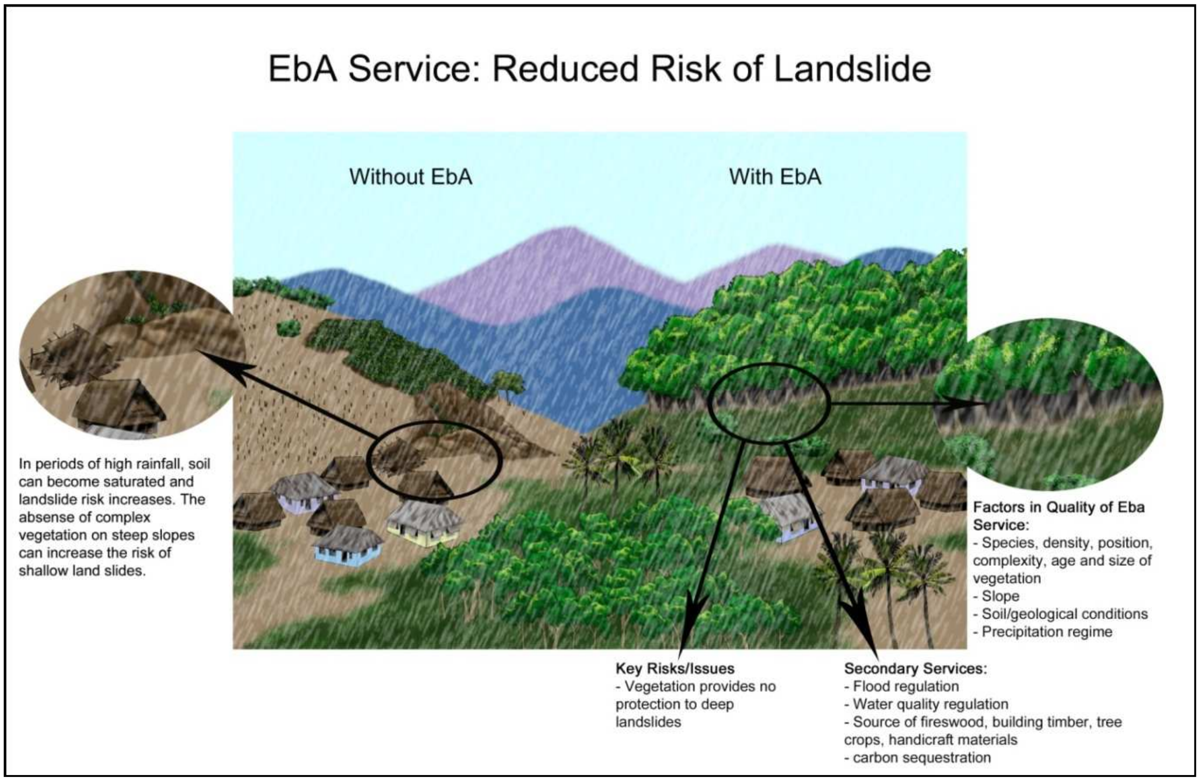


Figure 9 - Frequency of Landslides and Sediment Supply Rate for New and Expanded Landslides (Imaizumi,2008)

There is generalized guidance on the relationship between vegetation and landslide risk that suggests that removing woody vegetation on slopes exceeding 40 degrees should be avoided, and also in concave slope depressions(hollows) that accumulate subsurface water. As with all of these EbArelationships, the 'devil is in the detail' and local conditions need to be considered ahead of such guidance.



EbA Service: Reduced Risk of Landslide

In periods of high rainfall, soil can become saturated and landslide risk increases. The absense of complex vegetation on steep slopes can increase the risk of shallow land slides.

**Factors in Quality of Eba Service:**
- Species, density, position, complexity, age and size of vegetation
- Slope
- Soil/geological conditions
- Precipitation regime

**Key Risks/Issues**
- Vegetation provides no protection to deep landslides

**Secondary Services:**
- Flood regulation
- Water quality regulation
- Source of fireswood, building timber, tree crops, handicraft materials
- carbon sequestration

**Summary for Adaptation Planners: Slope Vegetation and Landslide Risk**

### Key Issues:

- There is confidence that the risk associated with shallow landslides can be reduced by increasing the complexity of the vegetation on slopes
- The strength of this relationship is defined by root strength and the ability of the vegetation to reduce the soil moisture through transpiration.
- Removing woody vegetation on slopes exceeding 40$^{o}$ should be avoided

### Considerations for Cost-Benefit Analysis:

The main issue for EbA projects involving conservation or restoration of native vegetation on slopes is that the opportunity cost may be too high; that is, the land could be used for crops or cleared for other activities and the associated revenue would be higher. Hence in a restoration scheme, accounting for opportunity costs or any compensation schemes to landowners should be included. In addition, any maintenance costs should be included. Finally, the time frame of the project should be included in the analysis. The main issue here for landslides is underlying geomorphology, which affects whether the vegetation on the slopes will be effective or not.

## 5.3 - Floodplain and Riverine Vegetation and Reduced Flood Damage

With likely changes in seasonality and increases in extreme climatic events under climate change, the floodrisk will increase in some regions. The capacity of floodplain vegetation to both delay a flood eventand reduce the total volume of flood waters/flood wave is highly dependent on the characteristics described in Table 1, as well as the size of the precipitation event and previous hydrological situation.

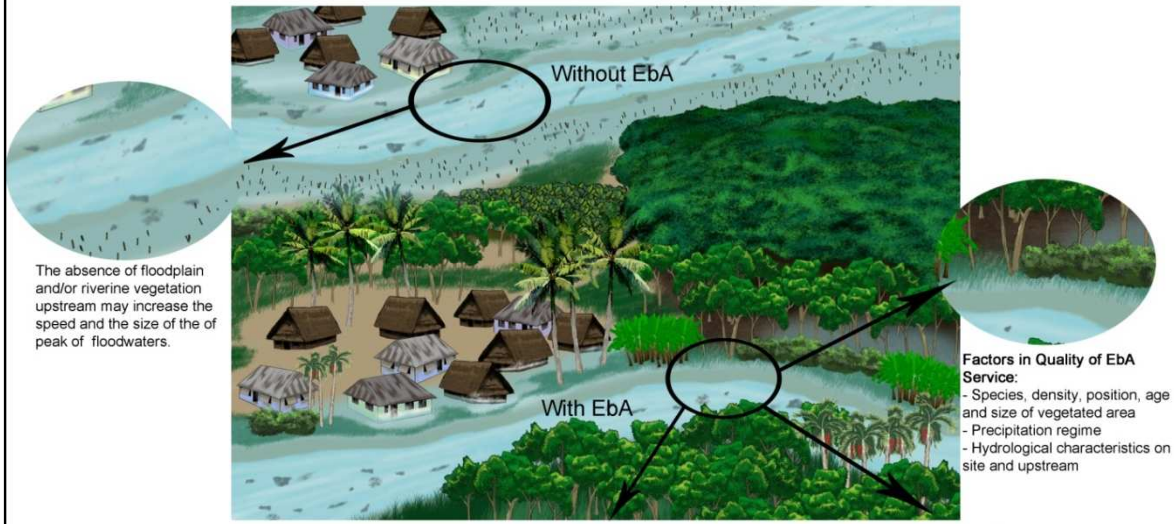
The risk of flooding willgenerally  increase as native vegetation in floodplains is converted in to agricultural and urban uses (Bates et al. 2008). Some researchers advocate levee removal and conversion of land back to native vegetation in order to improve flood protection capacity, and acknowledge there will therefore be high upfront costs (Opperman et al. 2009). While this is principally a problem in more developed countries, less developed countries can expect to see urbanization threaten the flood protection potential of their floodplains as well (Tockner and Stanford, 2002).

In a recent study on this topic in Chile, Ebert(2010) notes that anthropogenic land use changes increase the exposure of residents to potentially hazardous events and aggravate flood hazards by increasing surface water runoff after precipitation events.  Wetland retention on the other hand has been shown to reduce property damages in floodplains from flood events, when compared to built structures (Brody et al. 2009). While many studies of property damage due to floods are found in developed country research literature, the 'flashiness' of the hydrographs for tropical cyclones suggests that the problem with floods may be particularly severe in tropical developing countries(Terry et al. 2009).

This EbAfunction is typically considered within urban planning and various models are available to predict responses.  However, the classification system used within these models are typically divided into a small number of broad types: evergreen forest, cropland, pasture and the effects of finer land use classification and spatial distribution is difficult to determine from existing hydrological data (Jakeman et al, 2005).

Nevertheless, a number of studies have attempted to quantify this relationship based on observation of response under real flood conditions.  In a case study in the River LuzniceFloodplan in the Czech Republic,Pithart (2008) compared the performance of three floodplain segments (one preserved and two heavily transformed), it was estimated that the peaks were delayed by two days due to the floodplain vegetation in the preserved segment of this 12km long floodplain.

EbA Service: Reducing Flood Risk



The absence of floodplain and/or riverine vegetation upstream may increase the speed and the size of the of peak of floodwaters.

**Factors in Quality of EbA Service:**
- Species, density, position, age and size of vegetated area
- Precipitation regime
- Hydrological characteristics on site and upstream

**Key Risks/Issues:**
- Tradeoffs often exist between local effects versus 'whole of catchment' effects
- Allowing rivers to reconnect with landscapes may be more important that vegetation in some scenarios
- Use of invasive species

**Secondary Services:**
- Source of firewood, building timber, tree crops and handicraft materials
- Water quality regulation
- Carbon sequestration

Another example is from studies in Thailand in the 45.3km$^2$ Mae Uam sub-catchment. Using the IHACRES model, Jakemanet at (2005) demonstrated that deforestation increased the 'quick-flow' component of surface water, and also increased the total annual discharge. The dry season 'slow flow' component was higher in forested scenarios - where the majority of the streamflow derives from water that has percolated through the soil subsurface. Jakeman suggests that in forested catchments, deforestation of 20% was necessary before changes in streamflow can be observed.

## Summary for Adaptation Planners: Floodplain Vegetation and Reduced Flood Damage

### Key Issues:

- Floodplain vegetation has the capacity to delay flood waters and reduce the total volume of flood waters/flood wave
- This is a well understood function and many models are used to characterize this relationship within the context of urban planning and flood management.

### Considerations for Cost-Benefit Analysis:

- A major issue in floodplain re-vegetation is that these areas are usually inhabited by humans (urban areas) or used for agriculture. Hence damage to property and livelihoods in areas with unprotected floodplains can be substantial, and the associated costs huge. The case then, for instituting policies of protection and restoration of floodplain vegetation will generally be clear. The main issue here will be the lost income from valuable floodplain lands used for urbanized settlements or highly productive agriculture. In order to make floodplain vegetation an effective tool against flood damage, it must therefore be combined with strong zoning and enforcement, coastal vegetation restoration and proper incentives for implementation from the government.

## 5.4 - Seagrasses and Reduced Sedimentation

While sedimentation is one of the key causes of seagrass decline (Orth, 2006) the removal of sediment from the water column  prevention of its re-suspension is the key ecosystem function of seagrasses relevant to EbA. Bjork(2008) notes how the extended rhizome and root systems of seagrasses stabilize ocean floor sediments and prevent them from being re-suspended.  This function will help to maintain primary and secondary productivity in the coastal zone and is likely to become more important under increasingly variable climate conditions and is therefore a potentially important EbA function in areas where precipitation increases combined with source of sediment (ie from urban or agricultural development) are likely.

The potential for seagrass communities to provide these services is strongly dependent on the threshold at which the sedimentation rate surpasses the ecosystems ability to cope, leading to mortality:i.e.where sediment deposition is greater than the ability of the seagrass beneath it togrow through the sediments using energy reserves, plants will die. However, in a recent study of seagrass communities in the Great Barrier Reef, Waycott (2008) notes that no data on the specific sensitivity of seagrasses to burial is available although it is intuitive that larger, more robust species such as *Thalassiahemprichii*and *Enhalusacoroides*are more likely to survive than smaller ephemeral species.

Seagrass ecosystems can also be degraded by pesticides from agriculture, which can be washed into delta's and near shore waters as run-off. In the Pacific, however, the use of pesticides is generally a less significant problem relative to other regions due to the prevalence of shifting cultivation as a soil conditioner rather than a dependency on fertilizer. The increased turbidity associated with an increased likelihood of storm events and the availability of sediment from shifting cultivation means that sediment management in coastal areas could be a significant focus of EbAefforts(FAO, 2010). Importantly, the threat of sedimentation overcoming the ecosystem's ability to cope is relatively low.

Again in the study of the Great Barrier Reef, Waycott(2008) notes the ability of seagrasses living near the mouth of rivers to recover from sediment burial, and predicts a low vulnerability to this exposure threat. However, he adds that structurally smaller species will be more vulnerable to the impacts of sediment deposition as a small change in sediment profile will cover or erode them. A further physical benefit of seagrasses is their ability to attenuate waves, thereby protecting shores from erosion (Koch 2001).

One of the challenges for managing seagrasses for EbA in the tropics is the ephemeral nature of their distribution; their position can change from year to year, making monitoring and associated management difficult.

### Summary for Adaptation Planners: Seagrasses and Reduced Sedimentation from Floods

**Key Issues:**

- In coastal areas with high land use changes and increases in flooding risk, seagrasses can help to maintain primary and secondary productivity
- This function is species-specific, and local studies would be required to understand associated thresholds before the full EbA potential can be understood.
- The ephemeral nature of tropical seagrasses makes monitoring and management difficult

**Considerations for Benefit Cost Analysis:**

Due to their movement, incorporating protection and restoration of tropical seagrasseswithin a cost-benefit framework may be challenging.

## 5.5 - Agroforestry and Agricultural Yield Stability

High agricultural yields can be achieved and maintained in monocropping operations when precipitation and temperature regimes are maintained within optimal growth parameters. However, in areas where increased climate variability is likely, farmers will need to find techniques that are increasingly robust; that is, able to maintain stable yields across a wider variety of climatic conditions(Lin, 2008). EbA technique that helps to maintain yields across a wider range of environmental conditions is agroforestry. This section explores the role of both shade trees and shelter belts in the context of agroforestry in the Pacific.

Hannah (2005) notes that agroforestry land uses can be a constructive, biodiversity friendly part of a climate change-integrated conservation strategy when they:

- Maximise soil conservation
- Maintain high levels of natural tree cover
- Include appropriate levels of capital investment and
- Maintain options for conversion to conservation land uses

There have been a number of information resources that have been prepared to increase the uptake of agroforestry in Pacific Island countries, most notably the Agroforestry Guides for the Pacific Islands(2000) by Elevich and Wilkinson which describes agroforestry approaches which are appropriate for the Pacific Island context and which in most cases will potentially help maintain yield stability in the future. More recently, the FAO produced a resource that discusses agroforestry in the context of climate change adaptation within its Pacific Food Security Toolkit(2010). This toolkit includes a section on 'The Role of Ecosystems in Resilient Food Systems in the Pacific' and the guide also deals extensively with food production and good environmental management that underpins resilient production.

However, in its coverage of agriculture, this FAO resource deals exclusively with root crops. Non-food commodities such as coffee, grown by smallholders in the highlands of Papua New Guinea and in New Caledonia are not covered. As coffee is one of the extensively studied tropical agricultural commodities, some lessons are presented here on the EbA relationships which may be applicable to other agricultural commodities.

In the case of coffee production, shade trees provide a number of yield stabilizing functions that are relevant to climate change, as follows(Lin 2008, International Trade Centre 2010, Wittgens 2009):

- Decrease air temperatures (by up to 3-4 $^{o}$C)
- Decrease wind speeds
- Increase air humidity
- Protect flowers from intense rainfall
- Avoid large reductions in night temps (reduced risk of damage from frost)
- Prevent overbearing of fruit on a branch and associated biennial variations in yield.

However, it should be noted that these advantages are dependent on many other local conditions. For example, the utility of shade management in coffee production is also dependent on the quality of the soil. This is illustrated in Figure 10 (from Wittgens, 2009) in which it can be seen that production on 'good' soil and at ideal elevations for coffee production can be reduced by too much shade.

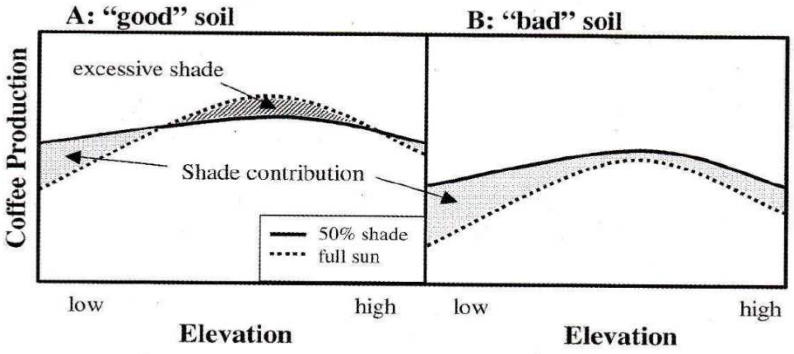
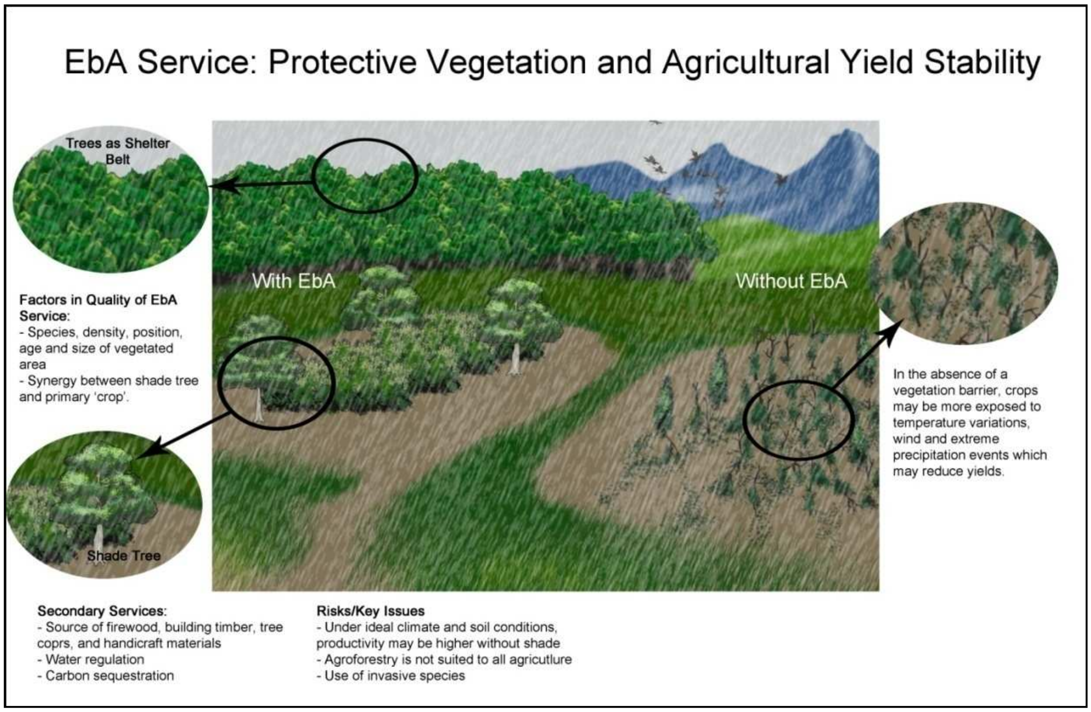


Figure 10 - Shade Contribution from Coffee (Wittgens, 2009)

Generally, the increased complexity of agroforestry can introduce a number of additional challenges for farmers. Specific limitations for the application of agroforestry in the Pacific observed by Elevich and Wilkinson(2000) include:

- shortage of information on tree/understorey interactions
- lack of data on trade-offs of mixed cropping systems
- Greater complexity in managing multiple species and multiple products
- Potential damage from harvest
- Increased challenges of marketing diversified products

Another important consideration in agroforestry is the minimization of the negative interactions between tree and crop(such as allelopathy, where one plant releasese chemicals into the environment that are detrimental to other plants growing in the vicinity) and the maximisation of positive interactions to get the best yields (Batish, 2008)



EbA Service: Protective Vegetation and Agricultural Yield Stability

**Factors in Quality of EbA Service:**
- Species, density, position, age and size of vegetated area
- Synergy between shade tree and primary 'crop'.

In the absence of a vegetation barrier, crops may be more exposed to temperature variations, wind and extreme precipitation events which may reduce yields.

**Secondary Services:**
- Source of firewood, building timber, tree coprs, and handicraft materials
- Water regulation
- Carbon sequestration

**Risks/Key Issues**
- Under ideal climate and soil conditions, productivity may be higher without shade
- Agroforestry is not suited to all agrictulture
- Use of invasive species

Field shelterbelts are used primarily to protect crop yields and the main microclimatic influence is windspeed reduction, reduction of wind erosion, reduction in the movement of fugitive pesticides and fertiliser, reduce odor emissions from animal enclosures and sequestration of carbon (Mize et al, 2008). Studies suggest that yield varies according to the distance from a shelterbelt, and the height of the tallest row of the shelterbelt(Mize et al, 2008).

**Summary for Adaptation Planners: Agroforestry and Agricultural Yield Stability**

**Key Issues:**
- Guidance for maintaining yield stability for root crops in the Pacific is provided in the FAO's toolbox
- Shade management using native trees can improve the stability of coffee yields, but a number of other drivers of production need to be examined.
- Need to be aware of the potential negative and positive tree-crop species interactions.

**Considerations for Cost-Benefit Analysis:**
- For both shade trees and shelterbelts, the key considerations should be on stability of yields and quantity of overall yields.
- For the effectiveness of shelterbelts, the distance from the shelterbelt and the height of the tallest row of the shelterbelt are key issues
- Mize et al (2008) describes different methods on how to quantify the benefits and costs of shelterbelt effects.

## 5.6 - Riverine Vegetation and Reduced Flood Damage

Flood waters usually rise following heavy rainfall, when the volume of runoff delivered to river networks exceeds the coping capacity of the system(Anderson, 2008). Related to floodplain vegetation(see previous section), riverine vegetation has the potential to reduce downstream impact from flooding, also offering hydraulic resistance which can delay and reduce the impact of floods.

As Anderson (2008) further observes, the common approach to reducing the risk of flooding is by increasing the network capacity, which is principally limited by the amount of resistance in the channels that make up the network. He also notes:

> "*Resistance can be thought of as the friction that slows down flow; greater resistance reduces the volume of water that a channel can hold before overflowing. Resistance is high at rapids were the stream bed is rough, and where the channel winds around tight bends. High resistance is also caused by vegetation, which occupies space in the channel and presents obstacles that slow down flow. It also happens that vegetation is relatively easy to remove. Therefore, the removal of vegetation from the area in and near stream channels (the riparian zone) has been practiced in the name of flood mitigation by generations of Australian landholders, sponsored by governments through major drainage and channelisation campaigns*."

This helps to describe the dominant approach of removing vegetation to reduce the risk of flooding events. Intuitively, this seems contrary to efforts to restore riverine vegetation: the result of adding vegetation should be to reverse the channel capacity improvements won by vegetation removal. For modeling efforts, flow resistance is commonly characterized by 'Mannings n': the higher the n value, the higher the resistance. Figure 11 suggests that vegetation can have a large impact on channel resistance; however the spread of Manning's n values for vegetation suggests that the increase due to vegetation is highly variable and probably guided by many factors.

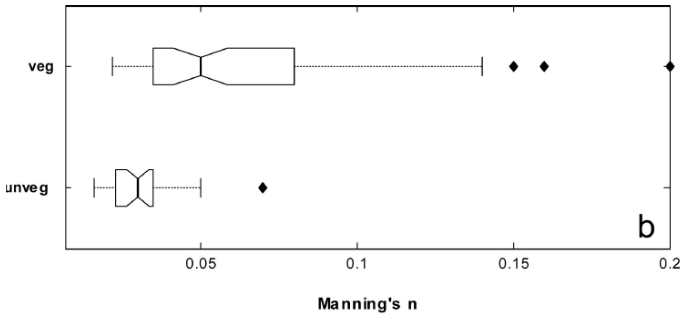
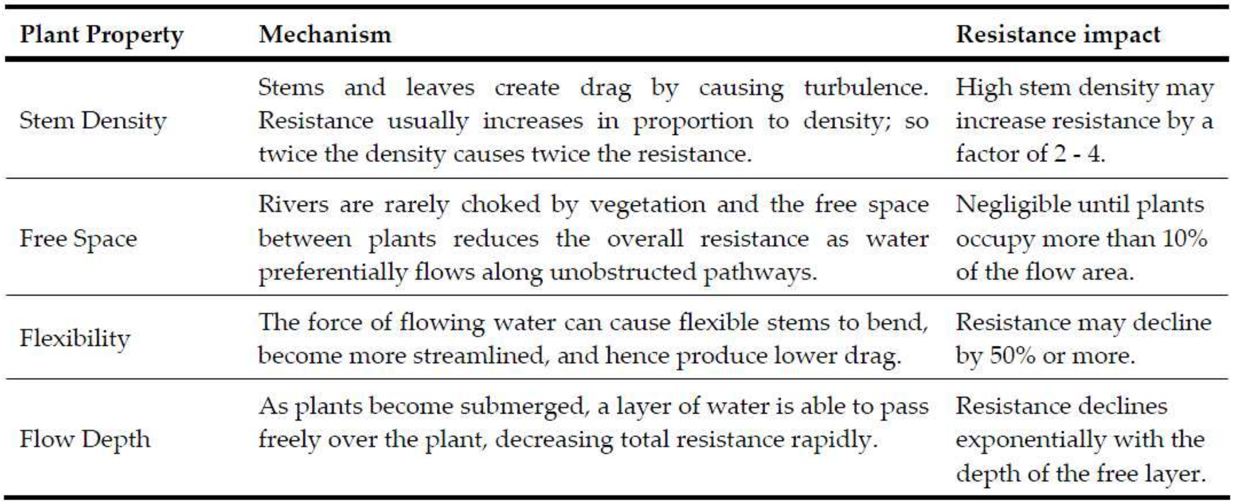


Figure 11 - the range of flow resistance values recommended for stream channels withvegetation and without vegetation; taken from a table compiled by Chow (1959).

However, Anderson further notes that attribution of mannings n is 'more an art than a science', and that this is especially true of vegetation that grows in a range shapes and sizes, and in complex mosaics along rivers. The ROVER model uses four key properties to define vegetation resistance: stem density, free space, flexibility and flow depth, see Figure 12.



| Plant Property | Mechanism | Resistance impact |
|---|---|---|
| Stem Density | Stems and leaves create drag by causing turbulence. Resistance usually increases in proportion to density; so twice the density causes twice the resistance. | High stem density may increase resistance by a factor of 2 - 4. |
| Free Space | Rivers are rarely choked by vegetation and the free space between plants reduces the overall resistance as water preferentially flows along unobstructed pathways. | Negligible until plants occupy more than 10% of the flow area. |
| Flexibility | The force of flowing water can cause flexible stems to bend, become more streamlined, and hence produce lower drag. | Resistance may decline by 50% or more. |
| Flow Depth | As plants become submerged, a layer of water is able to pass freely over the plant, decreasing total resistance rapidly. | Resistance declines exponentially with the depth of the free layer. |

Figure 12 - Key plant properties used in ROVER (ROughness of VEgetation in Rivers) model; the resistance mechanism and indicative impact (Anderson)

Anderson concludes that:

> *"The presence of vegetation in the upstream channels, by increasing flow resistance, will slow down a flood wave. Also, because vegetation reduces channel capacity, more of the flood water will be pushed out onto floodplains. Therefore, the effect of vegetation is to inhibit the development of large waves. Thus, a trade-off exists between the increase in flow depth caused by reduced channel capacity and the potential decrease in peak discharge of the flood wave that a densely vegetated channel network produces".*

Figure 13 helps to illustrate this relationship graphically, in channels of higher roughness the hydrograph arrives later and thepeak flow is attenuated more than for channels cleared of vegetation.

> "*The effect of revegetating the riparian zone on flooding can be seen as a battle between the local effect, which is to increase flood height, versus the whole of catchment effect, which is to hold back the flood, and so reduce downstream flood height. When the whole catchment is considered the latter effect can be dominant, so that result of this research demonstrates the counter-intuitive conclusion that the introduction of resistance can provide flood protection.*

The more comprehensive set of results from which this example is drawn, Anderson (2005), shows that the balance of the impact of replanting may fall either way. The relative impact varies depending on where the 'local' cross-section is located in the catchment, the size of the flood event considered, and of course how much of the channel network is replanted and at what density.

Anderson concludes that even in a large catchment, the impact of riparian restoration could be changes in peak depth and overbank duration in the order of 10-20%.

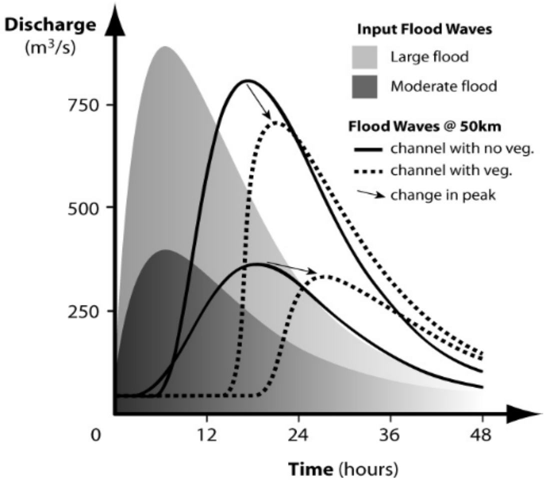


Figure 13 - Numerical routing of two flood waves down a 50 km reach, with and without vegetation (Anderson, 2008)

**<u>Summary for Adaptation Planners: Riverine Vegetation and Reduced Flood Damage</u>**

**Key Issues:**

- The impact of riparian restoration could be changes in peak depth and overbank duration in the order of 10-20%.
- Decision on revegetation in riparian zones is most likely a tradeoff between the local effect(increase flood height) versus the whole of catchment effect (hold back the flood, and so reduce downstream flood height).

**Considerations for Benefit Cost Analysis:**

- allowing rivers to develop sinuosity and to reconnect with the ambient landscapes is arguably even more important the vegetation

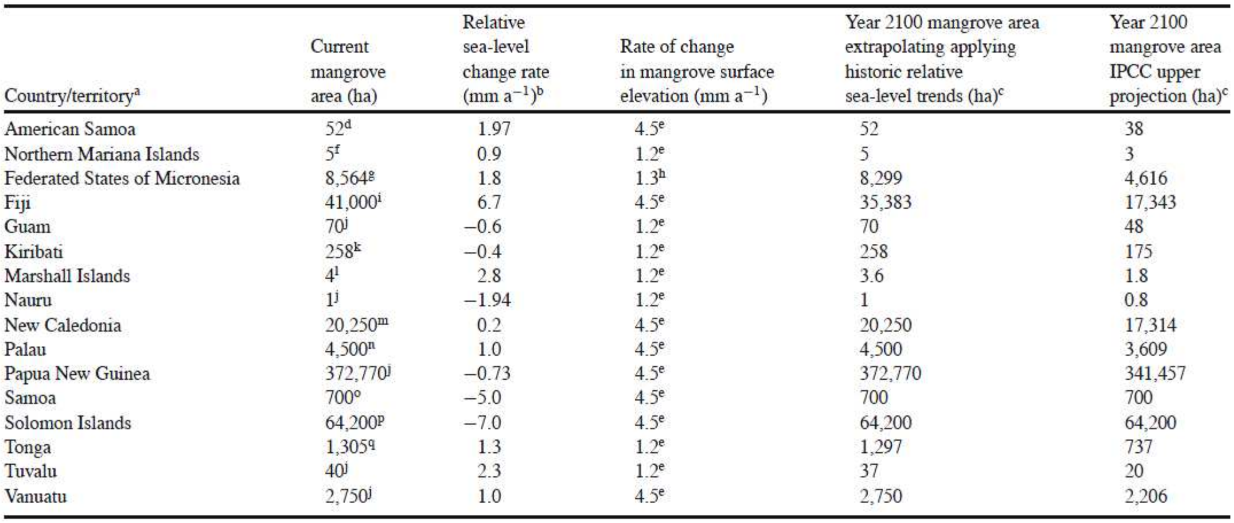
## 5.7 - Mangroves and Accommodation of Sea Level Rise

Sea level rise presents a challenge to communities that are dependent not only on the primary and secondary productivity of the mangrove system, but also the 'bioshield' function. As noted in Background document # 1, sea level rise(SLR) has the potential to inundate the systems and cause dieback where the systems become fully submerged. Enhancing the capacity of the system to accommodate SLR(and hence maintain these ecosystem functions) is therefore an example of EbA.

One of the simplest methods to establish inundation estimates from SLRis by matching potential rise against existing topographic data. This approach is taken in a recent study across the island of New Guinea by Legra (2008), but scenario development in this case was limited to a 1m sea level rise minimum due to poor vertical resolution of the Digital Elevation Models(DEM); it did not allow interpolation of SLR projections at elevations finer than 1m. However, even with the most accurate DEM, there are two possible mitigating scenarios for inundation that have been suggested by Leisz et al (2009). Firstly, that sea level rise may redistribute sediment, causing the creation of more wetlands and tidal forest areas rather than the complete inundation of vast low-lying areas. This will also depend on maintaining adequate mangrove cover to retain sediment. Second, it is also possible that increased precipitation resulting from climate change could a) increase sediment loads from upland areas may cause sufficient land aggradation to somewhat offset sea level rise effects and b) increase river discharges creating sufficient back pressure to somewhat mitigate stochastic tidal inundations. These possible effects depend on ensuring there is minimal human disturbance to the mangrove and upland watershed forests. (Leisz et al 2009).

Mangrove ecosystems typically adapt to rising water levels by reducing in stature, and by colonizing new, more favorable areas - known as 'landward migration'. However, they may also adapt by increasing peat production and growing upwards in their current position: so-called 'upward migration' (Salm and McLeod 2008). The most important limitation to landward migration is the presence of natural barriers such as steep slopes and cliffs, or artificial barriers, such as aquaculture ponds, roads or seawalls.

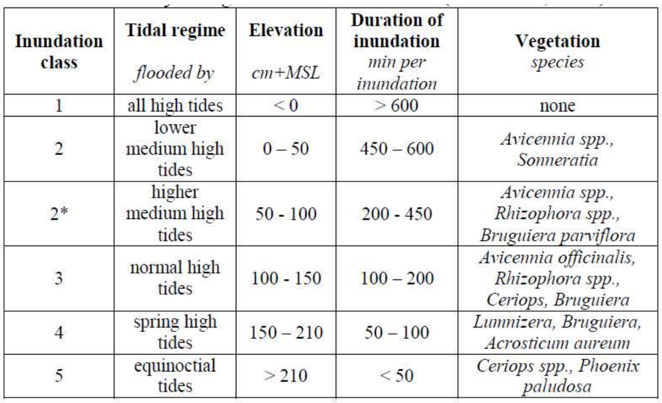
However, a key factor that will determine the success of either mode of migration is the rate of SLR - simply put,the rate of landward or upward migration will need to be faster than the rate of SLR. Gilman (2007) records observed landward migration rates of mangroves seaward margins across three study areas in American Samoa over four decades as between 25-72mm per annum, a raterate significantly higher than observations and projections for sea level rise, when the potential for accelerated SLR is ignored. Gilman(2007) also extrapolated existing relative sea-level trends through the year 2100(See Figure 14) , and estimated that indigenous mangroves in the Pacific islands region would be reduced by only 1.1%. However, using the IPCC's upper projection for global sea level rise through the year 2100, Gilman suggested that Pacific island mangrove area could be reduced by 12.4%. This suggest that generally speaking, mangrove forests are relatively resilient to climate change if sea level rise does not accelerate and therefore have a legitimate place in coastal adaptation responses.



| Country/territory[a] | Current mangrove area (ha) | Relative sea-level change rate (mm $a^{-1}$)[b] | Rate of change in mangrove surface elevation (mm $a^{-1}$) | Year 2100 mangrove area extrapolating applying historic relative sea-level trends (ha)[c] | Year 2100 mangrove area IPCC upper projection (ha)[c] |
|---|---|---|---|---|---|
| American Samoa | 52[d] | 1.97 | 4.5[e] | 52 | 38 |
| Northern Mariana Islands | 5[f] | 0.9 | 1.2[e] | 5 | 3 |
| Federated States of Micronesia | 8,564[g] | 1.8 | 1.3[h] | 8,299 | 4,616 |
| Fiji | 41,000[i] | 6.7 | 4.5[e] | 35,383 | 17,343 |
| Guam | 70[j] | −0.6 | 1.2[e] | 70 | 48 |
| Kiribati | 258[k] | −0.4 | 1.2[e] | 258 | 175 |
| Marshall Islands | 4[l] | 2.8 | 1.2[e] | 3.6 | 1.8 |
| Nauru | 1[j] | −1.94 | 1.2[e] | 1 | 0.8 |
| New Caledonia | 20,250[m] | 0.2 | 4.5[e] | 20,250 | 17,314 |
| Palau | 4,500[n] | 1.0 | 4.5[e] | 4,500 | 3,609 |
| Papua New Guinea | 372,770[j] | −0.73 | 4.5[e] | 372,770 | 341,457 |
| Samoa | 700[o] | −5.0 | 4.5[e] | 700 | 700 |
| Solomon Islands | 64,200[p] | −7.0 | 4.5[e] | 64,200 | 64,200 |
| Tonga | 1,305[q] | 1.3 | 1.2[e] | 1,297 | 737 |
| Tuvalu | 40[j] | 2.3 | 1.2[e] | 37 | 20 |
| Vanuatu | 2,750[j] | 1.0 | 4.5[e] | 2,750 | 2,206 |

**Figure 14 - Rough estimate of mangrove response to relative sea-level change for the 16 Pacific Island countries and territories where mangroves are indigenous(Gilman et al, 2007)**

Hydrological site characteristics are also a very important determinant for the establishment of mangroves (Hughes *et al*, 1998). One of the most useful hydrological tool in mangrove rehabilitation projects is the general classification for mangrove forests established by Watson in 1928 where the tidal range is divided into five inundation classes.There is increasing interest in the establishment of tools that help to guide decisions on mangrove restoration in the context of climate change, including most recent efforts by Oostewal(2010) to refine hydrological classification schemes for wetlands (see Figure 15), which were recently tested successfully by Dijksma (2011) for suitability in the sea level rise context .



| **Inundation class** | **Tidal regime** *flooded by* | **Elevation** *cm+MSL* | **Duration of inundation** *min per inundation* | **Vegetation** *species* |
|---|---|---|---|---|
| 1 | all high tides | < 0 | > 600 | none |
| 2 | lower medium high tides | 0 – 50 | 450 – 600 | *Avicennia spp., Sonneratia* |
| 2* | higher medium high tides | 50 - 100 | 200 - 450 | *Avicennia spp., Rhizophora spp., Bruguiera parviflora* |
| 3 | normal high tides | 100 - 150 | 100 – 200 | *Avicennia officinalis, Rhizophora spp., Ceriops, Bruguiera* |
| 4 | spring high tides | 150 – 210 | 50 – 100 | *Lumnizera, Bruguiera, Acrosticum aureum* |
| 5 | equinoctial tides | > 210 | < 50 | *Ceriops spp., Phoenix paludosa* |

**Figure 15 - New Hydrological Classification for Wetland Ecosystems (from Dijksma, 2011)**

There are also positive impacts for wetland ecosystems that may be associated with climate change. For example, increased levels of CO2 associated with continued greenhouse gas emissions are expected to enhance photosynthesis and mangrove growth rates (UNEP 1994). Ball(1997) notes some examples where increased levels of CO2 significantly increased photosynthesis and the average growth rates in mangrove species, but only when grown at lower salinity levels (Ball *et al.* 1997).

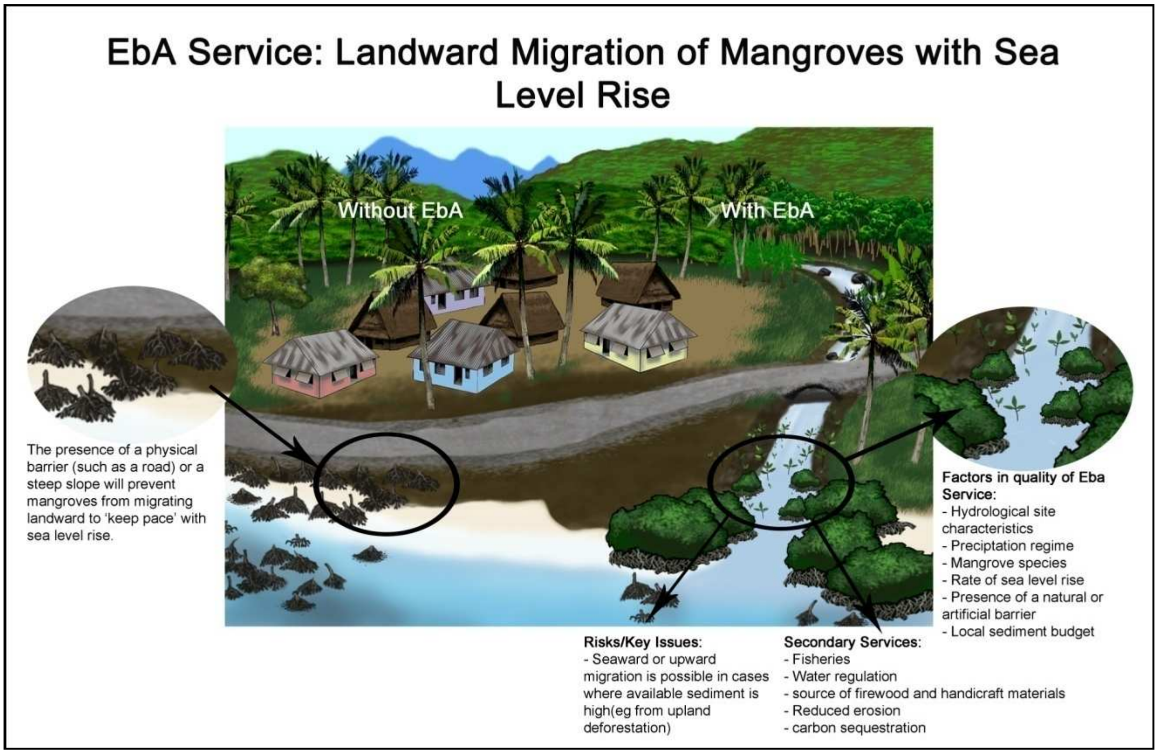
There are 6 key physical characteristics of mangrovesystems and the local environmental conditions that will the ability or mangroves to accommodate sea level rise:

- hydrological site characteristics;
- Precipitation (direct and on the catchment);
- vegetation species;
- rate of sea level rise;
- presence of natural or artificial barriers; and
- local sediment budget.

Based on the typologies of coastal adaptation described above, mangrove protection and restoration in the context of sea level rise is best characterised as an 'accommodation' option, although in cases where the conditions, including sediment budget - are suitable, upward migration could also be possible, which fits within the 'protection' category of climate adaptation.

Further, the potential of wetland ecosystems to help protect coastal communities from the impacts of sea level rise is influenced by the extent to which the local economy is dependent (indirectly or directly) on the local ecosystem services. To retain these services under sea level rise, the mangrove systems must have the capacity to migrate and so the conditions for migration must be established.

While it is possible that mangrove ecosystems can make a contribution to maintaining  coastal livelihoods under SLR in Pacific Island Countries and that SLR can be accommodated within wetland restoration and protection programs, there is not sufficient data available on the conditions under which these functions can be confidently integrated into coastal adaptation plans so such work is still considered experimental. However, given the range of other benefits of mangrove ecosystems, restoration and protection programs provide a broad set of functions which can be used to justify investment in most planning scenarios.



Similar to mangroves, seagrasses migrate landward with sea level rise and have extremely high light requirements and barriers to such migration will cause mortality (Orth, 2006). The capacity of these systems to migrate successfully will be an important In some areas of the Pacific, since there are high degrees of dependency on seagrasses for direct and indirect production of coastal resources (Unsworth and Cullen 2010). However, the relatively ephemeral nature of tropical seagrasses makes such management problematic.

**Summary for Adaptation Planners: Mangroves and Accommodation of Sea Level Rise**

**Key Issues:**

- The capacity of the mangrove system to migrate landward is dependent on the rate of sea level rise, precipitation regimes, the presence of a barrier and the local availability of sufficient sediment.

**Considerations for Benefit Cost Analysis:**

- The definition of coastal management objectives is critical here - i.e. whether the full range  of mangrove functions are being protected from sea level rise is being considered (protective/accommodation and maintenance of production)
- As with 5.1, the unintended consequences of hard infrastructure needs to be considered within the 'system boundaries' of the cost-benefit analysis

### 5.8 - Other EbA Relationships

While the above presents an overview of a selection of the key relationships for EbA relevant to the Pacific, it is not all inclusive. Other options include:

- Coral Reefs and protection from cyclones/storm surge
- Freshwater wetlands and mitigation of floods - capacity of such wetlands to 'suck up' water during floods, and release it during droughts
- Vegetation management and fire risk reduction

## 6 - Links AcrossEbA Relationships

While these 7 relationships have been presented as separate, there are clear connections between these functions that, while difficult to quantify, should as a minimum be qualified as additional benefits within adaptation planning. For example, Waycott (2008) notes that seagrasses will likely aid in buffering the impacts of climate change on coral reefs where they co-exist, although notes that no research has yet been conducted on this phenomenon.

# 7 - Conclusions and Recommendations

## 7.1 - Conclusions

1. That there is significant potential to better utilize Ecosystem-based Adaptation(EbA) within adaptation planning in the Pacific Islands.
2. That decision-makers should utilize economic methods and/or resilience-based frameworks to compare the merits EbA options with alternative adaptation solutions.
3. That there are a number of EbA relationships that are relevant to the Pacific Islands and which are reasonably well understood on a generic level(i.e. the processes are understood but quantification of service value can be challenging), and which can deliver a wide range of climate-relevant ecosystem services.
4. That there is a need to move beyond this generic understanding of EbA relationships in order to better inform decision-making on EbA
5. That site-specific issues will need to be carefully considered in EbA applications as there are many risks.

## 7.2 - Recommendations for Framing Guidance Based on Current Knowledge

1. That the key elements of section 5 (Key EbA Options for the Pacific) are converted into theEbA Toolbox for the Pacific which can then be used to help guide decision-makers on the introduction of EbA within their adaptation planning.
2. That the EbA components of the toolbox includes information on:
    a. Current knowledge of the EbA relationship (including uncertainties)
    b. Limitations and risks,
    c. Capacity requirements for application
    d. Generalized guidance/'rules of thumb'
    e. Access to more specific resources.

## 7.3 - Recommendations for New ResearchPriorities

1. That additional research is conductedthat will enable the establishment of classifications in EbA service delivery for each relationship (e.g. define species-level and ecosystem-level characteristics that comprise different levels of 'bioshield' functionality). This will involve comparative studies of the ecosystem service values of different ecosystems of the Pacific based on the relationships specified in section.
2. That the links between Ecosystem Health --> Ecosystem Function-->Ecosystem Service in the Pacific Island context are examined in more detail. Such research will help prioritize ecosystems based on their ecosystem service capacity. This will allow for some amount of tradeoff analysis based on what ecosystems should be conserved for climate adaptation needs.
3. That the different aspects of vulnerability, resiliency and sustainability in terms of planning and managing the short and long-term costs of EbA on coastlines are examined. For example, what are the most and least costly measures of implementingEbA plan in the specific ecosystem? What are the risks that are reduced and by how much? On different planning time horizons (political office, 5 year, 10 year, permanent) what are the major investments? How might that change with climate change? Is the goal to plan for seasonal storms or more rare, huge events?
4. That site based valuation studies of EbAwith scenario analyses included are established in the Pacific Islands.
5. That the way in which bundled ecosystem services affect the values of specific areas important in the Pacific Islands is examined. ie. where are strategic areas where multiple uses increase the cost effectiveness of anEbA option, as a rsult of additional value provided by other services arising from the same ecosystem. (subsistence wood collection, fishing, fisheries, nursery habitat, etc.)
6. That the socioeconomic character of the region/communities surrounding the ecosystem affect the value of the ecosystem service is examined. i.e How does population density, level of development, human development index, GDP, GDP/capita, etc. affect the ecosystem service and its value. How does the governance structure affect the resiliency or vulnerability of EbA in these specific Pacific sites?

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