Application of Cost-Benefit Analysis to Ecosystem based adaptation (EbA) solutions for climate change: Final results

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List of Acronyms

CBA: Cost-benefit Analysis

EbA: Ecosystem-based adaptation

FSM: Federated States of Micronesia

HH: Households

LEAP: Local Early Action Plan

LMMA: Locally Managed Marine Area

MPA: Marine Protected Area

NPV: Net present value

PAN: Protected Area Network

VA: Vulnerability Assessment

Background

Climate change impacts currently pose a threat to Micronesia and Melanesia communities and natural systems and are likely to intensify considerably in the future. Associated climate variability (e.g., more erratic or intense rainfall patterns, more intense storms) will have implications for the capacity of ecosystems to maintain the flow of services that they provide to communities. In addition to climate change, ecosystem degradation, due to overexploitation and pollution, has potential to exacerbate the vulnerability of communities and ecosystems.

The provision of ecosystem services to Micronesian and Melanesian communities is dependent on the health of ecosystems in the region. Healthy functioning ecosystems are more resilient to stressors, implying a greater element of flexibility in adaptation response options (Munang et al., 2013)[1].

Conservation efforts and sustainable management of natural capital can help communities to adapt to climate change impacts, whilst providing an array of co-benefits such as sustainable economic development, poverty alleviation and protection of livelihoods. The approach of Ecosystem based Adaptation (EbA) is grounded on the sustainable use of the ecosystems in order to maintain the direct benefits and co-benefits that ecosystem services provide in supporting human well-being.

EbA is defined by the Convention on Biological Diversity (2009) as "the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people and communities to adapt to the adverse effects of climate change at local, national, regional and global levels"[2]. This "may include sustainable management, conservation and restoration of ecosystems, as part of an overall adaptation strategy that takes into account the multiple social, economic and cultural co-benefits for local communities"[2]. As part of this approach it is important understand the carrying capacity of ecosystems, which relates to local context and type of ecosystems. EbA examples are the restoration of coastal ecosystems that protect communities from storm surges, forest restoration and riparian zones that protect communities from flooding and maintaining water quality.

EbA options are an integral part of the Pacific Climate Change Adaptation Project *Building the Resilience of Communities and Their Ecosystems To the Impacts of Climate Change in Micronesia and Melanesia* (Fig. 1). Through the use of the EbA approach, the project aimed to build or restore the resilience of Micronesia and Melanesia communities living in atoll islands and high islands. As part of the project, Cost-Benefit Analysis (CBA) of the adaptation strategies and actions identified by the communities through the Vulnerability Assessment process (LEAP-VA[3]) were conducted. In addition,

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[1] Munang R, et al. (2013) Climate change and Ecosystem-based Adaptation: a new pragmatic approach to buffering climate change impacts. Curr Opin Environ Sustain, http://dx.doi.org/10.1016/j.cosust.2012.12.001

[2] Convention on biological Diversity (2009). *Connecting biodiversity and climate change mitigation and adaptation*. Report of the Second Ad Hoc Technical Expert Group on Biodiversity and Climate Change. CBD Technical Series No 14. Secretariat of the Convention on Biological Diversity, Montreal, Canada.

[3] The Local Early Action Plan is a vulnerability assessment (VA) conducted with the Micronesian communities. A slightly different version of VA to climate change was conducted for the Ahus community in Manus (Papua New Guinea). Although the processes are different, they have the same goal of identifying communities' vulnerabilities to climate change and delineate a series of actions to support communities' adaptation to climate change.

services associated with low-lying atoll islands and watershed islands were identified as part of EbA options.

This chapter introduces some of the EbA options identified during the project to help communities and ecosystems to adapt to climate change in low-lying atoll islands and high islands watersheds.

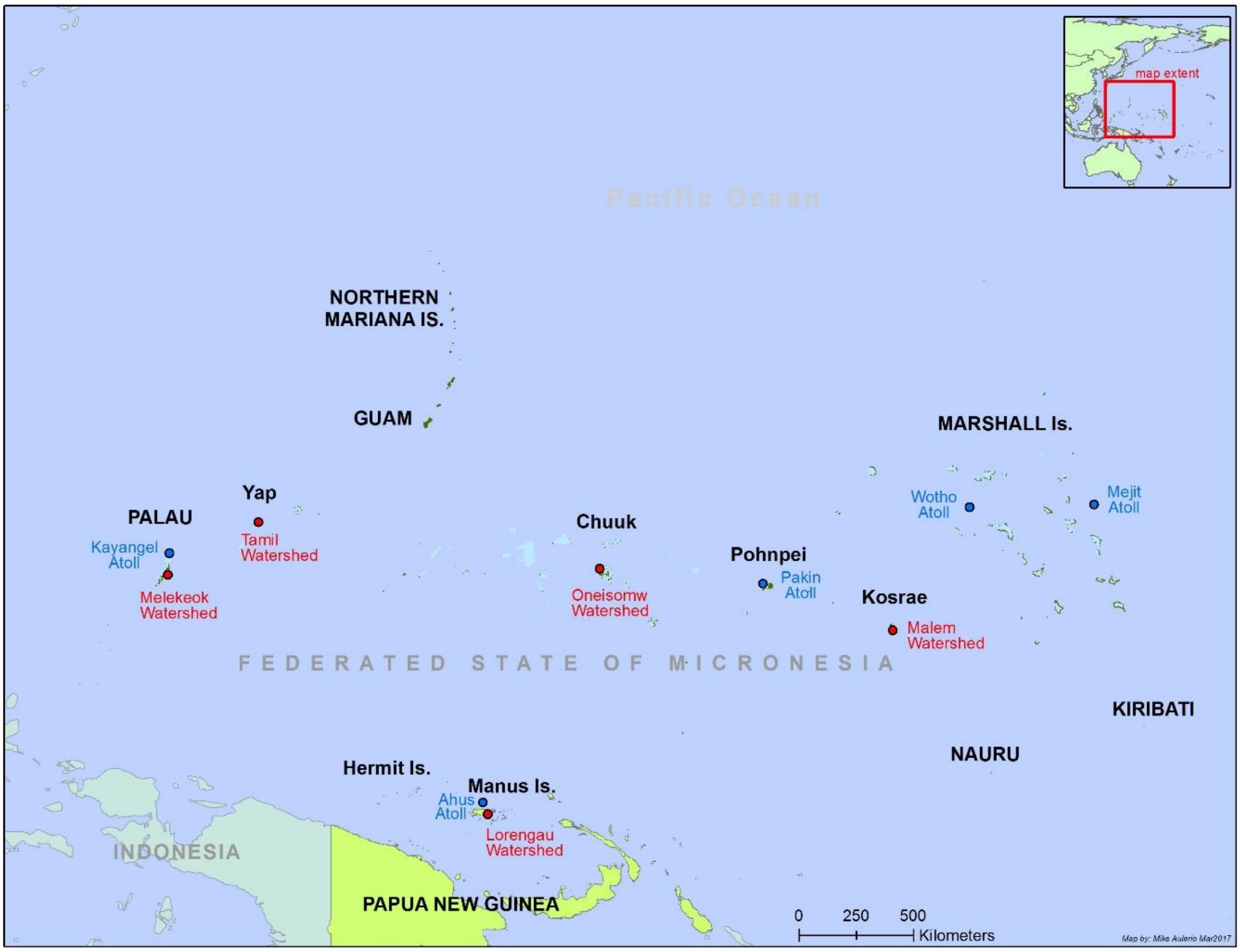
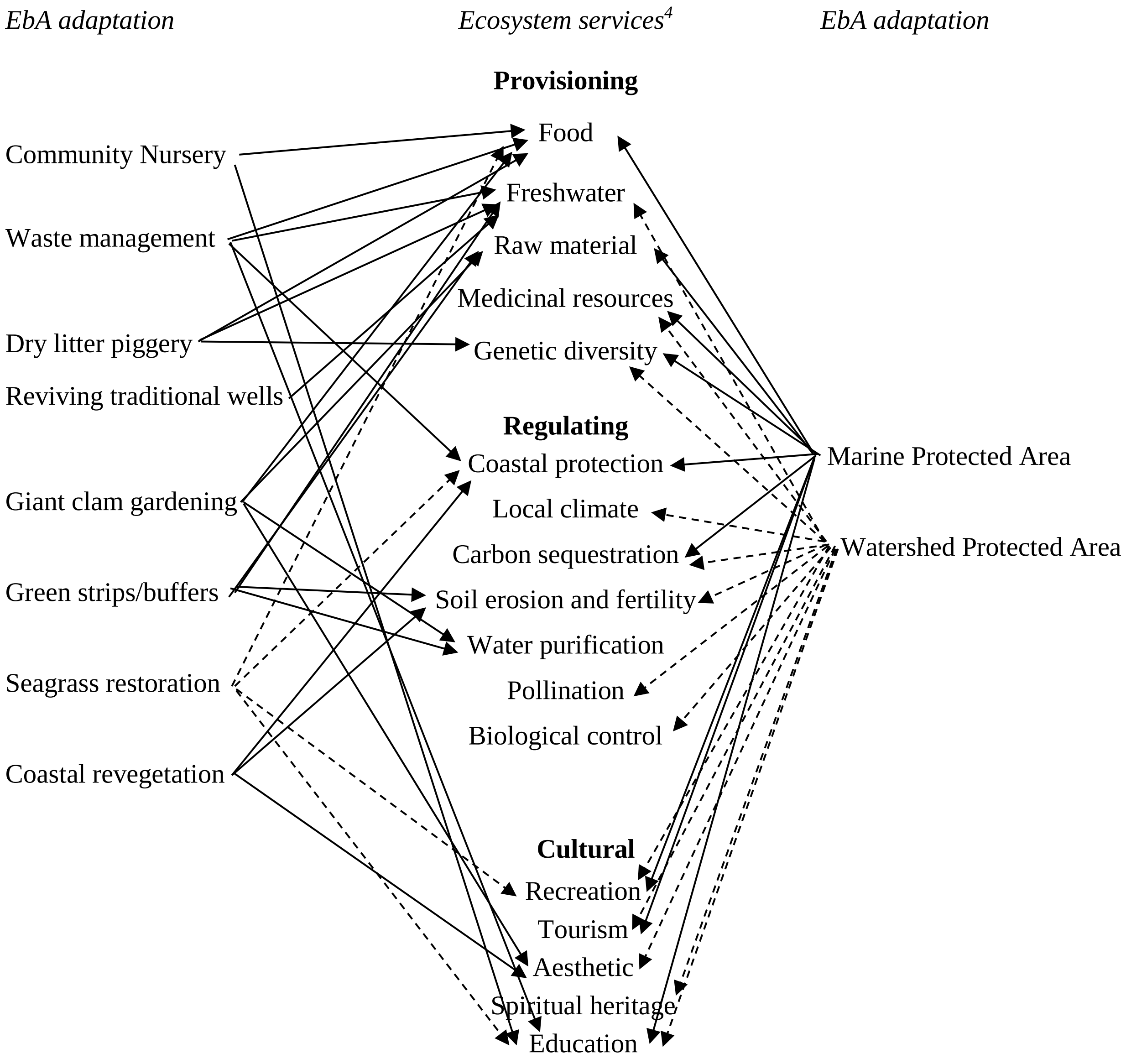


Figure1. Map of the low-lying atoll islands (●) and high islands watershed (●) sites selected for the project

Table 1. Ecosystem based adaptations indicated by the communities of high islands watershed and low-lying atolls in Micronesia and Melanesia.

System	Service	EbA	Action
High islands watershed	Water supply	Green buffers/strips	Establishment of vegetated areas ("strips") adjacent to streams, rivers, lakes and other waterways protecting aquatic environments from the impacts of surrounding land use.
		Watershed protection and conservation	Conservation of areas to reduce pressures driving loss and degradation of this system, through community planning, management activities and land use change.
		Reviving traditional wells	Improve status of water of wells that have been historically important for the community through appropriate lining and stabilization of the surrounding areas to reduce runoff.
		Waste Management	Implementation and enforcement of a waste management plan to reduce waterways pollution
	Shoreline protection	Shoreline revegetation	Establishment of vegetated areas to stabilise the shoreline
		Mangrove conservation and management	Establishment of rules and regulation to reduce pressures driving loss and degradation of mangroves through a ridge-to-reef approach that recognise connectivity of this ecosystem with others.
		Coral reef conservation	Establishment and enforcement of Marine Protected Areas (MPA) or Locally Managed Marine Areas (LMMA) regulations to reduce coral reef habitat destruction and degradation
	Food security - Fishery	MPA or LMMA	Conservation efforts and management through community participation. Planning of locally managed areas to relief pressure from coral reef
	Food security - Agriculture	Community nursery	Development of seedling nursery to manage traditional crops and revive traditional techniques for reducing dependency on imported food and improve nutrition factors in community diet
		Enhance soil fertility	Introduce practices that support soil fertility (e.g., brush and hoe, composting)
		Reduce loss of soil - reduce erosion	Avoid 'slash and burn' methods that prompt loss of soil organic matter
Low-lying atoll islands	Water supply	Conserve/Protect water lenses through the dry litter piggery system	Conservation of the water lens by removing the pressure that are driving water quality degradation
	Shoreline protection	Shoreline revegetation	Establishment of vegetated areas to stabilise the shoreline
		MPA and LMMA to conserve coral reefs	Establishment of rules and regulations to reduce coral habitat destruction and degradation
		Seagrasses restoration	Restore seagrass beds -Also, complimented with rules and regulations may enhance fishery
	Food security - Fishery	Establishment and enforcement of MPAs or LMMAs	Conservation efforts and management design through community participation and deputised wardens recognised locally and nationally
		Giant clam gardening	Clams arranged in circles in a way conducive to spawning in environmentally suited areas.
	Food security - Agriculture	Enhance soil fertility through pig manure	Introduce practices that support soil fertility (e.g., compost production from dry litter piggery)
		Protect crops from salt-water intrusion	Introduce crops and crop cultivation techniques that can support food security during climate related emergencies (floods, storms, droughts etc.)

Ecosystem services associated with the EbA solutions selected by the Micronesia and Melanesia sites



[4] Based on TEEB classification of Ecosystem services

Use of Cost-Benefit Analysis to evaluate EbA

- Cost-Benefit Analysis or CBA is the process of comparing the total expected costs to the total expected benefits of one or more actions, in order to choose the best or most profitable option. After the estimation of both costs and benefits, they are compared systematically to assess the net benefit of implementing the planned measures.
- The CBA of the EbA options for the Micronesia and Melanesia sites, aimed to identify, assess and monetise costs and benefits associated with the EbA options in terms of welfare changes due to the implementation of projects and associated improved status of ecosystems.
- Data for the CBAs were collected through household surveys (conducted between May-June 2016), collated from existing works or elicited from experts (Appendix 1). The robustness of the conclusions was tested by conducting sensitivity analyses.
- Results of the CBA were expressed in terms of Net Present Value (NPV), which represents the present value of the benefits minus the present value of the costs. Since the costs and benefits of an EbA option are incurred over time, costs and benefits that occur at different points in the future are converted to comparable "present values" using an appropriate discount rate. Applying a social rate of discount gives greater consideration to the welfare of future generations.
- Benefits of EbA can have effects on marketed goods and services (e.g., in terms of commercial fisheries revenues) or take the form of non-market effects by enhancing the provision of services that are not traded (e.g., recreation, pollination). EbA benefits that could not be monetised (e.g., soil fertility, pollination, aesthetic), were made explicit by presenting the information associated to the flow of these services in qualitative terms. For Micronesian and Melanesian community this information is extremely relevant, since cultural identity is deeply linked to ecosystems services.

Summary of CBA results for the EbA solutions selected by the Micronesia and Melanesia sites

Melekeok, Republic of Palau	
Site type	Watershed
EbA targets	Water and food security, coastal protection
Sample size	80% (n= 90 HH)
Average household income (US$/month)	$1,080
Households below poverty line (%)	28%
Total fishery value (US$/year)	$31,967
Cost of water (US$/gal)	$0.06
WTP for water (US$/HH/year)	$10.6 per year to move from a situation with "moderate water availability" to "high water availability"

EbA solutions	**Establishment of MPA**		**Watershed restoration with green strips/buffers**	
Area (ha)	171 ha (1.7 km^2)		2 ha (0.02 km^2)	
Time horizon	2017-2050		2017-2050	
Costs (US$)	Set-up	6,396	Planting (labour)	32,419
	Operation	62,043		
	Opportunity	38,869		
Total costs (US$)		***107,308***		***32,419***
Benefits	Fishery (catch increase)	44,039	Improvement of freshwater availability	76,670
	Coastal protection (reduction in damage)	68,286		
Total benefits (US$)		***112,326***		***76,670***
NPV at 5% discount rate		**5,017**		**44,251**
Co-benefits not included in CBA	Medicinal resources, raw material, genetic diversity; primary production; carbon sequestration; cultural and spiritual heritage, recreation, tourism, education		Raw material, habitat for species; soil erosion, soil fertility, water flow, water purification	
Key messages	• The MPA option results in positive net benefits, but involves high operating and opportunity costs. This option would be more viable if it is possible to reduce operating costs. • Requires long-term commitment to comply with rules and regulations		• Restoration of Ngerdorch watershed represents the better return on investment. Benefit-cost ratio indicates that each dollar invested yields a return of over two dollars in benefits. This is largely due to the high value that the community places on water security (WTP).	

Based on: Brander, L., Dijkstra, H., Franco, C. (2016) Cost-benefit analysis for Melekeok (Republic of Palau) climate change adaptation strategies. The Nature Conservancy.

Pakin, Pohnpei State, Federated States of Micronesia (FSM)

Low-lying atoll islands	
EbA targets	Water and food security
Sample size	100% (n =24 HH)
Average household income (US$/month)	$236.4
Community members below poverty line (%)	48%
Cost of water (US$/gal)	none
Total fishery value (US$/year)	$8,880
WTP for water (US$//HH/year)	$24 per year to move from a situation with "moderate water availability" to "high water availability"

EbA solutions	**Enforcement of MPA**		**Dry litter piggery**	
Area (ha)	300 ha (3 km^2)		9 pen units	
Time horizon	2017-2050		2017-2050	
Costs (US$)	Training Operation* Opportunity	25,855 0 6,245	Set-up O & M	11,174 75,761
Total costs (US$)		***32,100***		***86,935***
Benefits	Fishery (catch increase)	14,717	Improvement of freshwater availability Pig revenue	56,213 157,836
Total benefits (US$)		***14,717***		***214,049***
NPV at 5% discount rate		**-17,383**		**127,113**
Co-benefits not included in CBA	Medicinal resources, raw material, genetic diversity; primary production; carbon sequestration; cultural heritage (charismatic species as turtles, rays, sharks), recreation, tourism, education		Food, genetic diversity	
Key messages	• The MPA results in net costs, indicating that costs for the community are higher than gains. The option may become viable if training costs are reduced. • Overall, the ecological benefits of enforcing the MPA areas are high, but from an economic point of view this strategy presents net costs to community welfare, suggesting that financing mechanisms should be investigate (e.g. through green fees) to support this option in the long-term. It is important highlight that it may be possible to reduce training costs, if local experts are used. • Alternative funding from the dive industry should also be investigated as an opportunity to cover some of the operating costs.		• The piggery management option represents the better return on investment. Net benefits in terms of households' income and water quality are high, but operating costs are high as well in terms of time invested in managing the animals (prepare litter, source water during droughts, etc.). • The process and time required for managing pigs should be clearly presented to community hence allowing for an informed decision. • If households do not commit their time in managing caged animals the effectiveness of the dry litter piggery may be reduced. • Additional benefit is the potential production of compost for plant/crops nutrition	

Based on: Brander, L., Gilders, I., Franco, C. (2016) Cost-benefit analysis for Pakin (Pohnpei, FSM) climate change adaptation strategies. The Nature Conservancy.

Malem, Kosrae State, Federated States of Micronesia (FSM)

Site type	Watershed
EbA targets	Coastal protection, food and water security
Sample size	100% (n= 120 households using water from Malem dam)
Average household income (US$/month)	$486
Community members below poverty line	25%
Cost of water (US$/gal)	none
Total fishery value (US$/year)	$259,480
Water value per household (US$/month)	$3,907

EbA solutions	Establishment of MPA		Waste management		Coastal revegetation	
	22.26 ha (0.22 km^2)		Not available		Not available	
Time horizon	2017-2050		2017-2050		2017-2050	
Costs (US$)	Set-up Operation Opportunity	2,850 102,666 446,441	Set-up Operation	12,395 31,813	Set-up Operation	5,700 2,946
Total costs (US$)		***551,957***		***44,208***		***8,646***
Benefits (US$)	Fishery (catch increase)	526,053	Fishery (catch increase)	95,598	Coastal protection (reduction in damage)	37,607
	Coastal protection (reduction in damage)	94,018	Coastal protection (reduction in damage)	18,804		
			Improvement of freshwater availability	50,931		
Total benefits (US$)		***620,071***		***165,332***		***37,607***
NPV at 5% discount rate		**68,114**		**121,124**		**28,961**
Co-benefits not included in CBA	Medicinal resources, raw material, genetic diversity; primary production; carbon sequestration; cultural heritage (charismatic species as turtles, rays, sharks), recreation, tourism, education		Aesthetic, soil fertility (through composting of green and food waste), tourism, improved health		Control soil erosion, aesthetic	
Key messages	• MPA is a viable option, but benefits will be seen in the long-term • Requires long-term commitment of the community to comply with rules and regulations		• Community can expect to observe rapid benefits from this option if implemented appropriately and there are changes in present behaviours. • Requires long-term commitment to gain the full range of benefits		• Represents a positive improvement to community welfare, but absolute benefit is low because it is not expected that additional trees along the coastline will result in substantial reductions in flood damage	

Based on: Brander, L., Hagedoorn, L., Franco, C. (2016) Cost-benefit analysis for Malem (Kosrae, FSM) climate change strategies. The Nature Conservancy.

Tamil, Yap State, Federated States of Micronesia (FSM)

Site type	Watershed
EbA targets	Water and food security
Households interested by the project	194 (based on Yap Census, 2000)
Average income (US$/month)	$874 (based on Yap Census, 2000)
Households below poverty line (%)	basic needs 11.4%; food 2% per capita expenditure -Yap State
Cost of water (US$/gal)	$0.0015 (range consumption: 0-5000 gal)

EbA solutions	**Watershed Protected Area**		**Community nursery**		**Reviving traditional wells**	
	271 ha (2.7 km^2)		3 ha (0.03 km^2)		5 wells	
Time horizon	2017-2050		2017-2050		2017-2050	
Costs (US$)	Set-up Operation Opportunity	6,610 3,536 1,753,622	Set-up Operation	31,485 94,171	Set-up Operation	6,465 1,209
Total costs (US$)		***1,763,622***		***125,656***		***7,673***
Benefits (US$)	Avoided water costs	2,271,140	Alternative food for households	342,110	Improved freshwater availability	51,932
	Avoided medicinal costs	20,336				
Total benefits (US$)		***2,291,476***		***342,110***		***51,932***
NPV at 5% discount rate		**527,854**		**216,453**		**44,258**
Co-benefits not included in CBA	Regulates soil erosion and fertility, genetic diversity, raw material, pollination, habitat for species,					
Key messages	• Benefits of maintaining access to clean potable water by protecting the watershed area are high and extend to the entire community • For watershed protection, the opportunity costs would be the foregone income from development or agriculture production of the savannah land. • Investigate compensation options to discuss with the community. The forthcoming PAN legislation should be considered as option for supporting 'conservation' of this area.		• The community nursery provides a positive contribution to social welfare, • Requires long-term time commitment. • Requires long-term economic commitment, due to operation and maintenance costs. • Year-to-year market price fluctuations can have an impact on the financial status of this option. • Socio-economic benefits are extended to the community if an inclusive approach is used		• Absolute benefits associated with reviving and maintaining 5 community wells is low, but if the benefit is spread to the entire community municipal funding may be considered for this option since it can be pursued with small initial funds • The benefits associated with this option become particularly important in case of extreme weather events (e.g., typhoons) or failure of the main water system	

Based on: Franco, C., Brander, L. (2016). Cost-benefit analysis for Tamil (Yap, FSM) climate change adaptation strategies. The Nature Conservancy.

Note: the % of households below poverty line is representative of Yap State and is expressed in weekly pce

Oneisomw, Chuuk State, Federated States of Micronesia (FSM)

Site type	Watershed
EbA targets	Water security
Sample size	64% (n = 43 HH)
Average income (US$/month)	$100
Households below poverty line (%)	80%
Cost of water (US$/gal)	None- all sourced from natural springs and roof catchments

EbA solutions	**Vegetated buffers/strips and slopes stabilisation**		**Reviving traditional wells whilst establishing green buffers/strips**	
Area (ha)	0.28 ha (0.0028 km^2)		8 wells and 30.5 m of lemongrass	
Time horizon	2017-2050		2017-2050	
Costs (US$)	Set-up	11,756	Set-up	12,445
	Operation	1,473	Operation	5,891
Total costs (US$)		***13,229***		***18,336***
Benefits (US$)	Improved freshwater availability	23,306	Improved freshwater availability	90,049
	Avoided health costs	4,243	Avoided health costs	5,492
Total benefits (US$)		***32,549***		***95,541***
NPV at 5% discount rate		**19,320**		**77,204**
Co-benefits not included in CBA	Regulate soil erosion and fertility, raw material, regulate runoff, habitat for species		Regulate soil erosion and fertility, raw material, regulate runoff, habitat for species	
Key messages	• Green buffers/green strips and stabilisation of unconsolidated slopes, are effective answer in the face of climate uncertainty. • Benefits from these solutions will not be immediate and will not cover for the full water need of the community.		• Reviving wells and spring structures represent an important improvement for water preservation. • Preserving the actual water resources can help community to preserve water resources in the long-term. • These resources will partially cover for water needs and they become extremely relevant during emergencies	

Note: *the two EbA solutions for Oneisomw were also compared with the costs and benefits associated with the development of grey infrastructures (**community water tank and development of a water grid system for the villages**). **Costs** for tanks and water grid set-up and maintenance were higher than those for the proposed EbA solutions (**US$ 58,144**), but **benefits** were also higher (**US$ 100,792**). The development of water supply infrastructures can help support the immediate need of the community for water. Catchment systems and community tanks represent a higher cost but also an immediate answer to community water needs and improved water quality. There is a clear need for funds to support Oneisomw municipality to develop appropriate water infrastructures for the wellbeing of the entire community.*

Based on: Franco, C., Brander, L. (2016) Cost-benefit analysis for Oneisomw (Chuuk, FSM) climate change adaptation strategies. The Nature Conservancy

Ahus, Manus Province, Papua New Guinea

Site type	Low-lying island
EbA targets	Food security and coastal protection
Sample size	92% (n =131 HH)
Average income (US$/month)	$55.30
Households below poverty line (%)	unknown
Value of reef fish catch (US$/year)	$1,034,000

EbA solutions	Seagrass restoration		Giant clam gardening	
	5ha (0.05km^2)		1000 clams/year	
Time horizon	2017-2050		2017-2050	
Costs (US$)	Set-up	110,536	Set-up Operation & Maintenance	5,509 11,916
Total costs (US$)		***110,536***		***17,424***
Benefits (US$)	Fisheries (annual stock increase)	417,051	Alternative livelihood	33,139
	Coastal protection (reduction in damage)	1,266		
Total benefits (US$)		***418,316***		***33,139***
NPV at 5% discount rate		**307,781**		**15,714**
Co-benefits not included in CBA	Genetic diversity, habitat for species, primary production, nutrient cycling recreation, tourism, education		Raw material (shell), primary production, water purification, aesthetic, cultural heritage	
Key messages	• The seagrass restoration option provides a high return on investment. • There is a return of almost US$ 4 for every US$ 1 invested. • The scale of investment, however, is high with a total cost of over US$ 100,000. • Seagrass restoration is expensive but has potentially very high returns on investment.		• Giant clam gardening represents a positive adaptation option. • It yields almost US$ 2 in benefits for every US$ 1 invested.	

Based on: Brander, L., Hughes, L. Franco, C. (2016) Cost-Benefit Analysis of climate change adaptation options for Ahus Island, Papua New Guinea. The Nature Conservancy

Table 3. Identification of the strengths and weaknesses of the EbA options and external climatic, social and economic threats and opportunities.

EbA solution	Strengths	Weaknesses	Opportunities	Threats
Marine Protected Area	▪ Communities generally informed on benefits of marine resources protection ▪ Support fishery if well enforced ▪ Support coastal protection ▪ Encourage community members to work together ▪ Protect charismatic species (turtles, sharks, rays etc.)	▪ Lack of deputised officers ▪ Lack of monitoring program ▪ Lack of supporting financial system (e.g. PAN) ▪ Lack of social recognition for some communities (Pakin) ▪ No alternative livelihoods for those dependent on fisheries	▪ Sustainable financing ▪ Potential seasonal support from the dive industry ▪ Create synergies among stakeholders ▪ Revive pearl farming or other alternative livelihoods activities ▪ Potential for eco-tourism	▪ Poachers ▪ Climate change impacts (e.g. coral bleaching and ocean acidification) ▪ Funding discontinuities for monitoring ▪ Discontinuity of political support for MPAs ▪ May need external support in times of emergency
Watershed Protected Area	▪ Help maintaining functioning ecosystems and flow of services ▪ Can help regulate/control wildfires ▪ Would help preserving endemic species	▪ May lead to land users' exclusion ▪ Lack of acceptance in land use changes ▪ May lead to conflicts due to land use changes	▪ May lead to the creation of new jobs ▪ Potential partnership with research institutions (e.g. colleges, universities) ▪ Partnership with water authorities or utilities ▪ Partnership with government agencies	▪ Outbreak of invasive species (e.g. vines), pests or diseases ▪ Low compliance with regulations ▪ Wildfires and "slash and burn" ▪ Extensive development of areas surrounding the watershed ▪ Funding discontinuities for monitoring
Waste management	▪ Established location of the solid waste management centre ▪ Regular waste collection ▪ Encourage community members to work together ▪ Easy to implement with children and youths, becoming a "cultural norm"	▪ Lack of regulations for waste dumping ▪ Inefficient food waste sorting ▪ Requires time for the community to get use to waste segregation rules	▪ Establish relationships with the existing recycling and waste buying center. ▪ Partnership with government agencies ▪ Potential partnership with private companies	▪ High operating and maintenance costs ▪ Lack of households' commitment in segregating waste ▪ Illegal dumping ▪ Poor awareness and education

EbA solution	Strengths	Weaknesses	Opportunities	Threats
Watershed restoration through vegetated buffers/strips	▪ Support water filtration reducing costs for water treatment ▪ Regulates water flow reducing runoff and sedimentation ▪ Enhance soil fertility and productivity ▪ Near agriculture fields prevent sediments and nutrients entering waterways	▪ Requires time to develop ▪ Depending on the extension of the area to vegetate may require large quantity of seedlings ▪ Requires technical expertise for planting buffers/strips effectively	▪ Alternative medicinal sources ▪ Potential to repel insects ▪ Alternative source of raw material or food for livestock ▪ May lead to new skills development ▪ Use of drought tolerant grasses (e.g. lemongrass)	▪ Invasive species ▪ Wildfires ▪ Slash and burn practices ▪ Plant pests and diseases
Reviving traditional wells	▪ Alternative water source available ▪ Improved access to water in outer islands ▪ Technical expertise for wells restoration can be sourced locally ▪ Encourage community members to work together ▪ Would supply large number of people ▪ Projected increase in rainfall	▪ Lack of technical expertise and material for water testing ▪ Lack of water treatment ▪ Sourcing material for restoration may have an impact on local ecosystems (e.g. through sand mining) ▪ Users exclusion	▪ Improved health from better water quality and quantity ▪ Improved water capacity ▪ May lead to skill development in youth ▪ May support development of rules and regulations for reducing pollution near the wells ▪ May lead to trainings for water testing	▪ Extended dry season leading to drought ▪ Low compliance with rules and regulations for wells exploitation ▪ Wildfires ▪ Agriculture practices that increase erosion and runoff
Coastal revegetation	▪ Help retain soil and sand into the system	▪ Depending on the area revegetated coastal flooding may not be significantly reduced	▪ May lead to skill development in youth ▪ Partnership with Government agencies	▪ Poaching of wood ▪ Invasive species ▪ Plant pests and diseases ▪ Natural disasters and droughts

EbA solution	Strengths	Weaknesses	Opportunities	Threats
Giant clam gardening	▪ Strong culture and traditional knowledge ▪ Strong technical capacity ▪ Encourage community cohesion ▪ Traditional food	▪ Clams take long to growth at harvesting size ▪ If kept in sub-optimal conditions growth rates may decrease further ▪	▪ Partnership with government agencies and research community ▪ Partnership with other communities doing clams gardening	▪ Poachers ▪ Prolonged elevated seawater temperatures ▪ Predators
Seagrass restoration	▪ Enhance costal protection ▪ Support fishery ▪ Support nutrient cycling	▪ High initial costs ▪ Risk of being ineffective due to seagrasses mortality ▪ Risk of being ineffective due to inappropriate planting methods	▪ Build technical knowledge ▪ May lead to creation of an 'experts' team ▪ Partnership with government agencies ▪ Partnership with research community	▪ Prolonged elevated seawater temperatures ▪ Ocean acidification ▪ Pests and diseases ▪ Anchoring on seagrass beds ▪ Fishing methods
Dry litter piggery	▪ Existing technical knowledge and local support ▪ Communities are receptive to this method ▪ Proved support for water quality improvement ▪ Reduce volume of pig waste and recycle nutrients	▪ May lead to slight increase in the costs of attending the animal ▪ High time commitment to attend caged animals and to source litter ▪ Efforts required to manage the compost process ▪ Pathogens may still active	▪ Revive and re-establish traditional food crops (e.g. taro) ▪ Increase the variety of agroforestry products ▪ Improved soil fertility and crop productivity (due to compost)	▪ Diseases and pests ▪ Extended dry season leading to drought ▪ Natural disasters
Community nursery	▪ Control over quality and availability of plants ▪ Improved community health ▪ Develop local expertise on growing and handling seedlings ▪ Revive traditional methods	▪ High set-up and operation costs ▪ Poor soil quality ▪ Need for hiring and maintaining trained staff ▪ Long-term community commitment	▪ May lead to the creation of new jobs ▪ Alternative source of income for households ▪ May lead to improved soil fertility through composting ▪ Partnership with government agencies ▪ Partnership with research community (e.g. COM)	▪ Extended dry season leading to drought ▪ Market price fluctuation ▪ Market competition ▪ Pests and diseases infestations ▪ Natural disasters ▪ Vandalism ▪ Need external support in times of emergency

Conclusions

- Comparing different adaptation solutions in terms of monetary and non-monetary costs and benefits can empower communities to take informed decisions regarding which adaptation project better meets their needs.

- CBA highlights additional benefits associated with climate change adaptation strategies providing communities with knowledge on the flow of services from managing, conserving or restoring an ecosystem.

- Although CBA can be an effective tool for explicitly presenting the costs and benefits of EbA options, omission of non-market effects lessens its strength for options that provide several co-benefits that cannot be translated into monetary values (e.g., genetic diversity, pollination, primary production, nutrient cycling, soil formation).

- EbA solutions requiring long-term enforcement of rules and regulations are generally associated with the continuous need of funds for operation and therefore are more effective if associated with long-term sustainable financial instruments (e.g. entry-fees, trust funds, easements). This may require that the EbA options become part of the country policy framework, in order to ensure continuous flow of funds for enforcement.

- Mechanisms to support "emergency costs" should be investigated for those EbA solutions more prone to climate change threats (e.g., community nursery, dry litter piggery). Mechanisms that allow for re-entering the market rapidly in case of damages from extreme weather events should be investigated.

- Some EbA options become more effective if associated with grey infrastructures. For instance, response of EbA options to lack of water capacity is limited, whilst infrastructure implementation (e.g. tanks or water systems) provides an immediate answer to communities' water needs. This is also due to the fact that revegetation or restoration options may take some time before providing the full array of associated benefits

Appendix 1. Methods for assessing costs and benefits

Site	EbA	Costs	Benefits
Melekeok, Palau	Establishment of MPA	The costs for the establishment of the MPA were: i) initial costs for the establishment of the MPA; ii) operation and maintenance; iii) opportunity costs. The opportunity costs are costs associated with foregone income from fishery production on areas that are considered for protection. This 'loss' is taken into account as cost for the community and was estimated using information on the annual value of harvested marine resources by the community in Melekeok (approximately US$ 32,000 per year) and the size of the MPA as a proportion of total marine area (approximately 18%). Some harvesting effort could be displaced to other locations, thereby offsetting some of the opportunity costs of the MPA, but we do not attempt to model this effect. We assume that no-take restrictions are enforced in the MPA for the first ten years (2017-2026) in order to allow the ecosystem and stocks to recover. The costs for establishing and operating a MPA are generally sustained by an implementing agency. The costs for the implementing agency comprise the costs of establishing the MPA and the recurrent costs associated with the actual operation and management following its designation. To estimate the establishment costs of the MPA we make use of Model D from McCrea-Strubet al. (2011), which relates the establishment cost per km^2 to the area of the MPA. We assume that the establishment costs are incurred over the period 2017-2018 in equal annual instalments. To estimate the operational costs of the MPA we make use of Model 1 from Balmford et al. (2004), which relates the operating cost per km2 to the area of the MPA. We assume that these costs are incurred in each year over the period 2019-2050. In the Republic of Palau, the initial and operation costs are sustained by the National Protected Area Network (PAN) system.	The benefits of the MPA comprise two categories: 1. Increased harvest of marine resources. We assumed that harvest rates are 30% higher than the baseline after the 10-year no-take restriction is relaxed in 2027 (Kerwath et al., 2013). Total quantities harvested continue to decline over time due to other pressures that are not controlled by the MPA (e.g. warming, ocean acidification) but are higher than the baseline case without MPA protection. 2. Reduced risk of storm damage. The effectiveness of the MPA in reducing storm damage is likely to represents an improvement relative to the baseline. We assume that the improved structure of the reef with MPA protection results in a 5% local reduction in storm damage (Kench and Brander, 2006).

Site	EbA	Costs	Benefits
Melekeok, Palau	Watershed restoration with green strips/buffers	The costs for the restoration of Ngerdorch watershed were associated with: i) labour costs. We assume that the replanting process and costs are split equally and incurred 2017 and 2018. Labour costs for preparing and planting an area of 2 hectares with lemon grass are estimated on the basis that 1 m^2 of bare land requires approximately 72 lemon grass stalks; requiring 30 minutes of labour. Using the minimum wage rate of US$ 3.50 per hour, the total cost is US$ 35,000.	Estimated as the value of securing water availability to the community of Melekeok. The results of the household survey were used to estimate mean household willingness to pay to improve water availability (US$ 44 per month to move from a situation with "moderate water availability" to "high water availability"). This is a high amount but reflects the high level of concern in the community regarding water security.
Pakin, Pohnpei (FSM)	Enforcement of MPA	Data on costs of enforcement for i) equipment and material and ii) community training and awareness were elicited by experts and from previous enforcement in Pohnpei and Chuuk. ii) Opportunity cost was estimated using information on the annual value of harvested marine resources by the community in Pakin (US$ 8,880 per year) and the size of the MPA as a proportion of total marine area (approximately 10%). Some harvesting effort could be displaced to other locations, thereby offsetting some of the opportunity costs of the MPA, but we do not attempt to model this effect. Note that maintenance and operating costs (e.g. fuel for boat, salary for the deputised officers) were not included in the CBA analysis.	The benefits of the MPA comprised: i) increased harvest of marine resources. We assumed that harvest rates are 30% higher than the baseline after the 10-year no-take restriction is relaxed in 2027 (Kerwath et al., 2013). Total quantities harvested continue to decline over time due to other pressures that are not controlled by the MPA (e.g. warming, ocean acidification) but are higher than the baseline case without MPA protection.
	Dry litter piggery	Costs for the construction and material transportation for 9 pig pens were based on the costs associated with the 2 pig pens demo realized on island through GCCA funds; operation costs (labour) were derived from the household surveys conducted in May 2016. To note that costs associated with feed were not included as requested by the local organisation (Conservation Society Pohnpei), since traditionally pigs are adapted to the food sourced on island.	Benefit data were derived from the households survey conducted in May 2016. Benefits were estimated for i) households' income increase through the appropriate management of the island pigs; and ii) we assumed that the dry litter piggery will result in 0.05% improved water quality, and we considered the mean household willingness to pay to improve water availability (US$98.64 per month to move from a situation with "moderate water availability" to "high water availability"). This is a high amount but reflects the high level of concern in the community regarding water security.

Site	EbA	Costs	Benefits
Malem, Kosrae (FSM)	Waste Management	The costs to manage waste in Malem were i) initial costs, ii) land clearing and clean-up, iii) equipment and tools, iv) operating and v) maintenance. Estimates of the costs were provided by KCSO and Malem Municipal Government in June 2016.	The benefits of the waste management comprise three categories: 1. Reduced risk of storm damage. Waste management is likely to represents an improvement in coastal protection relative to the baseline. We assume that waste management will help improving the structure of the reef resulting in a 4% local reduction in storm damage (Kench and Brander, 2006). 2. Increased harvest of marine resources. We assumed that harvest rates are 5% higher than the baseline after implementation of waste management (Kerwath et al., 2013). Total quantities harvested continue to decline over time due to other pressures (e.g. warming, ocean acidification) but are higher than the baseline case without implementing waste management. 3. We assumed that implementing waste management will result in a 1% improvement of freshwater quality (Peters and Meybeck, 2009).
	Coastal revegetation	The costs considered in the CBA for the revegetation of the narrow strip of coastline between the shore and the road were associated with i) seedling collection ii) planting, iii) equipment. These costs were derived after consultation with KIRMA personnel that conducted similar projects in other areas (pers. comm. Mr. Erick Waguk)	Coastal re-vegetation benefits are due to the role that coastal vegetation plays as first barrier from storms, protecting infrastructures and persons and limiting storms damages. We assumed that revegetating the strip of coastline between the shore and the road will result in 8% local reduction in storm damage (Barbier et al., 2011).

Site	EbA	Costs	Benefits
Malem, Kosrae (FSM)	Establishment of MPA	The costs for establishing and operating a MPA are generally sustained by an implementing agency. Initial establishment costs were provided by the local NGO Kosrae Conservation and Safety Organization (KCSO) as for $3000. Operational costs of the MPA, included MPA community project manager and awareness and trainings for 5 years. We assumed that the community project manager costs are incurred in each year over the period 2019-2050. Opportunity cost was taken into account as cost for the community and was estimated using information on the annual value of harvested marine resources by the community in Malem (approximately US$ 259,480 per year) and the size of the MPA as a proportion of total marine area (approximately 20%). Some harvesting effort could be displaced to other locations, thereby offsetting some of the opportunity costs of the MPA, but we do not attempt to model this effect. We assume that no-take restrictions are enforced in the MPA for the first ten years (2017-2026) in order to allow the ecosystem and stocks to recover.	The benefits of the MPA comprise two categories: 1.Increased harvest of marine resources. We assumed that harvest rates are 30% higher than the baseline after the 10-year no-take restriction is relaxed in 2027 (Kerwath et al., 2013). Total quantities harvested continue to decline over time due to other pressures that are not controlled by the MPA (e.g. warming, ocean acidification) but are higher than the baseline case without MPA protection. 2. Reduced risk of storm damage. The effectiveness of the MPA in reducing storm damage is likely to represents an improvement relative to the baseline. We assume that the improved structure of the reef with MPA protection results in a 20% local reduction in storm damage (Kench and Brander, 2006).
Tamil, Yap (FSM)	Watershed Protected Area (WPA)	Establishment costs were provided by the local NGOs TRCT and YAPCAP as for $7150. Operational costs of the WPA, included meeting, awareness and training. We assumed that the community activity costs are incurred in each year over the period 2018-2050. Opportunity cost was based on the value of savannah land ($1.30 per square meter) and size of the WPA assuming over the period 2018-2050 each year a 2% of the area will converted for development or other purposes.	We assumed that extensive damages to watershed will degrade groundwater resources to a point of no-potable water and estimated avoided costs for drinking water for Tamil residents. It was assumed that each resident consumes 0.5 gal a day at a cost of US$ 0.15 per gal. An additional US$0.25 per week was added for transportation of water from Colonia to Tamil.
	Community nursery	The costs for the community nursery comprised three categories: (1) construction; (2) operation costs for a nursery producing and selling an average of 400 seedlings per month occur every year, (3) maintenance costs, assumed that equipment and tools have an average life expectancy of 6.5 years and the main structure (roof and wooden poles) has a life expectancy of 5-6 years (based on information derived from operating tree and vegetable nurseries in Yap).	We assumed households will use produced crops for their own consumption or sell part of the production. Crop value was assigned as the market price considering that total population consumes in average 0.3 lb a day of vegetables or other crops (breadfruit, taro, etc) and that, at present, average cost of these products is $1.5 per 1lb (Tamil community total income generation US$ 163,701 per year)

Site	EbA	Costs	Benefits
Tamil, Yap (FSM)	Reviving traditional wells	The costs to revive the traditional wells were i) construction of engineered barrier, ii) operation and iii) maintenance. Costs of managing and reducing pollution in the waterways were included as costs for outreach material. Costs were estimated for the 5 community wells.	We assumed that reviving 5 traditional wells will results in improved water capacity (7500 gal per day). Market value was used, as for GTWA residential water tariff of US$0.0015 per gallon (price associated with water consumption ranging between 0 and 5000 Ga).
Oneisomw, Chuuk (FSM)	Vegetated buffers/strips and slope stabilisation	Labour costs for stabilising 0.3 hectares of slopes area and preparing and planting approximately 300m of lemongrass were derived from consultations with USDA-NRCS personnel that conducted similar projects in other areas.	Benefits of lemongrass strips comprised two categories: (1) We assumed that stabilization of slopes and revegetation will result in a 20% improvement of freshwater quality due to reduced runoff and sedimentation (Helmers et al., 2008). (2) We assumed that improved water quality will help reducing water medical costs of water related diseases by 30%.
	Reviving traditional wells while establishing green buffers/strips	Labour costs for relining 8 open dug wells, stabilising 0.3 hectares of slopes area and preparing and planting approximately 300m of lemongrass were derived from consultations with USDA-NRCS personnel that conducted similar projects in other areas.	Benefits of wells restoration and lemongrass strips comprised two categories: (1) We assumed that reviving wells, stabilizing slopes and revegetating will result in a 50% improvement of freshwater quality due to reduced runoff and sedimentation (Helmers et al., 2008). (2) We assumed that improved water quality will help reducing water medical costs of water related diseases by 30%.
Ahus, Manus (PNG)	Seagrass restoration	For this activity, seagrasses will be transplanted to approximately 5 hectares of lagoon area. Costs comprised two categories: transplantation costs (30000 US$/ha, Fonseca et al., 1998) and opportunity cost due to harvesting restrictions in the replanted areas.	The benefits of seagrass restoration comprise two categories: (1) Increased harvest of marine resources. We assumed that harvest rates are 48% higher than the baseline (Blandon and Ermgassen 2014). Total quantities harvested decline over time due to other pressures independent from functioning seagrass ecosystem (e.g. warming, ocean acidification) but are higher than the baseline case without seagrass restoration. (2) Reduced risk of storm damage. Restored seagrass ecosystem is likely to represents an improvement relative to the baseline in reducing storm damage. We assume that the improved seagrass ecosystem results in a 8% local reduction in storm damage (Barbier et al., 2011).

Site	EbA	Costs	Benefits
Ahus, Manus, (PNG)	Giant clam gardening	The scale of farming is assumed to be in the order of 1000 clams per year. Costs included capital costs, training costs, operation (labour) and maintenance costs. Estimates for capital and maintenance costs were derived from the literature, labour and training costs estimates were provided by TNC PNG staff.	The benefit of giant clam gardening was relative to alternative livelihoods and access to traditional food. Market value of giant clam production was estimated based on a 90%survival rate of the 1000 clams and market price of US$2.50 per clam.