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Economic valuation for policy support in the context of ecosystem-based adaptation to climate change: An indicator, integrated based approach

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ABSTRACT

Ecosystem-based adaptation (EbA) includes a set of natural capital-based measures to adapt to climate change. UN Environment has called for measuring EbA costs and benefits before promoting the adoption of such a policy. Within such policy input, the paper objective is twofold. It first performs a critical survey of economic and valuation studies that measure the costs and benefits of undertaking EBA measures. It then proposes an integrated valuation approach, based on a set of 54 economic indicators that include ecological aspects and encompass the technical, financial and academic difficulties to perform thorough cost-benefit exercises, by providing policy-makers with simple, though rigorous evidence.

1. Introduction

Ecosystem based adaptation (EbA) "*uses biodiversity and ecosystem services as part of an overall adaptation strategy to help people and communities adapt to the negative effects of climate change at local, national, regional and global levels*" (UNEP, 2012). Fundamentally, "*EbA is the use of natural capital by people to adapt to climate change impacts, which can also have multiple co-benefits for mitigation, protection of livelihoods and poverty alleviation*" (Munang et al., 2013c). EbA options increase the resilience and capacity of selected ecosystems to naturally adapt to changes, including climate induced changes, over time. Effective EbA is where ecosystem-based approaches replace or augment conventional adaptation approaches to deliver superior outcomes for people and the community. The overall outcome is envisaged as an adaptive approach to implementation of adaptation initiatives that have been formulated with the role of ecosystems services at their heart and is becoming broadly applied worldwide.

There is, however, a crucial issue at the heart of effective EbA. It consists in the application of a well-founded valuation methodology that supports decision-making process and enables comparisons between conventional adaptation options (i.e. typically delivering a smaller range of services that are easier to quantify) with EbA options (i.e. deliver a greater range of options that are more difficult to quantify). When undertaking EbA, in fact, the decision-maker is both (1) restoring and conserving ecosystems for adapting to climate change pressures (e.g. coral reefs restoration for storm protection), and (2) restoring the resilience, the ecological/economic productivity and the capability of the ecosystems to regenerate and adapt to changes and shocks. She is, hence, investing in conserving and increasing the value of national natural capital. EbA options, in fact, produce several (present and future) additional positive impacts, beyond climate change adaptation.

In this context, valuing EbA impacts becomes crucial. EbA options' measurement, however, is a far more complex process compared to valuing more conventional or technical adaptation solutions, since it involves an assessment of (potentially large) non-market values that are often-times inadequately measured or missing altogether from cost-benefit assessments. This means that when deciding between options, technical adaptations might be unfairly favored or prioritized over ecosystem-based solutions. In addition, a critical challenge of economic valuations of EbA refers to the difficulties of valuing the (potentially large) array of benefits without market values. For example, urban green areas (such as parks) for adaptations to heat waves or storm events might provide a host of benefits such as cool shading, evaporative cooling, rainwater interception and storage, air pollution removal, habitat creation and biodiversity, as well as aesthetical, health and recreational values that do not have market prices. Improperly accounting for those

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Table 1. Coastal ecosystem based adaptation.

Coastal EbA Type	Action	Adaptation to Climate Change Effects
Mangrove Restoration and Conservation	Regeneration of ecosystems in areas where they have previously existed. Restoration of "the recovery of resilience and adaptive capacity of ecosystems that have been degraded, damaged, or destroyed". Successfully restored and conserved ecosystems recreate their former condition and strengthen the capacity to adapt to climate change over time	Attenuate waves' power, capture sediment to counteract coastal erosion, control ocean acidification, minimize sea surface temperature rise, slow storm surge water flows
Seagrass Restoration and Conservation		Reduce current velocity, dissipate wave energy and stabilize the sediment, buffering effect. Refugee for calcifying organisms, carbon sequestration
Coral Reef Restoration and Conservation		Attenuate waves 'power, limit waves height, reduce waves inundation, reduce coastal flooding and erosion
Dune and Beach Restoration and Conservation		Physical buffer to waves and storm surges. Protection of inland structures from flooding and damage. New beach profile after erosion events.
Coastal Wetland Restoration and Conservation		Attenuate waves and reduce waves inundation. Water store during time of high water, reducing coastal flooding. Provide freshwater source. Trap sediment and vertically make up soil.
Managed realignment Coastal Set-back Conservation	It involves setting back the line of actively maintained coastal defenses to a new line, inland of the original or, to rising ground.	Protection against flooding due to sea level rise, redefining the location of the coastline and maintenance of buffer ecosystems.
Living Breakwaters	Recreation and maintenance of the necklace of breakwaters to buffer coastal areas from, mollusks, and other organism	Control for wave damage and erosion while providing a more biodiverse habitat for juvenile fish, crustaceans and corals. Help increase resilience to acidification
Marine Protected Areas	MPAs restrict human activity for a conservation purpose, typically to protect natural or cultural resources.	Protected natural resources can strengthen the ecosystem resilience to climate change, including temperature and sea level rise, acidification of ecosystems, coastal flooding and erosion.
Sustainable Fisheries Management	Management Plans that consider the impact to sea temperature and ocean acidification on shifting species distribution and abundance	A sustainable exploitation of the fishery resource can strengthen its capacity to adapt to climate change.
Diversification and Protection of Ecosystem-Based Livelihoods	Supporting communities to protect and diversify their livelihoods. Reduce vulnerability for resource-dependent communities living in coastal areas, because ecosystem-based livelihoods are dependent on ecosystem services, which are sensitive to climate change impacts, such as changing rainfall patterns, saline intrusion from sea level rise, and changes to ocean temperature and acidity	Help reducing reliance on livelihoods that can be at risk from sea surface temperature rising, seal level rise, ocean acidification, storms.

values (or in some cases neglecting them altogether) definitely affects the economic valuations of EbA. Such an important area of research and policy warrants, therefore, greater attention.

In this context, the paper attempts to conceptualize a technical indicators-based framework that can correctly inform decision making on EbA adoption and implementation, The study presents a set of 54 economic indicators that encompass the technical, financial and academic difficulties to perform integrated and thorough economic valuation. The study aims at providing policymakers with simple, though rigorous evidence. The main objective of the technical framework aims at capturing the complexity of economic valuation of EbA costs and benefits, with computationally simple instruments. The proposed conceptual, methodological framework is applied to coastal EbA. When EbA is performed in coastal areas, ten different types of interventions may help addressing a range of climate change risks and impacts, as synthesized in Table 1[1].

The paper is organized as follows. Section 2 critically surveys economic studies that value costs and benefits generated by different EbA options. In addition, it presents an original assessment framework (based on 54 synthetic indicators) for the understanding and computation of economic costs and benefits generated by undertaking EbA options to climate change drivers. The economic indicators are grouped in 3 main sub-categories. Section 3 discusses the proposed methodology from a policy perspective. Section 4 concludes.

2. Methods

The choice of undertaking one or more EbA options can generate (present and future) costs and benefits that need to be valued and balanced. This is instrumental to achieve an informed decision on whether and how implementing the selected option. Economic analysis and valuation of EbA options' costs and benefits helps providing technical instruments that allow to (1) assessing the overall outcome; (2) enabling comparisons among adaptation methods and (3) support decision-making.

From this perspective, the section first surveys existing valuation studies, based on the performance of economic cost-benefit analysis methods, and then proposes an alternative valuation assessment methodology.

2.1. Critical survey of EbA costs and benefits valuation studies

For the compilation of the critical survey, we have scrutinized the literature on economic valuation of costs and benefits of marine and coastal EbA options. An initial search on google scholar has shown more than 40k papers from the academic and grey literature. We considered studies, analysis, applications and case-studies from all over the world, with the only constrain of English as a language. When refining the

[1] For a thorough description and explanations of the impacts of coastal EbA, see UNEP (2016).

Table 2. Valuation studies on coastal EbA options.

COSTS OF EbA OPTIONS			
Type of EbA options	Geographical Application	Costs (original study values)	Study
Wetland Conservation and Restoration			
Freshwater wetlands Restoration through hydrological manipulation	Denmark	1,300 US$/ha/year	Hoffman and Baattrup-Pedersen (2007)
Wetlands Restoration	United States	From US$170 per acre in the western Dakotas, Montana, Arkansas, and Louisiana to $6,100 per acre in the major corn-producing areas and along the Northern Pacific Coast.	USDA (2015)
Coral Reef Conservation and Restoration			
Structural Coral reef Restoration	Worldwide	Between US$20 and 155,000 per linear meter with a median project cost of US$ 1,290 per meter.	Ferrario et al. (2014)
Biological Restoration of coral reef	French Polynesia	500,000 US$/ha/year	Salvat et al. (2002)
Transplantation of Corals	New Caledonia	310,000 US$/ha/year	Job (2006)
Coral Reef Restoration	Grand Anse Bay, Grenada	1–10 ha at US$10 per coral	UNEP (2012)
Coral nursery and reef restoration	Windward, Carriacou Grenada,	50,000–1,000,000 US$ per ha	UNEP (2012)
Reef restoration. Nursery and out-planting on two hectares	Lauriston Beach, Carriacou Grenada	100,000–175,000 US$ per ha	UNEP (2012)
Coral Reef Restoration and Propagation	Laughing Bird Caye MPA, Belize	US$2 per coral. A square meter of reef only needs one coral planted because the selected species are so fast growing- they cover more than on square meter when mature in only five years.	Bowden-Kirby and Carne (2013)
Managed Realignment and Coastal Setbacks			
Establishment of a riparian buffer with and without fencing cost for Riparian zones	United States/North Carolina	3,100 US$/km without fencing and 9,900 US$/km with fencing	Holmes et al. (2012)
Dune and Beach Conservation and Restoration			
Beach nourishment	United Kingdom	£5,000-£200,000 per km	Scottish Natural Heritage. (2000) http://www.snh.org.uk/
Dunes Restoration through weed removal and native planting	Australia/Merimbula Beach	8,377 US$/ha/year	www.environment.nsw.gov.au (2012)
Dune stabilization using marram and lime grass transplants	United Kingdom	£20,000 per Km	Scottish Natural Heritage. (2000) http://www.snh.org.uk/
Beach Recycling and Profiling	United Kingdom	Costs for recycling vary widely, depending on the scheme objectives, volumes, distances of transport, frequency of ongoing works and the need for beach control structures. Minor works may cost only a few hundred pounds, while large scale works may run to £200,000/km and may need to be repeated annually.	Scottish Natural Heritage. (2000) http://www.snh.org.uk/
Seagrass Restoration and Conservation			
Seagrass restoration	The Netherlands	US$50,000/ha/year	Perillo et al. (2009)
Mechanical seagrass transplantation (including design and development, construction, testing and associated site selection)	Australia	US$1,000K/ha/year	Perillo et al. (2009)

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Table 2 (*continued*)

COSTS OF EbA OPTIONS			
Type of EbA options	Geographical Application	Costs (original study values)	Study
Seagrass manual planting	Australia	Volunteers planting. US$16–$34K/ha, depending on plant unit spacing. The same planting using professionals range from US$84 to US$168K/ha	McNeese et al. (2006)
Seagrass Restoration including monitoring	United States	between $570 and $972K/ha	Fonseca (2006)
Marine Protected Areas			
Marine Protected Areas Conservation	Worldwide	Recurrent annual expenditure on the 83 sampled MPAs, expressed per km2, ranged from zero to >$28 million per km2 per year (median, $775 per km2 per year).	Balmford et al. (2004)
Creation of a network of marine protected areas, MPAs (covering 20–30 per cent of the seas)	Worldwide	between 5 and 19 billion US$ to run per year	Balmford et al. (2004)
Creation and Maintenance of Marine Protected Areas (MPAs)	Worldwide	Estimated establishment costs for MPAs with increased size: from 0.5 to 1,000,000 Km2 span from 60 US$ to 63,752 US$ per Km2 Estimated annual maintenance costs for MPAs with increased size: from 0.5 to 1,000,000 Km2. span from 3 US$ to 293,639 to per Km2/year.	McCrea-Strub et al. (2014)
Creation of Marine Protected Areas (Seaflower MPA)	Colombia	228 US$ per Km2	Killmer et al. (2009)
Creation of Marine Protected Areas (Pilar MPA)	Philippines	4,568 US$ per Km2	Butardo-Toribio et al. (2009)
Creation of Marine Protected Areas (Talisay MPA)	Philippines	22,950 US$ per Km2	Butardo-Toribio et al. (2009)
Creation of Marine Protected Areas (Villahermosa MPA)	Philippines	11,802 US$ per Km2	Butardo-Toribio et al. (2009)
Creation of Marine Protected Areas (Bonaire MPA)	Netherlands Antilles	42,818 US$ per Km2	Dixon et al. (1993) Conversion in 2005 US$ by McCrea-Strub et al. (2014)
Creation of Marine Protected Areas (Nha Trang Bay MPA)	Vietnam	14,818 US$ per Km2	GEF (2005) Conversion in 2005 USD by McCrea-Strub et al. (2014)
Locally Managed Marine Area (including replenishment reserve and manages access areas)	Grande Anse Bay, Grenada	Annual cost (1,000K-1,750K US$)	UNEP (2012)
Mangroves Restoration and Conservation			
Mangrove Restoration	Worldwide	Range from US$225/ha to US$216,000/ha.	Lewis III (2001)
Replanting mangrove trees and other restoration measure	South Thailand	8,240 US$/ha intervention direct costs 118 US$/ha per year for maintenance and protecting of seedlings.	Barbier (2007)
Replanting mangrove trees	Fiji/Lami Town	2,396 US$/ha/year	Rao et al. (2013)
Mangrove restoration	Windward, Carriacou Grenada,	5,000–20,000 US$ ha	UNEP (2012), UNEP (2016)
BENEFITS OF EBA OPTIONS			
Type of EbA options	Geographical Application	Benefits (original study values)	Study
Wetland Conservation and Restoration			
Coastal Wetland Conservation	United Stated	23.2 billion US$ per year in storm protection services.	Costanza et al. (2008)

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Table 2 (*continued*)

COSTS OF EbA OPTIONS			
Type of EbA options	Geographical Application	Costs (original study values)	Study
Coral Reef Conservation and Restoration			
Coral Reef Restoration and conservation	Maldives	Around 2 billion US$ saving/ avoided costs (from choosing to build hard infrastructure such as seawalls, breakwaters and other forms of coastal protection to replace the natural reefs). This investment would maintain their critical protection service and could generate US$10 billion per year in co-benefits through tourism and sustainable fisheries.	Munang et al. (2013)
Coral reef preservation and conservation	Worldwide	Preservation of US$14 to US$20 billion in consumer surplus in 2110 (2014 USD, 3% discount rate) from consuming commercial reef fish.	Speers et al. (2016)
Coral reef preservation and conservation	Indonesia	Total Net Benefits to Individuals are US$33.3 per capita.	Cesar (1996)
Coral Reef Restoration	Grande Anse Bay, Grenada	Estimated mean value of 1 ha of coral reef is US$350K/year.	UNEP (2012)
Coral nursery and reef restoration	Windward, Carriacou Grenada,	Estimated mean value of 1 ha of coral reef is US$350K/year.	UNEP (2012)
Coral Reef restoration Nursery and out-planting on two hectares	Lauriston Beach, Carriacou Grenada	Contribute to beach protection and sand production. Increase value for fisheries and tourism	UNEP (2012)
Managed Realignment and Coastal Setbacks			
Managed Realignment/Watersheds Protection	United States	Benefits as avoided costs (US$ 462 million)	New York City (2011)
Managed Realignment	South Africa	US$ 387.5 million	Roberts et al. (2012)
Seagrass Restoration and Conservation			
Conserving Seagrass	Fiji Islands/Lami Town	Direct benefits of crabbing from seagrass equal FJD 123 per household. Using an estimate of 200 households, it is estimated that the direct benefits of the seagrass to be FJD 24,600. The total for this ecosystem is FJD 65,190	Rao et al. (2013)
Marine Protected Areas			
Locally Managed Marine Area (including replenishment reserve and manages access areas)	Grande Anse Bay, Grenada	Benefits to fisheries, tourism, sand production and coastal protection.	UNEP (2012) Cullis-Suzuki and Pauly (2010)
Mangroves Restoration and Conservation			
Mangroves Restoration and Conservation	South Thailand	Direct Benefits from storm protection are worth US$ 1,879 ha/year. Additional Benefits refer to the net income from collected forest products of US$ 101 per ha/ year, benefits from habitat fishery	Barbier (2007)

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Table 2 (*continued*)

COSTS OF EbA OPTIONS			
Type of EbA options	Geographical Application	Costs (original study values)	Study
		linkages (mainly the functioning of mangroves as fish nursery) worth US$ 171 per ha/year.	
Replanting mangrove trees	Fiji Islands/Lami Town	US$231,769,166 (discounted benefits for each scenario, calculated over 20-years, at a 3% discount rate).	Rao et al. (2013)
Mangrove restoration	Windward, Carriacou Grenada,	Benefits to shoreline protection, sediment stabilization, fisheries and aesthetics of coastline.	UNEP (2012)

search by using more specific key words (for instance narrowing to "EbA options", "marine EbA options", "economic valuation" "state-of-the arts" economic valuation techniques of costs and/or benefits, e.g. contingent valuation, stated choice and so on), the output strongly decreased to around 100 works. The reading of the abstract of selected papers was the required step to understand the focus and topic of the study. In fact, most studies on EbA are qualitative, when using economic analysis.

Finally, we ended up with a selection of papers (around 50), published in the period 2000–2016.

Table 2 reports the main content of the studies on EbA options in marine and coastal systems, where costs and benefits are measured in qualitative, quantitative and monetary terms.

The purpose of the survey aimed at checking for empirical regularities and commonalities that allow to point out general highlights. The search shows that the literature is very fragmented and does not allow to "build" a rigorous, general framework. This occurs because units of measurements, types of EbA options, socio-economic characteristics, geographical applications and valuation techniques vary broadly and are very context specific.

In order to systemize and summarize the surveyed literature, we have counted the frequency of types of applications and the minimum and maximum monetary value of the selected valuation studies. This exercise is only finalized to provide a synthetic, if not visual sketchy, overview on the state-of-the arts of economic valuation of coastal EbA.

Table 3 reports the main findings.

It does not exist a consistent corpus of studies that allows for direct comparability of values. In fact, most studies focus on the computation of costs or benefits only. Costs are often present, direct costs, generated by the concrete realization of and EbA intervention. Costs are computed on the margin. Benefits are mostly computed as avoided costs/damages and/or as additional benefits, indirectly generated by EbA on economic activities (mostly fishery and/or tourism). Benefits are computed as aggregated (discounted) values or just described and measured in qualitative terms[2].

Among the surveyed cases and studies on EbA costs valuation, the most frequent application (31.25%) refers to the creation of marine protected area (MPAs), followed by coral reef conservation/restoration (21.87%). Among the surveyed cases and studies on EbA benefits valuation, the most frequent application (42.85%) refers to the conservation/restoration of coral reef, followed by and mangroves conservation/restoration (21.428%).

When the valuation in monetary terms of both (present and future) EbA costs and benefits is performed (i.e. South Thailand and Fiji Lamu cases, for mangroves restoration/conservation), the future discounted benefits highly offset the present costs of the undertaken options.

Finally, even when costs and benefits are expressed in monetary terms, one has to be cautious in interpreting and comparing the figures. The measurement of EbA costs and benefits in monetary terms, in fact, also depends on the macro-economic milieu of the geographical area where a selected EbA option is implemented[3].

[2] In South Thailand, it has been computed that direct benefits from storm protection are worth US$ 1,879 ha/year. Additional benefits refer to the net income from collected forest products of US$ 101 ha/year. Benefits from habitat fishery linkages (mainly the functioning of mangroves as fish nursery) are worth US$ 171 ha/year. In the case of coral restauration and conservation in Lauriston Beach, Carriacou, Grenada, additional computed benefits indicate that an incremental 1% of conserved reef can attract more 487 international tourists for a value of 117,000 USD per day.

[3] The value of 1 dollar is very different in developing or wealthier countries. A "low value" in absolute terms might be very high in a concrete socio-economic context and has to be interpreted in the economic milieu where the EbA valuation is carried on.

Table 3. Summary statistics of EbA valuation studies and economic benefits and costs.

Costs 2017 (US$) of EbA Options			
Coastal EbA Option	Frequency of Studies	Minimum Value	Maximum Value
Wetland Conservation/Restoration	6.25 %	1,504 per ha per year	15,255 per ha per year
Coral Reef Conservation/Restoration	21.875%	2.03 per coral 20.18 per linear meter 51,850 per ha	10.3 per coral 157,251 per linear meter 1,037,000 per ha
Managed Realignment/Coastal Setbacks	3.125%	3,779 per km	12,068 per km
Dune/Beach Conservation/Restoration	12.5%	8,594 per km	332,995 per km
Seagrass Conservation/Restoration	12.5%	18,784 per ha	1,141,128 per ha
Marine Protected Areas	31.25%	64 per km2 (creation) 0 per km2 per year (maintenance)	68,215 per km2 (creation) 34 billion per km2 per year (maintenance)
Mangroves Conservation/Restoration	12.5%	287 per ha (Restoration) 118 per ha per year (maintenance)	275,616 per ha (Restoration) 2,431.94 per ha per year (maintenance)
Diversification/Protection of E-B livelihoods	0%	-	-
Sustainable Fisheries Management	0%	-	-
Living Breakwaters	0%	.	-
Benefits (2017 US$) of EbA Options			
Wetland Conservation/Restoration	7.142%	26.10 billion per year (avoided costs)	26.10 billion per year (total benefits)
Coral Reef Conservation/Restoration	42.85%	2.03 billion (avoided costs)	10.15 billion (co-benefits)
Managed Realignment/Coastal Setbacks	14.285%	401,84 million (avoided costs)	494.32 million (avoided costs)
Dune/Beach Conservation/Restoration	-	-	-
Seagrass Conservation/Restoration	7.142%	11,236,98 (total benefits)	29,778 (total benefits)
Marine Protected Areas	7.142%	-	-
Mangroves Conservation/Restoration	21.428%	2487 per ha/per year	235,245,703 (total benefits)
Diversification/Protection of E-B livelihoods	0%	-	-
Sustainable Fisheries Management	0%	-	-
Living Breakwaters	0%	.	-

2.2. Alternative methodology: EbA indicators

The section proposes to assess and value EbA options' costs and benefits by making the use of indicators. Indicators are measures that evaluate (indirectly) the level of a complex phenomenon, assessed by direct observation of other related phenomena, with a high common semantic content to the concept that one wants to measure. For this reason, we design a number of original indicators that compute economic costs and benefits generated when undertaking (each of the 10) EbA options.

As a general framework, the set of indicators were selected by the following criteria:

(1) validity (the capability of effectively measuring the concept under study);
(2) reliability (the ability to measure the concept in a stable manner across time);
(3) sensitivity to changes of what one wants to measure (the capability to adapt to data changes in a flexible manner);
(4) computational simplicity (the indicators are easily computable and do not require complex statistical/econometric operations);
(5) applicability for decision making (the degree of acceptability and uptake of the information for policy/management decisions, including public investments).
(6) applicability to each of the 10 EbA options, to engineering solutions and policy inaction.

In particular, the conceptualization and selection of indicators follow a precise reasoning. based on (1) the identification of the timing of the procedural steps required for EbA implementation and (2) the identification of all possible (present and future) direct/indirect costs and benefits, generated by EbA options' implementation. With respect to the timing of the EbA indicators, we have distinguished three different temporal dimensions: *ex ante*, contingent and *ex post* the selected EbA intervention. A set of indicators measures the *status quo* before performing the selected EbA option and provides an inventory (in simple physical terms and units of measurement) of the stock of natural capital in the area where EbA interventions have to be implemented. The *ex ante* assessment also values if and how much the stock of natural capital, and its capability to produce flows (e.g. ecosystem services), has been depleted by climate change events. Such operation is instrumental to the valuation of the efficacy and efficiency of the selected EbA options. Contingent to the EbA implementation, the indicators categorize the direct impacts of the adaptation option, including direct/indirect costs and benefits, measured in different ways, and possible negative externalities. For instance, the implementation of a selected EbA option can generate costs and benefits on local population during implementation (e.g. in coral reef restoration, fishers or scuba-divers could be forced to stop their activities as long as EbA operations have to be implemented. At the same time, local workers can be employed to collaborate with the EbA project). Finally, the set of indicators to be computed after the EbA option has been implemented, refers to maintenance and monitoring costs; a broad plethora of direct benefits generated from EbA with respect to adaptation to climate change, and a group of indirect benefits generated by well restored and conserved ecosystems beyond climate change adaptation. Those benefits include an improved economic productivity of the natural resource at stake, in a particular economic sector (e.g. dune and beach restoration can attract more tourists) and a new inventory of natural capital, after EbA intervention.

Table 4 reports and summarizes the rationale of the 54 indicators for the computation of costs and benefits derived from EbA options. Appendix 1 explains the computation method for each indicator.

The 54 indicators can also be categorized in three main groups: social resilient indicators; (strictly) economic indicators and biodiversity/environmental indicators, as synthesized in Figure 1.

The sub-categorization is important because the decision-maker and the stakeholders involved in a selected EbA option might attribute a

Table 4. EbA costs and benefits economic indices and indicators.

EbA Time Frame	Category	Rationale	Index/Indicator and Identification Code
Preliminary to EbA intervention	Natural Capital	The set of indicators aims at creating an inventory of natural resources in the area under study. Simple census indicators, a kind of straightforward assessment of the quantity of natural capital	Beach length (A1)
			Coral Reef Length/Area (A2)
			Mangrove Area (A3)
			Dunes length/Area (A4)
			Seagrass Area (A5)
			Number of MPAs (A6)
			Dimension of MPA (A7)
			Length and Area of Natural Breakwaters (A8)
			Area of Wetland (A9)
	Natural Capital Depletion (due to CC drivers) in a particular time period	The set of indicators aims at creating an inventory of ES lost in the area under study, because of selected climate change drivers in a scenario with no adaptation options.	Lost Beach length (B1)
			Lost Coral Reef Length/Area (B2)
			Lost Mangrove Area (B3)
			Lost Dunes length/Area (B4)
			Lost Seagrass Area (B5)
			Lost Number of MPAs (B6)
			Lost Dimension of MPA (B7)
			Lost Length of Natural Breakwaters (B8)
			Lost Area of Wetland (B9)
Contingent to EbA intervention	EbA Intervention Technical Organization And Productivity	This set of simple indicators aims at describing and measuring the economic production function (e.g. the technical organization of the EbA intervention) in a selected area.	Number of National and International Experts (C1)
			Number of Workers (C2)
			Number of ES necessary for Restoration and Conservation (C3)
			Number of technical instruments (C4)
			Number of machinery (C5)
			Impact of an additional input on EbA option (C6)
	Costs of EbA intervention	This set of simple indicators aims at measuring different types of costs generated by a selected EbA option in a selected area/region.	Total Costs (D1)
			Fixed Cost (D2)
			Variable Costs (D3)
			Average Costs (D4)
			Marginal Costs (per input, per dimension of the intervention) (D5)
			Opportunity Costs of Land (D6)
	Efficiency of EbA Intervention	This set of simple indicators aims at measuring the performance of the selected EbA option in terms of time and efficacy.	Expected Time for EbA completion (E1)
			Degree of substitutability of Engineering/Built Capital with Natural Capital (E2)
	Direct Benefits of EbA Intervention	This set of simple indicators aims at measuring different types of direct gains generated by a selected EbA option in a selected area/region	Benefits on local Employment (F1)
			Benefits on local Economy (F2)
	EbA (potential) negative Externalities	The set of simple indicators measures potential negative impacts generated by the implementation of the EbA option on the local communities	Number of Days that the selected economic activity cannot be performed as BAU and value of the related income loss. (G1)
Posterior to EbA intervention	Monitoring and Maintenance Costs	This set of simple indicators aims at measuring different types of costs generated by monitoring and maintaining the EbA option, after realization, in a selected area/region	Total Costs (H1)
			Fixed Cost (H2)
			Variable Costs (H3)
			Average Costs (H4)
			Marginal Costs (per input, per dimension of the intervention) (H5)
	Direct Benefits of EbA Intervention (related to adaptation to climate change drivers)	This set of simple indicators aims at measuring all the possible gains directly derived from the implementations of EbA options in a selected area.	Avoided/Minimized Coastal Erosion (I1)
			Avoided/Minimized Total Damages (I2)
			Avoided/Minimized loss and damages in real estate (I3)
			Avoided/Minimized loss and damages to coastal villages in developing/less developed areas (I4)
			Avoided/Minimized loss and damages in infrastructures (I6)
			Avoided/Minimized damages to Agriculture Sector (I6)
			Avoided/Minimized damages to Fishery Sector (I7)
			Avoided/Minimized damages to Tourism Sector (I8)
			Avoided/Minimized Remediation/Reconstruction Costs (I9)
			Decreased Insurance Costs (I10)

(*continued on next page*)

Table 4 (*continued*)

EbA Time Frame	Category	Rationale	Index/Indicator and Identification Code
	EbA Indirect Benefits or Positive Externalities Natural Capital Appreciation (due to the EbA intervention) in a particular time period	This set of simple indicators aims at measuring all the possible gains indirectly derived from the implementations of EbA options in a selected area	Increased value (appreciation) of the natural capital stock due to the EbA intervention (J1)
			J.1.1. Increased Beach length
			J.1.2. Increased Coral Reef Length/Area
			J.1.3. Increased Mangrove Area
			J.1.4. Increased Dunes length/Area
			J.1.5. Increased Seagrass Area
			J.1.6. Increased Number of MPAs
			J.1.7. Increased Dimension of MPA
			J.1.8. Increased Length of Natural Breakwaters
			J.1.9. Increased Area of Wetland
			Ecosystems Productivity in Coastal Tourism (J2)
			Ecosystems Productivity in Fishery and Aquaculture (J3)
			Ecosystems Productivity in Agriculture (J4)

different importance (attach different weights) to the different types of indicators. A decision maker, in fact, might attach a higher weight to the social resilient indicators and a lower weight to the economic indicators. Such weights or scores must be computed case-by case and can be useful to calibrating the computation of indicators and meta-indicator. In fact, each single indicator condenses information at analytical level. Many indicators can be synthesized in meta-indicator, like for instance, a simple benefit-cost ratio (B/C ratio)[4].

3. Discussion

The capability of costs-benefits methodologies and techniques to provide informative contents for decision-making is limited in the case of EbA. This occurs for two reasons. First, EbA is a context-specific, case-by-case exercise (UNEP, 2012) and so is the economic valuation of EbA costs and benefits that mostly depend on contingent scenarios and available data. Second, identifying and computing EbA costs and benefits is an integrated exercise that can be based on a plethora of economic, social and ecological aspects. Attaching a monetary value to EbA costs and benefits is only the final step of a thorough integrated procedure that should include the assessment of (1) climate change drivers, impacts and vulnerability[5]; (2) socio-economic milieu and (3) geographical, ecological and environmental local peculiarities[6]. Such complexity may not be captured by standard economic valuation methodologies and related computational procedures. The methodological heterogeneity and often incompleteness of many studies, in fact, may not provide a systematic, integrated support for policy decision making for EbA options. In addition to that, alternative ecosystem valuation methodologies can inform policy choices to better reflect local needs, improve living standards and facilitate more effective adaptation strategies to climate change. "*Alternative ecosystem valuation methodologies, in fact, can enable new pathways towards climate change adaptation and the improvement of living standards that would be particularly suitable for low-income settings where natural resources are vulnerable and financial resources scarce*" (Folkersen, 2018, p.1, p.1).

From this perspective, using indicators can overcome (at least some of) the difficulties, including the computational complexity, required by state-of-the arts economic valuation methodologies and techniques. Despite possible limitations, which will probably emerge with further research and the application of the assessment methodology to case-studies, the proposed indicators framework presents several advantages. Indicators are easy to compute, and the required data are often available and easy to gather and collect. In addition, the indicators are very flexible in application. The indicators attempt to gather and value information that might be neglected and not accounted when performing cost-benefit analysis with state-of the arts valuation methodologies, given that methodological protocols can be very rigorous but bounding and limitative in assessing complexity. The indicators attempt to cover the multi-faceted valuation reality, generated by EbA implementation.

The matrix of 54 indicators is conceived as a menu list. The analyst (scientists, practitioners and/or policy-makers) will use and will compute those indicators that are required by the valuation tailored to the specific case-study at issue (time period, geographical scale, macroeconomic milieu, ecological status, location and so on). The indicators are very effective in communicating the main message they have to convey. In addition., the same assessment structure can be used for computing costs and benefits of both EbA options and alternative options to climate change adaptation (i.e. engineering based adaptation intervention). This allows comparisons among different policies and climate change adaptation options.

4. Conclusions

In the last few decades, a considerable amount of work has gone into the monetary valuation of the services provided by the environment to human well-being. Based on the framework of economics, the monetization of ecosystem services has been advocated as a way to make visible the hidden benefits that nature provides. The hope is that if the services of nature (including adaptation to climate change) can be expressed in amounts of money, policy makers and markets will see their value and act to insure they are used in a sustainable way. Although frequently presented as a novel approach it actually has a very long history (Baveye et al., 2013).

[4] Such synthetic indicator can support decision-making scenario by employing a mathematical equation that results in a quantitative estimate. The estimate is useful to scope out the benefits of a situation against the costs of the situation. It is a ratio of benefits divided by costs. When we divide the value of the benefits by the value of the costs, the result indicates how much we get in benefits for every unit of money spent in the project. The computation of B/C ratio is based on estimation, and of course estimation is valid only if the data and the source that spawn the hypothesized numbers.

[5] Climate Change Impacts Assessment refers to the selection of relevant climate change drivers and their most important impacts on coastal systems in the particular area under study. EbA options, in fact, depend on the peculiar climate change drivers and impacted sectors. Vulnerability Assessment refers to the quantitative assessment of the consequences of climate change drivers on human activities and the environment in coastal systems. This assessment is very important because can be interpreted as the cost of policy inaction.

[6] The impacts of climate change on environment and human activities are mostly determined by two main elements: (1) the specific economic and environmental characteristics of the territory and population hit by the climatic event, and (2) the adaptation measures in place in the selected area. Adaptation measures vary depending on a plethora of factors. For instance, adaptation measures can be classified based on the sectors considered, the methodology, the timing, goal and motive of their implementation. Adaptation can include reactive or anticipatory actions, or can be planned or autonomous, engineering or ecosystem based.

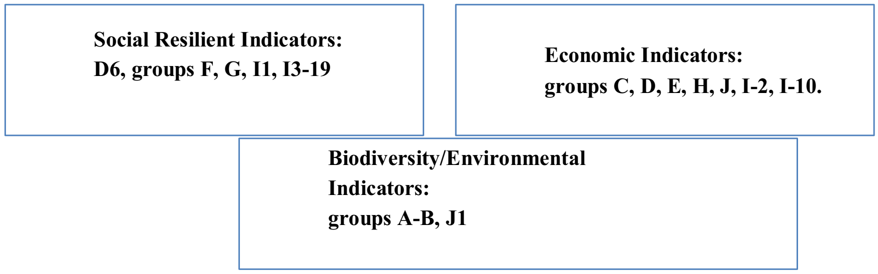

Figure 1. Social, economic and environmental sub-categories.

From this perspective, the paper has provided an assessment framework for the identification and computation of economic costs and benefits generated by undertaking EbA options to climate change drivers. After having critically reviewed a broad literature in the topic of economic valuation of EbA costs and benefits, we have presented and illustrated 54 synthetic indicators, grouped in 3 main sub-categories (social resilient, economic and biodiversity/environmental). The proposed framework is instrumental to provide rigorous, but easy-to-compute valuation instruments that inform the policy supporting the implementation of EbA options. Ecosystems and natural capital present resilience and capability of self-restoration to adapt to climate change and are important production inputs in green economies and drivers of green economic growth. Investing in EbA options today, beyond climate change adaptation, implies increasing the value of the stock of natural capital in the future because EbA allows ecosystems to continue and provide their services and generate the related benefits. In addition, investing in EbA improves the quality, hence increases the value of the natural capital. Such feature might result appealing for those economies, like SIDS (Small Islands Development States), where environment is an important driver of economic growth (e.g. tourism). From this perspective, the technical calculation of EbA impacts, through the proposed methodological framework, can correctly inform decision making.

Declarations

Author contribution statement

Laura Onofri: Conceived and designed the analysis; Analyzed and interpreted the data; Wrote the paper.

Paulo A.L.D. Nunes: Conceived and designed the analysis; Analyzed and interpreted the data.

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References

Balmford, A., Gravestock, P., Hockley, N., McClean, C.J., Roberts, C.M., 2004. The worldwide costs of marine protected areas. Proc. Natl. Acad. Sci. Unit. States Am. 101, 9694–9697.

Barbier, E., 2007. Valuing ecosystem services as productive inputs. Econom. Pol. January 2007, 177–229.

Baveye, F., Baveye, J., Gowdy, J., 2013. Monetary valuation of ecosystem services: it matters to get the time-line right. Ecol. Econ. 95, 231–236.

Bowden-Kirby, A., Carne, L., 2013. Thermal tolerance as a factor in caribbean acropora restoration. In: Proceedings of the 12th International Coral Reef Symposium, Cairns, Australia, 9-13 July 2012 20A Restoration of Coral Reefs.

Butardo-Toribio, M.Z., Alino, P.M., Guiang, E.S., 2009. Cost–benefit study of marine protected areas: implications on financing and institutional needs. Philippine Agric. Sci. 92, 153–169.

Cesar, H., 1996. Economic Analysis of Indonesian Coral Reefs. The World Bank, Washington, DC.

Costanza, R., et al., 2008. The value of coastal wetlands for hurricane protection. AMBIO A J. Hum. Environ. 37 (4), 241–248.

Cullis-Suzuki, S., Pauly, D., 2010. Marine protected area costs as ''beneficial'' fisheries subsidies: a global evaluation. Coast. Manag. 38, 113–121.

Dixon, J.A., Scura, L.F., van't Hof, T., 1993. Meeting ecological and economic goals: marine parks in the Caribbean. Ambio 22, 117–125.

Ferrario, F., et al., 2014. The effectiveness of coral reefs for coastal hazard risk reduction and adaptation. Nat. Commun. 5, 3794.

Folkersen, M., 2018. Ecosystem valuation: changing discourse in a time of climate change. Ecosyst. Serv. 29, 1–12.

Fonseca, M., 2006. Wrap-up of seagrass restoration: success, failure and lessons about the costs of both. In: Treat, S.F., Lewis III, R.R. (Eds.), Seagrass Restoration: Success, Failure, and the Costsof Both. Selected Papers presented at a workshop, Mote Marine Laboratory, Sarasota, Florida, March 11–12, 2003. Lewis Environmental Services, Valrico, Florida, pp. 169–175 (21) (PDF) Seagrass restoration.

Global Environmental Facility (GEF), 2005. CORALINA. Colombia, Caribbean Archipelago Biosphere reserve: Regional marine Protected Area System, GEF MSP, Grant TF No. 023881, Project Completion Report.

Hoffmann, C.C., Baatrupp-Pedersen, A., 2007. Re-establishing freshwater wetlands in Denmark. Ecol. Eng. 30 (2), 157–166.

Holmes, P.M., Rebelo, A.G., Dorse, C., Wood, J., 2012. Can Cape Town's unique biodiversity be saved? Balancing conservation imperatives and development needs. Ecol. Soc. 17 (2), 28.

Job, S., 2006. Transplantation des coraux du port de Goro Nickel et suivi de l'opération. Rapport technique. SOPRONER – GINGER.

Killmer, A., Lemay, M., Olivera, R., Balcazar, F., Jimenez, J., Restrepo, L., 2009. Colombia, Protecting Biodiversity in the Southwestern Caribbean Sea (CO-X1004).

Lewis III, R.R., 2001. Mangrove Restoration - Costs and Benefits of Successful Ecological Restoration in Proceedings of the Mangrove Valuation Workshop, Universiti Sains Malaysia, Penang, 4–8 April, 2001. Beijer International Institute of Ecological Economics, Stockholm, Sweden.

McCrea-Strub, A., et al., 2014. Understanding the cost of establishing marine protected areas. Mar. Pol. 35, 1–9.

McNeese, P.L., Kruer, C.R., Kenworthy, W.J., Schwarzschild, A.C., Wells, P., Hobbs, J., 2006. Topographic restoration of boat grounding damage at the Lignumvitae Submerged Land Management Area. In: Treat, S.F., Lewis III, R.R. (Eds.), Seagrass Restoration: Success, Failure, and the Costs of Both. Selected Papers presented at a workshop, Mote Marine Laboratory, Sarasota, Florida, March 11–12, 2003. Lewis Environmental Services, Valrico, Florida, pp. 131–146.

Munang, R., Thiaw, I., Alverson, K., Goumandakoye, M., Mebratu, D., Liu, J., 2013. Using ecosystem-based adaptation actions to tackle food insecurity. Environ. Sci. Policy Sustain. Dev. 55, 29–35.

Munang, R., Thiaw, I., Alverson, K., Liu, J., Han, Z., 2013. The role of ecosystem services in climate change adaptation and disaster risk reduction. Curr. Opin. Environ. Sustain. 5 (1), 47–52.

Munang, R., Thiaw, I., Alverson, K., Mumba, M., Liu, J., Rivington, M., 2013. Climate change and ecosystem-based adaptation: a new pragmatic approach to buffering climate change impacts. Curr. Opin. Environ. Sustain. 5, 67–71.

Perillo, G.M.E., Wolanski, E., Cahoon, D.R., Brinson, M.M. (Eds.), 2009. Coastal Wetlands: an Ecosystem Integrated Approach. Elsevier.

Roberts, D., Boon, R., Nicci, D., Douwes, E., Govender, N., Macinnes, A., McLean, C., O' Donoghue, S., Spires, M., 2012. Exploring ecosystem-based adaptation in Durban, South Africa: "Learning-by-doing" at the local government coal face. Environ. Urban. 24 (1), 167–195.

Rao, N.S., Carruthers, T.J.B., Anderson, P., Sivo, L., Saxby, T., Durbin, T., Jungblut, V., Hills, T., Chape, S., 2013. An economic analysis of ecosystem-based adaptation and engineering options for climate change adaptation in Lami Town, Republic of the Fiji Islands. In: A Technical Report by the Secretariat of the Pacifi C Regional Environment Programme. – Apia, Samoa : SPREP 2013.

Salvat, B., Chancerelle, Y., Schrimm, M., Morancy, R., Porcher, M., Aubanel, A., 2002. Restoration d'une zone corallienne dégradée et implantation d'un jardin corallien. Rev. Ecol. Supp. 9, 81–96.

Speers, Ann E., et al., 2016. Impacts of climate change and ocean acidification on coral reef fisheries: an integrated ecological–economic model. Ecol. Econ. 128, 33–43.

UNEP, 2012. Guidance Manual "Ecosystem-Based Adaptation Guidance: Moving from Principles to Practice".

UNEP, 2012. Building Capacity for Coastal Ecosystem-Based Adaptation in Small Island Developing States (SIDS) Assessing Climate Vulnerability in Grenada and Responding with Coastal Ecosystem-Based Adaptation Action.

UNEP, 2016. Options for ecosystem based adaptations (EBA). In: Coastal Environments: a Guide for Environmental Managers and Planners. UNEP, Nairobi.

USDA, 2015. Effects and Effectiveness of USDA Wetland Conservation Practices in the Mid-Atlantic Region: A Report on the Conservation Effects Assessment Project Mid-Atlantic Regional Wetland Assessment 2008 – 2015. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcseprd1097415.pdf. Accessed online on 04/04/2018.