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

Laura Onofri a,*, Paulo A.L.D. Nunes b

a TESAF - Department of Land, Agriculture, Environment, Forestry, University of Padova, Viale dell’Università, 16, 35020 Legnaro, PD, Italy
b Office of the Assistant Director-General, Climate, Biodiversity, Land and Water Department, Food and Agriculture Organization of the United Nations, Viale delle Terme di Caracalla - 00153 Rome, Italy

A R T I C L E   I N F O
Keywords:
Economics
Environmental science
Ecosystem based adaptation (EBA)
Climate change
Cost-benefit analysis
Economic valuation
Economic indicators
Environmental policy

A B S T R A C T

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 policymakers 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 aesthetic, health and recreational values that do not have market prices. Improperly accounting for those
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.

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.

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. |

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 | 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 Bastrup-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$10 per coral | UNEP (2012) |
| Coral nursery and reef restoration | Windward, Carriacou Grenada, | 50,000-1,000,000 US$/ha per ha | UNEP (2012) |
| Reef restoration. Nursery and out-planting on two hectares | Lauriston Beach, Carriacou Grenada | 100,000–175,000 US$/ha 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) |

(continued on next page)
| 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 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 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 | 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) |

**Table 2 (continued)**

| Type of EbA options | Geographical Application | Benefits (original study values) | Study |
|---------------------|--------------------------|--------------------------------|-------|
| Wetland Conservation and Restoration | United Stated | 23.2 billion US$ per year in storm protection services. | Costanza et al. (2008) |

(continued on next page)
| 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.                                      | Csor (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) Callis-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)                |
search by using more specific keywords (for instance narrowing to “EBA options”, “marine EBA options”, “economic valuation” “state-of-the-art” 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-art of economic evaluation 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.

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 of coral reef (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.²

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 restoration 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.
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 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 intervention 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

| 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 (I5) 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) |
| | | | J1.1. Increased Beach length |
| | | | J1.2. Increased Coral Reef Length/Area |
| | | | J1.3. Increased Mangrove Area |
| | | | J1.4. Increased Dunes length/Area |
| | | | J1.5. Increased Seagrass Area |
| | | | J1.6. Increased Number of MPAs |
| | | | J1.7. Increased Dimension of MPA |
| | | | J1.8. Increased Length of Natural Breakwaters |
| | | | J1.9. Increased Area of Wetland |
| | | | Ecosystems Productivity in Coastal Tourism (J2) |
| | | | Ecosystems Productivity in Fishery and Aquaculture (J3) |
| | | | Ecosystems Productivity in Agriculture (J4) |

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; (2) socio-economic milieu and (3) geographical, ecological and environmental local peculiarities. Such complexity may not be captured by standard economic valuation methodologies and related computational procedures.

**Footnotes**

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.

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-art 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 limiting 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).
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.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing interest statement

The authors declare no conflict of interest.

Additional information

Supplementary content related to this article has been published online at https://doi.org/10.1016/j.heliyon.2020.e04650.

Acknowledgements

The authors would like to thank Stuart Crane, Keith Alverson, John Gowdy, David Simpson, the participants to the 2019 Manchester EAERE (Environmental and Resource Economics Association) Meeting and three anonymous referees for interesting remarks. The usual disclaimer applies.

The views and opinions expressed in this article are those of the authors and do not necessarily reflect the official policy or position of FAO.

References

Balbontín, A., Gravenstock, P., Hockley, N., McLean, C.J., Roberts, C.M., 2004. The worldwide costs of marine protected areas. Proc. Natl. Acad. Sci. Unit. States Am. 101, 9684–9697.

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.L., Alino, P.M., Granada, F.T. (Eds.) Florida 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.

Costanza, R., Boatz, M., Joppa, L.N., 2014. Marine protected area costs as “beneficial” fisheries subsidies: a global evaluation. Coast. Manag. 38, 113–121.

Dixon, J.A., Scra, 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., et al., 2008. 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 Costs of 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) (PS) Seagrass restoration, Global Environmental Facility (GEF). 2005. CORALINA, Colombia, Caribbean Archipelago Biopshere reserve: Regional marine Protected Area System, GEF MSP, Grant TF No. 023881, Project Completion Report.

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

Holmes, P.M., Rebelo, A.G., Done, 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’évolution des coraux. Rapport technique. SOPRONER – GINGER.

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

Lewis III, R.R., 2001. Mangrove Restoration – Costs and Benefits. Selected Papers presented at a workshop, Mote Marine Laboratory, Sarasota, Florida, March 11–12, 2003. Lewis Environmental Services, Valrico, Florida, pp. 169–175 (21) (PS) Seagrass restoration, Global Environmental Facility (GEF). 2005. CORALINA, Colombia, Caribbean Archipelago Biopshere reserve: Regional marine Protected Area System, GEF MSP, Grant TF No. 023881, Project Completion Report.

McNeese, P.L., Kruer, C.R., Kenworthy, W.J., Schwarzschild, A.C., Wells, P., Hobbs, J., 1993. Meeting ecological and economic goals: marine parks in the Caribbean. Ambio 22, 117–125.

Ministry of the Environment and Tourism,Gambia, 2009. Gambia National Strategy for Climate Change and Green Economy 2009–2012.

Munang, R., Thiaw, I., Alverson, K., 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.

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.

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.

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.

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.

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.

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.

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.

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.

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., Droues, 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., Garruthers, 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 Pacific 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/nrcsrpr1097415.pdf. Accessed online on 04/04/2018.