ECOSYSTEM SERVICES PROTOCOLS TO ASSIST THE COASTAL ZONE MANAGEMENT – A TRANSDISCIPLINARY DIALOGUE

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Abstract
The present study presents a transdisciplinary effort in searching, selecting, developing and implementing indicators for the assessment of ecosystem services (ESs) in the coastal zone. Despite the various classifications developed in recent years, the majority of the relevant studies result in qualitative evaluations of the main ESs of the coastal zone, and, thus, there has been no clear and/or comprehensive assessment approach. Our study aims at developing protocols to quantitatively assess the ecosystem services of the coastal zone and encouraging experts and managers to consider them in their socio-economic assessments. The semi-enclosed Kalloni Bay (Lesvos, Greece) is used as a case study. The main ecosystem services are briefly introduced and indicators of ecosystem services are selected using inputs from a transdisciplinary dialogue Finally, results from the implementation of protocols involving the selected indicators are presented and discussed. The importance of Bay regulating service is assessed, since Kalloni Bay receives annually 35 tn of Phosphorus and 75 tn of Nitrogen. In general, slightly higher salinities are observed in the embayment compared with those of the open sea during the mixing period, whereas the Bay opperates as sink and/or source of nutrients depending on the stratification period or mixing period. For 2050 under a combined Sea Level Rise scenario of 1.6 m, ~43 – 86% of Kalloni beaches will be completely (at least temporarily) eroded based on the low and high projection of the combined ensembles, respectively.
Keywords: *coastal zone, ecosystem services, indicators, erosion*
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1. Introduction

Research on ecosystem services (ESs), i.e. the benefits derived from natural ecosystems, has increased exponentially over the last decade, with most studies focusing on the mapping and evaluation mainly of terrestrial ecosystem services. With regard to marine and coastal ESs, Liquete et al. (2013) reviewed 145 studies and suggested a list of 476 relevant indicators. Fisheries appear as the most frequently analyzed 'provisioning' ES, with water purification and coastal protection and recreation and tourism being the most commonly studied ESs associated with the 'regulation and maintenance' and 'cultural' ES, respectively. The majority of these studies concerned coastal areas with mangroves and coastal wetlands and a coastal ES classification system was proposed (Liquete et al., 2013) that integrated, updated and improved previous classifications schemes such as those of the Millennium Ecosystem Assessment (2005), the Economics of Ecosystems and Biodiversity (TEEB, 2010), the Common International Classification of Ecosystem Services – CICES (Haines-Young and Potschin, 2011) and the system proposed by Beaumont et al. (2007).

Management of the coastal areas of the Mediterranean islands which are characterised by high cultural, social, economic and historical value can be effectively facilitated by approaches that map and evaluate their ecosystem services. The objective of the present contribution is to present the results of a study involving the development of protocols to assess the main ESs of the coastal environment of Kalloni Bay, a large semi-enclosed embayment in the island of Lesvos, Greece (Fig.1).

2. Methodology

In the present study, the classification system of Liquete et al. (2013) is used as it focuses on coastal and marine ESs. The most important ESs were selected (Table 1) and specific protocols designed to evaluate the services using quantitative indicators. Each protocol includes information related to the approach applied to estimate indicators selected to be representative and/or to be quantitatively assessed, the strengths, weaknesses and time effort of the method, and the related references. In Table 2, a protocol related to 'regulating and maintenance' indicator class is shown, that includes the analysis of terrestrial and coastal erosion ESs.

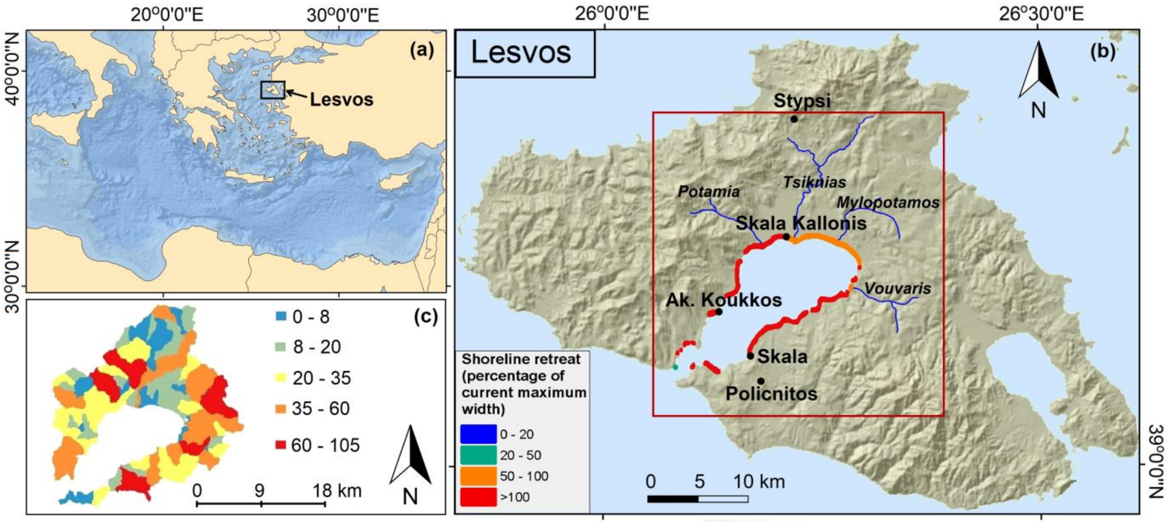

Figure 1. Location (a, b); Projections of maximum (at least temporally) retreat of Kalloni beaches under a combined SLR of 1.6m (see text) expressed as percentages of their initial maximum widths; and drainage basin of Kalloni Bay (Lesvos, Greece), showing also the Phosphorous export to the coastal zone (kg/ha/yr) (right) (c). Mediterranean bathymetric data from GEBCO_2014 Grid, http://www.gebco.net/.

3. Results

Development of Ecosystem Service Protocols

Several protocols were developed to assess the various ESs associated with the specific environment of Kalloni Bay (Table 1). Some of them are found on theoretical assumptions or literature reviews, but the majority are based on practical estimations using either simple and easy to use approaches or more complex and data hungry models.

Table 1 ES associated with the coastal environment of Kalloni Bay

Indicator class	**Classification** (Liquete et al., 2013**)**	**ES selected**
Provisioning	Food Provision	**Fish catch**
	Water Storage and Provision	**Water mass balance** of the drainage area and the embayment water circulation
	Biotic materials and biofuels	Fishing boats, fishing equipment, marine aggregates
Regulating and Maintenance	Water purification	**Terrestrial fluxes of N and P** Contribution of the river basin processes to mitigate nutrients load. Estimation of the terrestrial water mass balance; point and diffused nutrient sources; assessment of the main processes (i.e. nitrification, denitrification) involved water purification.
	Air quality regulation	-
	Coastal protection	**Terrestrial erosion** Soil erosion of the terrestrial environment (detachment and transport of soil material by wind or water) **Coastal erosion (beach retreat)** Beach exposure to environmental (climatic) change (i.e. sea level rise)
	Climate regulation	**Climate adjustment**

		The contribution of the marine ecosystem to regulate climate through their influence on the hydrologic cycle, temperature adjustments and mitigation of atmospheric pollution
	Ocean nourishment	**Nutrients cycle** Fate and transport of nutrients
	Life cycle maintenance	**Biodiversity** Ecological quality characterization based on biological criteria and in physicochemical and hydro-morphological data
	Biological regulation	**Bathing water quality**
Cultural	Symbolic and aesthetic values	**Cultural ecosystem services** Environmental perceptions affect the cultural heritage, aesthetic experiences and the spiritual development. There are multiple ways that ecosystems interact with local communities and find expression through local identity, customs, cultural heritage, gastronomy, art and crafts, and the physical and mental health. The above are related mostly to qualitative evaluations (e.g. questionnaire surveys, other social research techniques), due to their intangible and non-measurable character.
	Recreation and tourism	**Tourist/visitor arrivals and touristic beds** The number of people visiting/staying and the number of touristic beds/infrastructure reflect the popularity of a destination with specific ecosystem characteristics such as the presence of aesthetically and environmentally sound beaches or charismatic species. **Birdwatching; hiking; bike/walking trails; fishing; diving and other ecosystem based recreational activities; land coverage** The number and variety of recreational activities underline the plurality of the offered cultural ecosystem services. User numbers for such activities provide evidence on their social value and significance. Land coverage (km^2 or percentage) for touristic/recreational uses illustrates the plethora of the cultural ESs; greater coverage relates to greater attraction. Land coverage (km^2 or percentage) of protected areas (marine or terrestrial) reflects their value/importance.
	Cognitive effects	**Biodiversity conservation and protection; scientific and local knowledge; public awareness;** Scientists, researchers and local communities explore the functions/interconnections between ecosystems and people, so they can design ecosystem-oriented approaches according to the sustainability principles. Number of papers/ publications/ studies/ lectures and conferences about the ecosystems of an area, shows their significance for both experts and local communities. Also the number of local organizations, associations and NGOs illustrates the social value of the area's ESs.

Table 2 Protocol for the 'regulating and maintenance' ESs of Climate Adjustment and Terrestrial and Coastal Erosion

Indicator Class	**Climate adjustment** Ecosystem contribution to climate regulation through its influence on the hydrologic cycle, temperature and the mitigation of atmospheric pollution	**Terrestrial and coastal erosion** a) Soil (terrestrial) erosion (soil loss, downstream sedimentation); b) Beach erosion due to sea level rise
Indicator	Redfield index	a) Universal Soil Loss Equation USLE; b) Cross-shore (1D) analytical and numerical morphodynamic models
Methodology	Measurements of atmospheric and sea CO2. If pCO2 is higher than the atmospheric, then the sea operates as a sink. (Krasakopoulou & Pagou, 2011)	a) USLE assesses the average annual rate of soil erosion on a sloping terrain on the basis of the rainfall, soil type, slope, crop, land cover, and erosion control practices (Margaroni et al., 2015); b) Beach retreat is predicted by ensembles of seven cross-shore (1D) analytical and numerical morphodynamic models, set up/forced on the basis of collected information and different long-term and short-term sea level rise scenarios (Monioudi et al., 2017; Tzoraki et al., 2018)
Strengths	In case of data availability, the COx air - sea models are adjusted or determined experimentally	(a) Easy to estimate at spatial scales. Joint Research Center (JRC) offers soil erosion maps at national level for the EU Member States. (b) User - friendly GUIs developed/used
Weaknesses	High frequency and analytical precision of chemical information necessary for the safe characterization of a marine environment as CO_2 source or sink, based on the measurement of the parameters of the carbonaceous salts	(a) Specific soil parameters (e.g. organic matter content) are not available in the web. Validation of erosion rates in the field is always a difficult exercise (b) Need of specific field data such as detailed bathymetry and high frequency wave monitoring information
Estimated time of application	Seasonal sampling for the evaluation of the net flux of CO2 air-sea	Time is needed to collect the data and specific knowledge of GIS High computation time (>1 day)

Application of the ES protocols in Kalloni Bay, Greece

These protocols have been used in the coastal zone of Kalloni Bay (Fig. 1), and some representative results are presented below. For instance, for the assessment of both 'water storage and provision' and 'ocean nourishment' ESs, the freshwater mass balance is needed. The Soil Water Assessment Tool (SWAT) model (http://swat.tamu.edu/software/arcswat/) (Neitsch et al., 2011) was used to simulate the hydrologic processes at basin scale. In Figure 2 SWAT monthly results related to the hydrological processes of precipitation, snow melting, surface flow, lateral flow, water yield, evapotranspiration and potential evapotranspiration are presented.

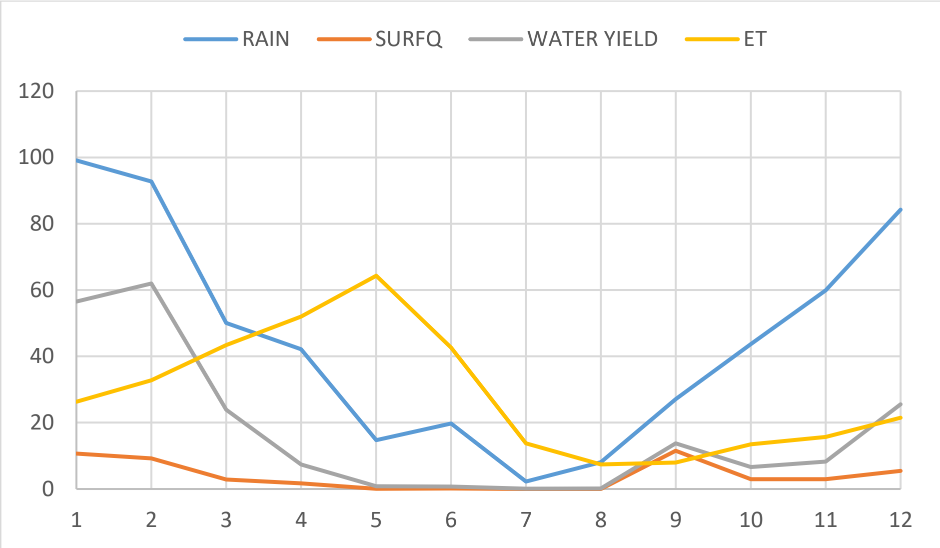

Figure 2. Monthly variation in mm of the main hydrological processes in Kalloni bay (Rain, Surface Runoff, Water Yield and Evapotranspiration)

The most important rivers in terms of surface drainage and flow rate are the Tsiknias (84.6 km^2) and Mylopotamos (50 km^2) rivers in the northern part of the embayment, Potamia (48.6 km^2) to the west and Vouvaris (24.3 km^2). A land area of about 406 km^2 drains into the embayment, where various human activities take place, mainly urbanization, tourism, agriculture and livestock farming. Therefore, the embayment receives rich in nutrients surface run-offs from the agricultural land, mostly untreated urban waste waters from the surrouding towns and villages (total population of about 15,000) and industrial wastes from small industrial units/installations (mills, dairies and fabric dyeing units) (Spatharis et al., 2009). InVEST modeling indicates a decrease from north to south in the nutrient loads entering Kalloni Bay. InVEST modeling, has estimated that an annually total of 35 tn of phosphorus and 75 tn of nitrogen enters Kalloni Bay (Chalazas et al., 2017). This may be linked to the above-mentioned increased supply from the north, soil composition, inclination and nutrient sources along the sub-basins.

Application of the biogeochemical model LOICZ for both phases (mixing and stratification periods) of the Kalloni Bay gave interesting results for the water mass balance and circulation and the nutrient (nitrogen and phosphorous) mass balances. LOICZ modeling has suggested that significant differences exist in the two examined phase periods. In general, slightly higher salinities are observed in the embayment compared with those of the open sea during the mixing period, whereas the opposite is indicated for the stratification period. The results could be improved by implementing a sampling strategy, so that nutrient measurements cover also the summer period, where activities in Kalloni Bay basin are different, the freshwater supply is small and the phosphorus and nitrogen concentrations higher. In addition, the spatial distribution of nutrients suggested by the InVEST modeling (Chalazas et al., 2017) could be modified, considering specific land uses, and appropriate mass from the burden on households, industry and the atmosphere in order to create more realistic effects. With regard to runoff data, it is possible to improve the SWAT results by taking into account information on rainfall, temperature, humidity, solar radiation and wind speeds from local stations located in the mountainous areas of the basin (e.g. at Stypsi). Since SWAT has the potential to estimate soil nutrient loss, calibration of the soil load within the Kalloni Bay basin by field sampling could better simulate the diffusion of point or non-pollutants.

The retreat/erosion of Kalloni beaches under episodic sea level rise (due to the combination of storm surges and wave set-ups) and relative sea level rise RSLR was estimated using a 'short-term' ensemble comprising 4 numerical models and a 'long-term' consisting of 3 analytical models respectively. More details regarding the beach erosion methodology can be found in Monioudi et al., 2017. The geo-spatial characteristics and other attributes of the beaches (beach width and area, sediment texture, density of backshore infrastructure etc.) were recorded using the images, related optical information and tools available in the *Google Earth Pro* application. The models were set up using linear profiles. A range of bed slopes from 1/10 to 1/30 was used. Most of the beaches are characterized by mild slopes of ~1/30, thus the high estimates of the model ensembles can be considered as more accurate for most of the Kalloni beaches. Wave forcing was based on in situ measurements; mean maximum wave heights and corresponding wave periods were set as 1 m and 4 s, respectively. With regard to the sediment texture, it was found (from photographic material of *Google Earth Pro* application and field observations) that Kalloni beaches are composed mostly of sands (a range of 0.2-1mm was used). Concerning long-term beach erosion under RSLRs (according to projections for the study area) of 0.2 m (average rise under the Representative Concentration Pathway scenarios RCP4.5 and RCP8.5 for the year 2050), 0.5 m (RCP4.5, 2100) and 0.76 m (RCP8.5, 2100) above the mean sea level of 1995 (Vousdoukas et al., 2017), was projected as 2.2 – 6.7, 5.3 – 16 and 8.1 – 24.3 m respectively. With regard to short-term SLRs, the 100-year event is projected to be of about 1.4 m under both RCP scenarios (Vousdoukas et al., 2017) which may induce temporally erosion of Kalloni beaches of 15 – 42.2 m. Ranges of reduction in "dry" beach widths were estimated through the comparison between the projected ranges of beach retreat/erosion and the maximum-recorded beach width for future sea levels under the combined RSLRs and the short-term sea level rise, using consecutively the long- and short-term ensembles. For 2050 under a combined SLR scenario of 1.6 m, ~43 – 86% of Kalloni beaches will be completely (at least temporarily) eroded (from which ~21 and ~94% respectively are fronting assets) based on the low and high projection of the combined ensembles, respectively.

4. Conclusions

The development of protocols for ESs proved to be an efficient tool to study in an integrated manner the coastal ESs. Various tools were used that require various data inputs and diverse methodologies. In all protocol, application, the main issue that has been the need for specific information relevant to the coastal and marine environment. In the absence of such information, assumptions were made and, in many cases, the parameter values used were adapted from previous similar studies. Also, collaboration between experts from different disciplines has created very useful dialogs with regard to the objectives and implementation of the protocols.

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