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Article *in* Journal of Coastal Research · March 2016

Impact Factor: 0.98 · DOI: 10.2112/SI75-220.1

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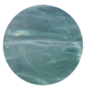

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Journal of Coastal Research	SI	75	1097 - 1101	Coconut Creek, Florida	2016

Ecosystem Services and Their Benefits as Coastal Protection in Highly Urbanised Environments

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ABSTRACT

Guisado-Pintado, E.; Navas, F., and Malvárez, G., 2016. Ecosystem Services and Their Benefits as Coastal Protection in Highly Urbanised Environments. *In:* Vila-Concejo, A.; Bruce, E.; Kennedy, D.M., and McCarroll, R.J. (eds.), *Proceedings of the 14th International Coastal Symposium* (Sydney, Australia). *Journal of Coastal Research*, Special Issue, No. 75, pp. 1097 - 1101. Coconut Creek (Florida), ISSN 0749-0208.

Coastal hazards from hydro-meteorological events such as flooding, shoreline erosion, storm surges and sea level rise, have been widely studied not least because they can have significant impacts on human activities and assets, adversely affecting the economy, well-being and safety of coastal communities. Coastal hazards are a major concern for local populations and authorities and recently European Union Directives and Horizon 2020 strategies have focussed on building a common framework to manage those events, to take adequate and coordinated measures to reduce it. As a result, the quantification and evaluation of ecosystem services provided by coastal systems for human populations have begun to be incorporated into policy and decision-making processes in order to preserve both ecosystems and the benefits these offer. Notwithstanding the considerable progress that has been made in recent years, successful delivery of indicators to evaluate and map the Coastal Protection ecosystem service at adequate spatial scale is still uncommon. In this paper existing indicators at a European scale for Coastal Protection service (capacity, flow and benefit) are adapted and applied to a coastal area in southern Spain where urban and tourism activities are the main drivers whilst coastal exposure to hazards is increasing. Results highlight the importance of scale and resolution when approaching coastal systems and the importance of using accurate and local-regional sets of data. Further, the need to understand the spatial and temporal variability of the Coastal Protection service and the non-linearity response is shown to be essential when developing coastal and marine management strategies.

ADDITIONAL INDEX WORDS: *Coastal hazards, habitats, vulnerability, Cascade model.*

INTRODUCTION

Natural hazards have become important forcing variables in their interaction with human activity (coastal vulnerability) and particularly in their negative impacts on the economy and the safety of coastal communities (McLaughlin and Cooper, 2010). The increasing impact of flood events, rising sea-levels and storm erosion effects is currently a major concern for coastal populations and authorities.

Growing demands placed on coastal and marine resources from various economic sectors have also led to habitat loss, pollution, over-exploitation and a general degradation of ecosystems (EEA, 2010). Recent policies and regulations (EU Biodiversity Strategy, Flood Directive) have clearly stated the need for inclusion of Ecosystem Services (ES) assessments in socio-economic analysis such as Cost-Benefits appraisals and risk reduction programmes. Ecosystem Services are usually viewed as providing benefits from natural systems to human well-being or as the actual benefits derived from nature to people (MEA, 2005). Coastal and marine ecosystems are particularly linked to the Coastal Protection (CP) service, namely the natural defence of the coastal zone against inundation, erosion from waves, storms and sea level rise, which contribute up to 77% of the global ecosystem service value (Martinez *et al*., 2007). Hence, CP can be interpreted as the ecosystem's capacity to supply natural hazard and erosion regulation (MEA, 2005), as well as the actual benefits derived from moderation of extreme events, regulation of water flows and erosion prevention (TEEB, 2010). Therefore, CP is a combination of the above services that act over a narrow coastal strip where both the drivers (waves, storms, sea-level rise) and the protection elements (geomorphology, emerged and submerged habitats) are interconnected.

Despite the considerable progress made in recent years, with wide-ranging assessments being conducted of the CP benefits from specific coastal ecosystems such as mangroves and estuaries (Barbier *et al*., 2011), wetlands (Costanza *et al.*, 2008) and protection against tsunamis (Danielsen *et al*., 2005), data and methods are still somewhat limited (Barbier, 2012). Compared to terrestrial ecosystem assessments, there is a low resolution and/or paucity of spatially explicit information on complex coastal and marine environments. This therefore presents a challenging problem when quantifying functions and benefits (Maes *et al*., 2012). Apart from a recent proposal of CP indicators at a continental European scale (Liquete *et al*., 2013) and the INVEST model, a decision support tool for local ecosystem mapping (Guerry *et al*., 2012), little progress has been made in providing a

DOI: 10.2112/SI75-220.1 received 15 October, 2015; accepted in revision 15 January, 2015.
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holistic approach to ES benefits in which all components of the continuum coastal-marine ecosystems are considered and further mapped. While different approaches can be considered in the assessment of ES, the *Cascade model* (CM) is the one adopted here, as it links both the biodiversity to human well-being through the flow of ES (Haines-Young and Potschin, 2010) and it supports the representation of ES at various scales (e.g. Maes *et al*., 2012; Liquete *et al*., 2013). The CM approach considers the *Capacity* of an ecosystem to deliver a service based on its internal structure (e.g. presence of sand dunes or cliffs), the exposure to processes (e.g. waves, tides, currents) and its ecological functions (e.g. wave attenuation, sediment redistribution). Those functions eventually can provide a *Flow* of ecosystem services (e.g. erosion protection) which might contribute to human well-being and thus could be rendered into specific *Benefits* (e.g. contribution to safety, reduction of risk). Additionally, benefits can be translated into monetary values, for example, the estimated damage from a storm event.

In this paper, the ecosystem service CP- Coastal Protection is assessed through the calculation of quantitative indicators and their metrics for a touristic area on the southern coast of Spain. The indicators (initially proposed at European scale by Liquete *et al*., 2013) have been significantly adapted to a local scale in order to consider key physical and socio-economic specificities of the study area.

STUDY AREA

The Costa del Sol, located along the Andalusia Mediterranean coast of Southern Spain, is a renowned global tourist destination, being one of the most visited places in Spain. The peak of tourist infrastructure development took place in the 1960's, resulting in a significant population growth and a corresponding transformation of the coastal landscape. This has resulted in irreversible environmental impacts from the aggressive urbanisation undertaken (Guisado *et al*., 2013). However, despite the fact that in 2012, the population of the littoral area was around 520,000 inhabitants, with an annual average increment of >20,000 inhabitants/year (IECA, 2013), well-preserved natural spots and low-urbanised areas still remain. The study area comprises eight coastal municipalities (Figure 1) that encompasses a coastal stretch of some 107 km long with a WSW-ENE orientation. The proximity of the Sierras to the Mediterranean coastline and the presence of a narrow continental platform with a predominance of soft coastal cliffs results in coastal plains associated with river mouths and narrow beaches where coastal dunes are rarely found. Nevertheless, at some spots medium to wide beaches are backed by small aeolian planes and other minor sedimentary formations. The dune field at Cabopino is probably the best representative of this type of environment. Seabed habitats are mainly composed of medium to fine sands, where seagrass meadows and other hard substrata are more scattered, only relevant to the west of Marbella. With a microtidal range, the wave action is the main hydrodynamic agent. Beach profiles are quite steep and the resulting surf zone is generally steep and narrow, which marks a concentration of wave action within a narrow fringe (Malvárez, 2012). These physical attributes along with a dense urban and touristic coastal area makes the Costa del Sol a highly vulnerable area, where flooding events are enhanced by the presence of narrow and steep rivers, and erosion effects by storms are of major concern to local and regional authorities, and population in general.

METHODS

For the purpose of this research, the coastal zone is defined as the area potentially affected by extreme hydrodynamic conditions and includes all coastal and marine systems (excluding habitats far inland). The coastal area is then delimited by the 100 m depth isobath (with a maximum extent of 1 nautical mile offshore from the territorial waters baseline following the Water Framework Directive) and 100 m height topographic contour given the existence of steep slopes (continental platform and coastal cliffs). From these limits, 76 calculation units (CU) of 1 km length perpendicular to the coast were delineated for geoprocessing and indicator calculation.

Following the CM approach and guided by previous studies (Liquete *et al*., 2013, CMA, 2011), the following indicators are proposed to assess CP along the Costa del Sol. The Inherent Capacity (CPcap) as the natural ability of coastal and marine ecosystems to protect against natural hazards (flood, erosion) based on their ecological and geological characteristics. The Natural exposure (CPexp) defined as the predicted need of protection based on oceanographic and climatic conditions (waves, tides, etc.). Then finally, Human demand (CPdem), as the calculated need of coastal populations for protection based on the presence of residents, tourists and assets. The CP service flow (combination of CPcap and CPexp) is understood as the potential of an ecosystem to deliver a service (capacity) and the need of doing it (exposure). On the other hand, the combination of the Cpflow and the specific demand (CPdem) of a given coastal area provides an indication of the benefit (CPben) for society.

Variables used and Indicators calculation

The spatial scale (here mainly local and municipal) determines the resolution and complexity that should be considered and so variables were fully adapted using locally updated data and based on specificities of the Costa del Sol. For *CPcap*, habitats and natural structures (Table 1) were selected following expert-based ranking (in agreement with previous studies from Pendleton *et al*., 2010; Liquete *et al*., 2013), and further ordered into a meaningfully sequence based on their influence and role in coastal protection. Additionally, for these qualitative variables (geomorphology, seabed and emerged habitats) weighting values were applied in order to assess their protection capacity in the study area. The resulting indicator is defined as $CPcap = 0.33geo + 0.25 slope + 0.21 seahab + 0.21 emerhab$.

Regarding the *CPexp*, given that tide is insignificant in the Mediterranean (average of 0.8m), the influence of waves (especially high energy events), rising sea level and erosion impacts are very important. The exposure indicator is defined as $CPexp = 0.29 wav + 0.29 ero + 0.23 slr - 0.19 tide$.

Furthermore, a variable to account for tourism demand (hotel beds/coastal length) was also considered, resulting in *CPdem= 0.35 pop+0.25 inf +0.15 art + 0.10 her+ 0.25 tour*.

Table 1. *List of variables, data sources and geo-processes considered in the calculation of Coastal Protection indicators of CPcap, CPexp and CPdem.*

Variable	Database	Reference	Scale	Geoprocess
Bathymetry Topography	Topo-bathymetry integrated model from land-sea.	CMA-REDIAM, 2010	20x20 m	Delimitation of study site and mean slope (slope) *CPcap*
Geomorphology	Coastal shoreline geomorphology and defence works.	CMA-REDIAM, 2000	1:5000	Weighted average based on coastal protection (geo, seahab, emerhab) *CPcap*
Seabed habitats	Seabed morphology: ecocartography from Málaga.	MMA, 2005	1:5000	
Emerged Habitats	EU Corine Land Cover (CLC) dataset from 2006.	EEA, 2012	100 m	
Waves	Modelled data (SWAN) from buoy records (WANA 2011011) of maximum wave height for the decade 2000-2010.	SWAN (Booij, 1999); Puertos del Estado, 2010.	20 m	Mean significant wave height (wav) *CPexp*
Erosion rates	Coastal Vulnerability Index. Indicator of Erosion trend measured from 1956-2005 (m/yr).	CMA, 2011	1:100.000	Mean Erosion rate (ero) *CPexp*
Sea level trend	Global grid of mean sea level trends (satellite altimetry 1992-2010).	Ssalto/Duacs /AVISO; CNES, 2010	1/3 deg.	Mean sea level trend (slr) *CPexp*
Tidal range	Tidal amplitude from M2 calculated for 1993- 2014 for Málaga.	Puertos del Estado, 2015		Mean tidal range (tide) *CPexp*
Population density	Spatial distribution of Andalusian population in 2013.	IECA/REDIAM, 2013.	250 m	Population density (pop) *CPdem*
Infrastructures	Infrastructures in the coastal zone represented by the regional roads network.	IECA, 2011	1:100.000	Infrastructures density (inf) *CPdem*
Artificial surface	EU Corine Land Cover (CLC) dataset from 2006.	EEA, 2012	100 m	% artificial surface (art) *CPdem*
Natural Heritage	Natural protected areas, Red Natura 2000 and Biosphere Reserves.	IECA/REDIAM, 2015.	1:10.000	% nat heritage (her) *CPdem*
Tourism demand	Socio-economic Coastal Vulnerability Index. Indicator for touristic accommodation by coastal length (hotel, beds).	CMA, 2011	1:100.000	Mean Touristic density (tour) *CPdem*

Note: Further information on variables used and full references can be found in this link (http://dx.doi.org/10.13140/RG.2.1.2389.1284).

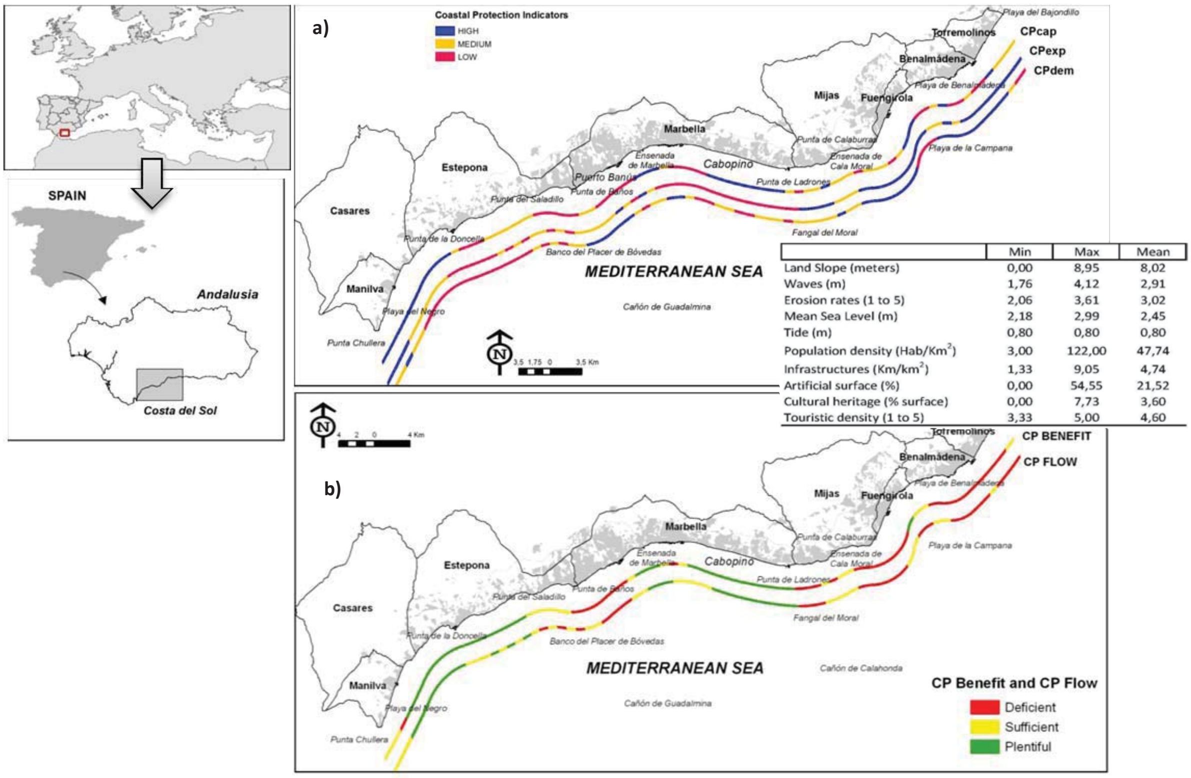
A total amount of 13 biophysical variables (Table 1) were normalised and weighted, based on minima and maxima after aggregation within each CU. Resulting values are dimensionless and thus have no meaning in absolute terms but are designed for comparative analysis. For all indicators positive linear relationships between variables were assumed based on weights, except for the tide as it's considered to be defensive since it builds a protective buffer zone (lower values of CPexp). In addition, human structures (e.g. ports) are not taken into consideration in the assessment of ecosystem services as they cannot be considered natural systems.

RESULTS

Three qualitative indicators (CPcap, CPexp and Cpdem) ranked as low, medium and high based on 33rd and 66th percentile, were calculated and mapped along the 107 km of Costa del Sol. Lower values of CPcap, less capacity of adaptation to potential changes, are found around urban beaches of the municipalities of Estepona, Marbella and Mijas and are driven mainly by low values of *geo* (artificial beaches) and *emerhab* (open spaces with no vegetation). Conversely, high values are due to the combination of *geo* (well-developed beaches with dune systems or cliffs), the presence of seabed habitats with capacity to disrupt water movement (seagrass meadows, rock substrata), and are found around Cabopino and western of Punta de la Doncella, where valuable coastal ecosystems still persist (Figure 1a).

Across the study area, CPexp is mainly determined by waves and erosion rates (greater around ports and urban beaches) and to a lesser extent by mean sea level trends which increase towards the E. Therefore, lower values are found to the E of Marbella (around Cabopino) which is both sheltered from eastern storms (less exposed) and represents a dissipative environment, whereas the eastern and more exposed coastal strip from Mijas to Torremolinos shows higher CPexp values. Population density (that peaks in Mijas) and the presence of artificial surfaces (*art*) are the main drivers for higher values of CPdem encountered in Puerto Banús and the city of Marbella. Along the East part, where 49% of the coast has been deeply transformed, the tourism demand variable reaches the greatest values (around 60,000 touristic beds in 2014) and thus determines Cpdem values. Low values are scattered along the Ensenada de Marbella-Cabopino and from Estepona to Manilva. The joint effect of the capacity, exposure and demand affect ecosystem dynamics and functions, and thus the services (flow and benefit) that they can provide. The CPflow is found to be 'satisfactory' in 36% of the coast (CPcap=CPexp) and 'abundant' (CPcap>CPexp) across 30% of the study area (mainly around Cabopino and W of Estepona). However, around 33% of the Costa del Sol (mainly eastern municipalities) falls into the 'Deficient' category (CPcap<CPexp) and thus are less stable in terms of resilience as they lack sufficient protection capability under changing scenarios of coastal hazards.

Finally, the Coastal Protection benefit for society is determined as 'satisfactory' or 'abundant' along 60% of the area, while 39% is categorised as 'Deficient' (Figure 1b) due to the fact that the demand is greater than the capacity of the ecosystem to provide the services (Puerto Banús surroundings and scattered sites alongside the eastern municipalities).



	Min	Max	Mean
Land Slope (meters)	0,00	8,95	8,02
Waves (m)	1,76	4,12	2,91
Erosion rates (1 to 5)	2,06	3,61	3,02
Mean Sea Level (m)	2,18	2,99	2,45
Tide (m)	0,80	0,80	0,80
Population density (Hab/Km^2)	3,00	122,00	47,74
Infrastructures (Km/km^2)	1,33	9,05	4,74
Artificial surface (%)	0,00	54,55	21,52
Cultural heritage (% surface)	0,00	7,73	3,60
Touristic density (1 to 5)	3,33	5,00	4,60

Figure 1. a) CP indicators of Capacity, Exposure and Demand and main statistics of variables. b) CP indicators of Flow and Benefit.

DISCUSSION

Natural ecosystems play an important role in hazards regulation and risk protection, which impacts have been increasing as population density and coastal and marine demands increase. However, the capacity of the ecosystems to provide services and their role of protection under extreme events is still poorly understood and thus benefits are undervalued or not considered in decision-making processes. Coastal management and prevention programmes, however, can no doubt be improved if the protective role of natural ecosystems and their relationship with Human, Social and Built capitals are considered (Pérez Maqueo *et al*., 2007).

In this approximation, the ES assessment evidences the deficient coastal zones in terms of coastal protection services. Thus, results can drive actions oriented to increasing resilience along low capacity areas with poor *flow* where significant erosion and flood problems occur (33% of the coast). Better management of low CPbenefit areas (39%) would also result where demand should be controlled in order to enhance ecosystem function for coastal hazards response.

Different areas along the Costa del Sol, with similar patterns and exposure to natural coastal hazards, have varying levels of capacity, depending on past socio-economic and urban development decisions, and on the status of their natural capital (ecosystem and habitats). Moreover, as CP varies in time (storms frequency, vegetation status) and space (heterogeneity across geomorphology and seabed and emerged habitats) non-lineal protection services against natural hazards should be considered when designing management plans and conservation strategies. Further, synergetic processes and complex relationships between coastal and marine variables will require cognisance of the entire land-sea continuum to guarantee the maintenance of functions and services. Here the *Capacity* and *Flow* indicators represent the current natural provision of coastal protection in the area, based on their geophysical attributes. However, given the accelerated degradation of ecosystems and facing the future consequences of climate change and growing coastal population, those areas with "covered" CPflow should also need to be included in adaptive strategies. Certainly, through this approach (CM) the capacity, exposure and demand of ecosystems, as well as their flow and benefit, could easily be translated into information that can ultimately drive institutional and social responses (Daily *et al*., 2009).

Whilst maps of CP benefits show where future research and actions should be focused in protection of important areas, CPcap and CPdem provide an insight into vulnerable zones for potential intervention action (Cabopino dune system among others). Although some attempts have been made to integrate the economic valuation of the ecosystem, this still remains controversial and complex as it requires many assumptions to me made (e.g. ES provide many benefits yet most of them have no market value) and thus the translation of ecosystem values and their benefits into monetary terms, remains a huge challenge. Although in our approach the indicator of benefit could be used as a proxy for this (Liquete *et al*., 2013), in agreement with Heal (2000) we believe that the key issue is not to value ecosystem services in economic terms but to demonstrate the incentives and benefits for their protection.

CONCLUSIONS

In the present work, an approximation of coastal ecosystem services, including the provision of meaningful cartography of CP at adequate spatial scale, and the protective role from natural hazards is presented. Results enhance the inclusion of Ecosystem services' assessments in coastal management plans (ICZM strategies) as well as helping support current and future Directives implementation (e.g. Floods). The characterisation of CP indicators could help to drive strategies and actions as they are indicative of needed protection and vulnerable areas for intervention. However, further research should consider future scenarios of climate change, population and economic trends and their influence in the provision of the Coastal Protection service.

ACKNOWLEDGMENTS

Thank goes to C. Liquete and D.J. for their advices and to the Regional Government of Andalusia (CMA, IECA & REDIAM) for data provision.

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