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Ecosystem service value losses from coastal erosion in Europe: historical trends and future projections

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Abstract Coastal zones experience increased rates of coastal erosion, due to rising sea levels, increased storm surge frequencies, reduced sediment delivery and anthropogenic transformations. Yet, coastal zones host ecosystems that provide associated services which, therefore, may be lost due to coastal erosion. In this paper we assess to what extent past and future coastal erosion patterns lead to losses in land cover types and associated ecosystem service values. Hence, historical (based on CORINE land cover information) and projected (based on Dynamic and Interactive Vulnerability Assessment - DIVA - simulations) coastal erosion patterns are used in combination with a benefits transfer approach. DIVA projections are based on regionalized IPCC scenarios. Relative to the period 1975–2050, a case study is provided for selected European coastal country member states. For historical (1975–2006) coastal erosion trends, we observe territory losses in coastal agricultural, water body and forest & semi-natural areas – total coastal erosion equaling over 4,500 km^2. Corresponding coastal ecosystem service values decrease from about €22.3 billion per year in 1975 to about €21.6 billion per year in 2006. For future (2006–2050) coastal erosion projections, total territory losses equal between ~3,700 km^2 and ~5,800 km^2 – coastal wetland areas being affected most severely. Corresponding coastal ecosystem service values decrease to between €20.1 and €19.4 billion per year by 2050. Hence, we argue that the response strategy of EU member states to deal with coastal erosion and climate change impacts should be based on the economic as well as the ecological importance of their coastal zones.

Keywords Climate change · Coastal erosion · Environment · Ecosystem service values

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Introduction

Coastal zones in Europe experience increased rates of erosion due to rising sea levels, increased storm surge frequencies, reduced sediment delivery to the coast, as well as anthropogenic degradation and transformation of natural coastal areas (EEA 2006a, b). Although the impacts of coastal erosion are confined to coastal areas, these areas host between 15 % (<10 km from coast) and 40 % (<100 km from coast) of the world population (UN 2005; EEA 2006a) as well as a wide variety of terrestrial, aquatic and coastal ecosystems that provide a series of ecosystem services (EEA 2006a; Martinez et al. 2007). Hence, it is argued that these ecosystems and associated ecosystem service values may be lost due to coastal erosion (EEA 2006a; Nicholls and Tol 2006; Alves et al. 2009).

The importance of ecosystem functions, services and values is increasingly recognized since the release of the Millennium Ecosystem Assessment (MA 2005), though their use in policy and decision support tools is still lacking

(De Groot et al. 2010). Review of the coastal research literature shows that while various studies analyze historical and/or future coastline evolution (see Eurosion 2004; EEA 2006a) and other studies assess coastal ecosystem service values (e.g. Costanza et al. 1997; Martinez et al. 2007; Brenner et al. 2010), only few studies estimate the ecosystem service value losses associated with coastal erosion. Studies that assess this environmental-economic impact of (climate change induced) coastal erosion apply, at the continental/global scale, partial or general equilibrium approaches (e.g. Leatherman and Nicholls 1995; Nicholls and Hoozemans 1996; Yohe and Schlesinger 1998; Darwin and Tol 2001; Bosello et al. 2006), which have the disadvantage that spatially explicit detail on local socio-economic and, in particular, environmental conditions is sacrificed to obtain consistent data sets (Knogge et al. 2004). Only few studies assess, at the local scale, the environmental-economic impact of (climate change induced) coastal erosion using direct cost methods, thereby taking into account spatially explicit environmental-economic considerations (e.g. Alves et al. 2009; Roebeling et al. 2011). Invariably, these studies assess the environmental-economic impact of *future* (climate change induced) coastal erosion.

This paper aims to contribute to these earlier studies and policy debate regarding the environmental-economic importance of coastal ecosystems, by assessing to what extent past (historical) as well as future (projected) coastal erosion patterns lead to losses in land cover types and associated ecosystem service values. To this end, historical (1975–2006) and projected (2006–2050) coastal erosion patterns are used in combination with a benefits transfer approach for the valuation of ecosystem services. While historical coastal erosion patterns are based on CORINE land cover information (Bossard et al. 2000), projected coastal erosion patterns are based on Dynamic and Interactive Vulnerability Assessment (DIVA) simulations (Hinkel and Klein 2009; Ionescu et al. 2009) for lower and upper bound regionalized sea level rise estimates (derived from the IPCC-SRES scenarios; Nakicenovic and Swart 2000). Benefit transfer estimates for ecosystem service values are based on Costanza et al. (1997) and Martinez et al. (2007). A case study is provided for selected European coastal country member states, including Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal and Spain.

The structure of the paper is as follows. In the next section we provide a detailed description of the applied methodology, which employs a benefits transfer approach in combination with historical and projected coastal erosion patterns to determine ecosystem service value losses from past (historical) as well as future (projected) coastal erosion. Next, in the 'Results' section, baseline (1975) land cover and ecosystem service values for selected European coastal country member states are given and, in turn, historical (1975–2006) as well as future (2006–2050) land cover and ecosystem service value loss estimates are presented. Finally, the 'Discussion and conclusions' section offers concluding remarks and observations.

Methodology

With the aim to determine past as well as future land cover and ecosystem service value losses from coastal erosion along the European coast (Results), we develop and apply an environmental-economic (direct cost) approach that combines a benefit transfer approach (for the valuation of ecosystem service values; Ecosystem service valuation), historical coastal land use map intersections (for the determination of historical coastal erosion patterns; Historical coastal erosion patterns) and DIVA scenario simulations (to explore future coastal erosion projections; Future coastal erosion projections).

Ecosystem service valuation

Benefit transfer (BT) is an economic valuation tool that uses valuation estimates from other areas (study sites) and applies them to a similar location (policy sites) (Brouwer 2000). This is done by adapting and applying estimates from existing studies that best suit the new context, using one or more of the following BT techniques (see Downing and Ozuna 1996; Bergstrom and De Civita 1999; Groothuis 2003): a) benefit estimate transfer, which involves the extrapolation of estimates from one site to another (i.e. values are directly substituted from the study site to the policy site), b) benefit function transfer, which involves the transfer of economic functions between the sites (i.e. coefficients are used to determine policy site values), c) meta-analysis, which combines the findings of independent studies related to the research topic as to summarize the body of evidence relating to a particular issue, and d) preference calibration, which uses existing benefit estimates derived from different methodologies and combines them to develop a theoretically consistent estimate for policy site values.

Costanza et al. (1997) is, perhaps, the most recognized and widely cited study utilizing BT techniques for the estimation of ecosystem service values (Liu et al. 2010). Based on over 100 local ecosystem service valuation studies, they produced global ecosystem service value estimates for 17 ecosystem services and 16 ecosystem types (in US $/ha/yr) as to estimate the total economic value of the world's ecosystem services. Given the continental scale of our research and recognizing that it is beyond the scope of this paper to obtain specific ecosystem service value estimates for European coastal country member states, we use the benefit estimate transfer technique to draw conclusions as to the value of coastal ecosystem service values in

Europe. To this end, ecosystem service values for the 16 ecosystem types from Costanza et al. (1997) and Martinez et al. (2007) are matched to the Corine Land Cover (CLC) land use typologies (Bossard et al. 2000; Table 1). All values are converted into 2000 €/ha/yr using the inflation GDP deflator and the corresponding exchange rate (World Bank 2009).

Historical coastal erosion patterns

To obtain insight in the scale of historical coastal erosion and the subsequent land cover type losses along the European coast, historical (1975, 1990, 2000 and 2006) coastal land cover information for Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal and Spain is obtained using 100 m Corine Land Cover (CLC) information (Bossard et al. 2000). While the EEA land cover information for 1990 (CLC1990), 2000 (CLC2000) and 2006 (CLC2006) is directly available (EEA 2009a, b, c), the 1975 land cover is obtained through intersection of the 1990 land cover (CLC1990; EEA 2009a) and the 1975–1990 coastal land cover change (EEA 2002) information. The coastal zone is defined as the area within 10 km from the 1975 coastline (EEA 2006a), and covers about 221,000 km^2.

Historical coastal erosion and land cover type loss estimates are, now, obtained through intersection of the 1975 coastal land cover information and the 1990, 2000 or 2006 coastal land cover information. We refer to coastal erosion when any of the CLC land cover types is converted to the CLC land cover type 'Sea and ocean'. In case coastal land cover information is not available (as for Germany, Spain, Greece and Italy in 2006), we take land cover to be unchanged since the latest available CLC information. Corresponding historical coastal land cover and ecosystem service value estimates for 1975, 1990, 2000 and 2006, are calculated per considered member state.

Future coastal erosion projections

To obtain insight in the scale of future coastal erosion and the subsequent land cover type losses along the European coast, future (2005–2050) coastal erosion projections for Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal and Spain are obtained using the Dynamic and Interactive Vulnerability Assessment (DIVA) tool. The DIVA tool explores the vulnerability of coastal areas to climate change, is rooted in a common GIS database, and integrates projections for relative sea-level rise, land loss, coastal flooding and wetland change (Hinkel and Klein 2009; Ionescu et al. 2009).

DIVA is based on 1450 coastal segments in Europe and 19 land use classes from the IMAGE 2.2 model (Hinkel and Klein 2009), and driven by IPCC-SRES scenarios (Nakicenovic and Swart 2000). Sea-level rise projections are based on CLIMBER-2 model runs (Petoukhov et al. 2000) forced by IPCC-SRES scenarios (Nakicenovic and Swart 2000), and are location specific for uniform (i.e. equal around the world) or regionalized (i.e. adjusted according to water thermal expansion patterns and vertical land movements of natural origin) conditions. Land loss projections are a function of submergence and coastal erosion, with direct coastal erosion estimated using a modified version of the Bruun-rule (Nicholls 2002; Zhang et al. 2004) and indirect coastal erosion estimated using a simplified version of the ASMITA model (Aggregated Scale Morphological Interaction between a Tidal basin and the Adjacent coast; Stive et al. 1998; Van Goor et al. 2003). Coastal flooding projections are a function of sea-level rise and storm surges, and are computed for return periods from 1-in-1 to 1-in-1,000 years (Hinkel and Klein 2009). Finally, wetland change projections comprise horizontal migration and vertical movement (Nicholls et al. 1999), and are driven by the sea-level to tidal range ratio, sediment supply, coastal nourishment (when applicable) and accommodation space for wetland migration.

Future coastal erosion and land cover type loss estimates are based on DIVA simulations for lower bound (B1-regionalized) and upper bound (A1Fi-regionalized) IPCC-SRES scenarios (Nakicenovic and Swart 2000).[1] We thereby assume medium climate sensitivity, regionalized sea-level change, no soft (beach nourishment) or hard (dike construction) adaptation measures, and constant dike heights. Over the period 2005 to 2050, coastal erosion estimates per segment are calculated for the IMAGE model land use classes 'coastal wetlands', 'agricultural areas' and 'forests & semi-natural areas' which, in turn, are matched to the CLC land use typologies and ecosystem service values (see Table 1). Corresponding future coastal land cover and ecosystem service value estimates by 2025 and 2050 are calculated per considered member state, through subtraction of loss estimates relative to the (historical) 2006 coastal land cover and ecosystem service value information.

Results

The historical baseline situation is given for the year 1975 – the year for which the earliest coastal land cover information for Europe was obtained. Tables 2 and 3 summarizes the baseline (1975) coastal land cover and ecosystems service values for the concerned European coastal country member states. The coastal zone covers about 221,000 km^2, with

[1] Relative to 1995, the B1-regionalized and A1Fi-regionalized scenarios correspond with a global mean sea-level rise of 0.35 and 1.07 meters by 2100, respectively (Nakicenovic and Swart 2000).

Table 1 Coastal ecosystem service values per CLC land cover type (in 2000€; based on Costanza et al. 1997; Bossard et al. 2000; Martinez et al. 2007)

Level 1	Level 2	Level 3	Code	Value (€/ha/yr)
Wetlands	Inland wetlands	Inland marshes	411	22,714
		Peatbogs	412	0
	Coastal wetlands	Salt marshes	421	11,588
		Salines	422	11,588
		Intertidal flats	423	0
Water bodies	Inland waters	All categories	511–512	9,857
	Marine waters	Coastal lagoons	521	22,044
		Estuaries	522	26,485
Artificial surfaces	All categories	All categories	111–142	0
Agricultural areas	Arable land	All categories	211–213	107
	Permanent crops	All categories	221–223	107
	Pastures	Pastures	231	269
	Heterogeneous agricultural areas	All categories	241–244	107
Forests & semi-natural areas	Forests	All categories	311–313	350
	Shrub/herbaceous vegetation	All categories	321–324	269
	Open spaces (little/no vegetation)	Beaches, dunes, sand plains	331	22,714
		Bare rock	332	0
		Sparsely vegetated areas	333	269
		Burnt areas	334	0

land cover dominated by agricultural (52 %) and forest & semi-natural (32 %) areas. Wetland, artificial and water body areas account, respectively, for only 7 %, 6 % and 3 % of the coastal zone area. Total ecosystem service values for the European coastal zone equal about €22.3 billion per year. In contrast with the dominant land use distribution, agricultural areas only provide 6 % of total ecosystem service values – largest ecosystem service values being provided by water body (48 %), forest & semi-natural (25 %) and wetland (21 %) areas.

For historical coastal erosion trends over the period 1975 to 2006 (Table 2), we observe land cover changes in mainly coastal agricultural (−6.4 %), water body (−4.7 %) and forest & semi-natural (−1.5 %) areas – with total coastal erosion equaling over 4,500 km^2 (−2.0 %) and coastal erosion rates averaging about 145 km^2 per year over the concerned period. Note that the reduction in agricultural area is largely explained by the urbanization of rural areas (EEA 2006a, b), as is also evidenced by the inverse relationship between agricultural and artificial areas. Total coastal ecosystem service values over the period 1975 to 2006 (Table 3), decrease from about €22.3 billion per year in 1975 to about €21.6 billion per year in 2006 – a decrease of about 3.2 % in coastal ecosystem service values. Largest ecosystem service value losses accrue to agricultural (−5.6 %), forest & semi-natural (−5.3 %) and water body (−2.8 %) area losses.

For future coastal erosion projections over the period 2006 to 2050 (Table 2), total territory losses equal between ~3,700 km^2 (−1.7 %) and ~5,800 km^2

Table 2 Historical (1975, 1990 and 2006) and projected (2025 and 2050) coastal land cover

CLC land cover type	1975 ($10^3 km^2$)	1990 ($10^3 km^2$)	2006 ($10^3 km^2$)	2025 ($10^3 km^2$)	2050 ($10^3 km^2$)
Wetlands	15.4	15.6	15.4	13.5–14.1	11.0–12.4
Water bodies[a]	5.7	5.4	5.5	5.5	5.5
Artificial surfaces	12.6	14.8	17.0	17.0	17.0
Agricultural areas	116.0	110.4	108.5	108.3–108.4	107.8–108.2
Forest & semi-natural areas	71.3	70.9	70.2	70.1–70.1	69.5–69.9
Total	221.0	217.2	216.5	214.3–215.1	210.7–212.8

[a]Water bodies excluding the CLC land cover type 'Sea and ocean'

Table 3 Historical (1975, 1990 and 2006) and projected (2025 and 2050) coastal ecosystems service values (in 2000€)

CLC land cover type	1975 (10^9 €/yr)	1990 (10^9 €/yr)	2006 (10^9 €/yr)	2025 (10^9 €/yr)	2050 (10^9 €/yr)
Wetlands	4.74	4.63	4.69	3.79–4.08	2.56–3.22
Water bodies[a]	10.64	10.35	10.34	10.34	10.34
Artificial surfaces	0.00	0.00	0.00	0.00	0.00
Agricultural areas	1.44	1.39	1.36	1.36–1.36	1.35–1.35
Forest & semi-natural areas	5.52	5.38	5.23	5.22–5.23	5.18–5.21
Total	22.34	21.76	21.62	20.71–21.00	19.43–20.12

[a]Water bodies excluding the CLC land cover type 'Sea and ocean'

(−2.7 %) for optimistic (B1-regionalized) and pessimistic (A1Fi-regionalized) IPCC-SRES scenarios, respectively. We observe largest territory losses in coastal wetland (−19.5 %–−28.5 %) areas, and some territory losses in coastal forest & semi-natural (−0.5 %–−1.0 %) and agricultural (−0.3 %–−0.6 %) areas. Corresponding total coastal ecosystem service values over the period 2006 to 2050 (Table 3), decrease from about €21.6 billion per year in 2006 to between €20.1 (B1-regionalized) and €19.4 (A1Fi-regionalized) billion per year by 2050 – a decrease in coastal ecosystem service values of between 6.9 % and 10.1 %. Over 90 % of these ecosystem service value losses are attributed to the erosion of coastal wetland ecosystems that provide important waste treatment, disturbance regulation and genetic resource ecosystem services (Costanza et al. 1997; Martinez et al. 2007).

Discussion and conclusions

Based on historical (Bossard et al. 2000) and projected (Hinkel and Klein 2009; Ionescu et al. 2009) coastal erosion patterns in combination with benefit transfer estimates for ecosystem service values (Costanza et al. 1997; Martinez et al. 2007), we assess to what extent past (1975–2006) as well as future (2006–2050) coastal erosion patterns lead to losses in land cover types and associated ecosystem service values for selected European coastal country member states. Previous studies asses, invariably, the environmental-economic impact of *future* (climate change induced) coastal erosion, with only the local scale studies taking into account the spatially explicit environmental-economic conditions (e.g. Leatherman and Nicholls 1995; Yohe and Schlesinger 1998; Darwin and Tol 2001; Bosello et al. 2006; Alves et al. 2009). This paper not only highlights the environmental-economic importance of coastal ecosystems in Europe, but also demonstrates to what extent these ecosystem service values have been lost in the past and are likely to be lost in the future.

For the baseline year 1975, it is shown that the value of coastal ecosystem services equals about €22.3 billion per year – an estimate in line with Martínez et al. (2007) who value coastal ecosystem services for the concerned European coastal country member states at $18.6 billion per year between 1992 and 1993. For historical (1975–2006) coastal erosion trends, we observe territory losses of over 4,500 km^2 and corresponding coastal ecosystem service values decrease to about €21.6 billion per year by 2006. For future (2006–2050) coastal erosion projections, we observe further territory losses of between ~3,700 km^2 (B1-regionalized) and ~5,800 km^2 (A1Fi-regionalized) and corresponding coastal ecosystem service values further decrease to between €20.1 and €19.4 billion per year by 2050. Ecosystem service value losses, thus, amount to up to €2.9 billion per year by 2050 – i.e. an almost 15 % decrease in coastal ecosystem service values as compared to 1975.

There are few research areas in which ecosystem service values are explicitly considered, including natural resource damage assessment studies of pollution events and cost-benefit analysis studies of water and forest resource-use as well as road-infrastructure planning (De Groot et al. 2010; Liu et al 2010). From the literature review it is clear that this deficiency is also present in coastal research and, based on our results, we consequently argue that the response strategy of EU member states to deal with coastal erosion and climate change impacts should be based on the economic as well as the ecological importance of their coastal zones. To this end, not only direct (market) economic values but also (non-market) coastal ecosystem service values need to be included in, for example, impact assessment, cost-benefit analysis and cost-effectiveness assessment studies (Alves et al. 2009; Roebeling et al. 2011).

Some caveats to this study remain. First, historical coastal land cover changes include changes not necessarily due to coastal erosion and, hence, presented historical ecosystem service value losses from coastal erosion may have been overestimated. This overestimation is, however, small as the above mentioned land cover changes predominantly apply to the transition of agricultural to artificial areas that both reveal relatively low ecosystem service values.

Second, the used ecosystem service values are derived from Costanza et al. (1997) and Martinez et al. (2007) using the benefit estimate transfer technique and, consequently, estimates may include errors related to quality of underlying valuation studies, extrapolation of values between sites, conceptual differences between underlying valuation studies and differences in the scale of environmental services between sites (Brouwer 2000; Wilson and Hoehn 2006). Also, neither dynamic non-linearities nor interdependencies between ecosystem functions and services are taken into account (Costanza et al. 1997). Future research is needed to obtain specific likelihood estimates for European coastal ecosystem service values, based on landscape, ecosystem and/or plot scale valuation studies (De Groot et al. 2010).

Finally, it needs to be emphasized that, in line with Costanza et al. (1997), Martinez et al. (2007) and Brenner et al. (2010), this study focuses on 'non-market' coastal ecosystem service values alone and, consequently, we do not claim to have estimated the full welfare implications from historical and future coastal erosion. Self-evidently, coastal protection and/or retreat adaptation decisions are better based in full welfare analyses (Bosello et al. 2006) – in particular when they include spatially explicit detail on local socio-economic and environmental conditions (Knogge et al. 2004).

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