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RESEARCH ARTICLE

Habitat dynamics at the catchment–coast interface: contributions from ELOISE

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Abstract

This paper summarises contributions made by the ELOISE cluster of research projects to our understanding of European coastal habitat dynamics. 'Habitat' is used as the key concept defining Europe's coastal ecosystems following the European Community, which uses 'habitat' as formal currency in its directives on water and nature use, management and conservation. Eight aggregate habitat categories are identified: cliffs, shingle beaches, and associated kelp beds; dune complexes with freshwater wetlands; salt marsh; sandbanks and mudflats; seagrass beds, lagoons; subtidal sediments, and open sea pelagic. We distinguish between dynamics 'within' and 'between' habitats. The former tend to be coupled to physical forcing. The latter concern transitions from one habitat to another. Both types have been charted for the eight habitat categories.

The Drivers–Pressures–State–Impact–Response framework is used to review the possible impact on habitat of foreseen future changes in key drivers and pressures, which would lead to major changes in the state of European coastal ecosystems. Drivers comprise climate change, the increase in built-up area, expansion and intensification of trade, ports and related industry, as well as of fishing, aquaculture and agriculture. Together these would lead to sea level rise and coastal erosion, contamination, eutrophication, and loss of biodiversity, but to different extents in Europe's regional seas. This report concludes with specific recommendations for future European coastal research.

Keywords: *European coasts, coastal habitats, habitat dynamics, DPSIR, aggregate habitat typology*

1. Introduction

ELOISE (European Land–Ocean Interaction Studies) is a thematic network, instigated by the Commission of the European Union (EC), where coastal zone research is focused on questions of how the land–ocean interaction operates, and how this is influenced by human activities. ELOISE research was designed to support integrated coastal zone management and spatial planning by nurturing a coherent European coastal zone research network of high scientific value and of direct relevance to society. ELOISE also represents the European Union's input to the LOICZ (Land Ocean Interaction in the Coastal Zone) Core Project of the International Geosphere Biosphere Programme (IGBP). Since its inception, ELOISE has

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encompassed a total of 55 projects funded by the European Commission's Directorate General Research. This renders it one of the world's largest coastal research initiatives.

Funding of research activities by the EC is allocated primarily on the basis of scientific quality. However, recent years have seen the emergence of an additional criterion—societal relevance. We view the societal relevance of ELOISE products as the provision of good scientific knowledge to support coastal management. In such a context, ELOISE research is reviewed in terms of its contributions to our understanding of coastal habitat dynamics. The notion of 'habitat' has become a key component of European environmental and conservation policy.

Europe's comparatively long and dissected coastline offers an exceptionally wide range of natural and semi-natural habitats. These habitats are subject to internally as well as externally driven change, and have been so over geological time scales. Major geological drivers in the coastal zone over the past 3–5 millennia are: (a) the continuing northward movement of the African continental plate towards Southern Europe, including seismic and volcanic activity, (b) climatic variability, and (c) the aftermath of the last Weichselian (or Devensian) ice age. Man's impact has become important in driving coastal habitat dynamics probably since the Bronze Age, when sea-faring nations developed along the Mediterranean and expanded north, west and east along most European coasts. Earliest human impacts probably include major changes in coastal forests following increasing needs for wood (Ponting 1991), as well as extermination of larger vertebrates on land (Schule 1993, Breitenmoser 1998) and overexploiting nearshore fisheries (e.g. Wolff 2000, Wing and Wing 2001). Colonisation of river catchments by sedentary farming societies will also have greatly altered the hydrology and sediment delivery of rivers to the sea over several millennia (e.g. Hanson 1990).

Present-day impacts on coastal habitats are probably unprecedented and can be expected to continue to increase in spatial extent and intensity because coastal populations and the pressures of economic activities and urbanisation on coasts are increasing (e.g. Nicholls and Klein 2005, Turner 2005). In response to these foreseen developments, by no means restricted to the coast, the EC has issued the Habitat Directive (92/43/EEC), a legal framework, currently under implementation, which aims to conserve a suite of natural habitats across Europe. This article reviews ELOISE research and its contribution to our understanding of coastal habitat dynamics. It aims to:

- synthesise ELOISE research products on coastal habitat dynamics;
- identify the main drivers and pressures causing habitat change;
- identify habitats most vulnerable to these pressures; and
- make specific recommendations for future research into habitat dynamics.

The terms 'driver' and 'pressure' are taken from the Driver, Pressure, State, Impact and Response (DPSIR) framework as discussed in Section 5. Acronyms are elaborated in Annex 1.

2. Defining coastal habitat dynamics

2.1. Habitat

A substantial literature exists on the definition of 'habitat' and related concepts, such as ecotope or biotope (e.g. Klijn 1994). One example, from an ecological textbook, is: 'the spatial subdivision of the environment within an ecosystem into convenient units' (e.g. Deshmukh 1986). Moss and Wyatt (1994) simply equate biotope and habitat in their description of the CORINE (CoORdination of INformation on the Environment) effort to create a harmonised European habitat classification and database. The Habitat Directive identifies natural and semi-natural habitats that have conservation priority. It circumvents possible confusion on the delineation of specific habitats across gradual transitions and over spatial scale and extent with a generic definition coupled to a specified list of well-defined habitat types in its annexes. The directive definition is (92/43/EEC):

> natural habitat means terrestrial or aquatic areas distinguished by geographic, abiotic and biotic features, whether entirely natural or semi-natural.

The CORINE classification has been superseded by the European Nature Information System (EUNIS) of the European Environment Agency (EEA), which is substantially more comprehensive, especially for marine habitats (see Figure 1). EUNIS contains information on select species, habitat types and sites, based on national data collected through EIONET (The European Environment Information and Observation Network, coordinated by the EEA) and from international organisations. EUNIS information is being used to support the NATURA2000 process, for EEA reports, and for international co-ordination. NATURA2000 is a continental-wide ecological network of reserves and connecting corridors. Examples of international cooperation include the Bern Convention EMERALD Network, and the Helsinki, OSPAR and Barcelona conventions. EUNIS defines habitat more closely (http://eunis.eea.eu.int/index.jsp):

> plant and animal communities as the characterising elements of the biotic environment, together with abiotic factors (soil, climate, water availability and quality, and others), operating together at a particular scale.

The Habitat Directive focuses on priority habitats that are geographically characteristic, and/or are threatened and so have conservation urgency. In contrast, we consider all coastal

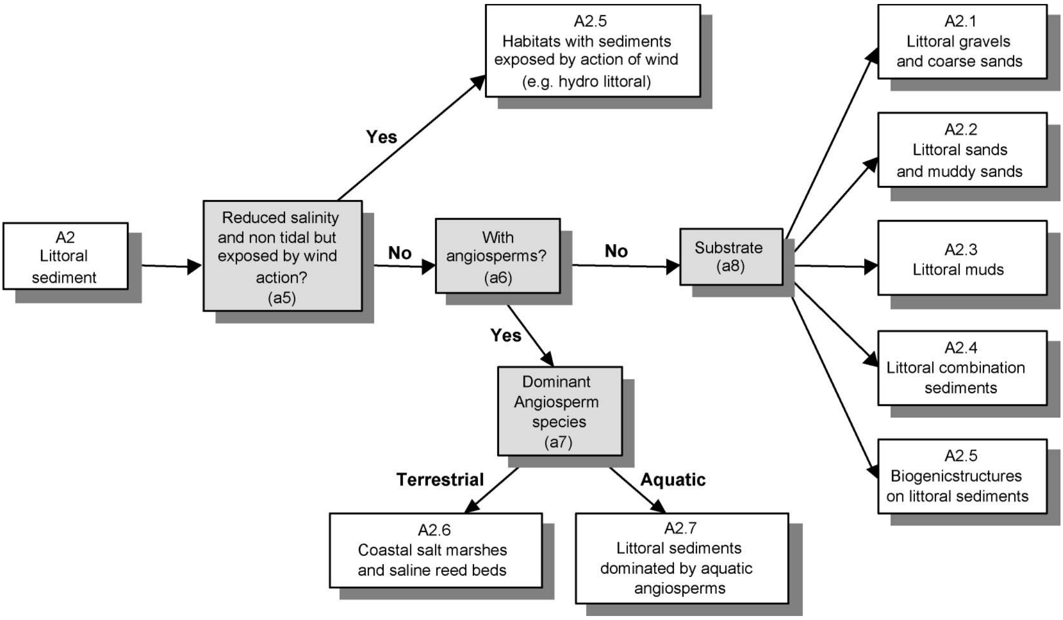

Figure 1. Part of the EUNIS habitat classification for marine habitats (http://eunis.eea.eu.int/index.jsp).

habitats, including the open pelagic and deeper demersal sediments of Europe's regional seas, which are included in the EUNIS classification.

2.2. Dynamics

Our perspective on 'dynamics' encompasses:

- within habitat changes due to internal or external forces, as a result of which the habitat itself remains identifiable; and
- profound changes in the nature of a habitat leading to a transition into another type.

Changes within a habitat could be gradual species replacement in a benthic macrofauna community as a result of colonisation from the south during prolonged periods of higher mean annual water temperatures. Rapid shifts to shorter-lived species in response to more frequent disturbance by bottom-trawling fishing vessels are well-established examples (e.g. Frid et al. 2000). Changes in the type of habitat could be cyclic, reversible or irreversible. Transition from one habitat to another could be due to gradual succession, such as occurs in salt marshes that accrete with positive sediment trapping (Leendertse et al. 1997, Lefeuvre and Bouchard 2002). Cyclic habitat transitions can be illustrated by the accretion – erosion cycle associated with moving sand dunes (e.g. Marbà and Duarte 1995). Irreversible change is illustrated by the conversion of natural habitats to 'human' habitats, such as occurs with port and tourist developments.

2.3. Coastal habitat typology

A substantial number of coastal habitats have been formally defined in the Habitat Directive (92/43/EEC) or are listed in the EUNIS classification. The European Union for Coastal Conservation (EUCC) has arranged them according to their abundance in various European coastal landscapes, since some habitats are ubiquitous and others have a more restricted occurrence (www.coastalguide.org/typology). Different coastal landscape types have been identified on the basis of predominant substrate, slope and prevailing tidal regime (see Table I). These serve as a landscape typology over which the habitat typology is cross-tabulated (Table II). Table II will be used later to identify the most important habitats for European regional seas and to downscale drivers of change and their effects to specific habitats.

Table II suggests that a distinction between hard rock and sedimentary coastlines is useful in identifying clusters of predominant habitats. For example, European seagrass beds can only be found on unconsolidated sediments, and stands of macro-algal kelp are abundant only on hard rock. Several habitats have rather similar patterns of occurrence across landscapes, and so probably occur together. Examples are mudflats and sandbars, cliffs and shingle bars, and wetland and dune systems. Such patterns have a simple, direct geomorphological or geogenetic basis. The distribution of seagrass beds over the different landscape types with unconsolidated sediments is not very distinct. Apparently seagrass beds may occur along many coasts. This is confirmed by older literature (e.g. Den Hartog 1970) and in more recent GIS databases (e.g. http://stort.unep-wcmc.org/imaps/marine/seagrass/viewer.htm).

Three further aspects are highlighted. Firstly, the pelagic and deep-sea sediments of the open sea have been omitted from the typology, but can be added easily. Secondly, habitat types differ in their degree of homogeneity and spatial extent. Estuaries and lagoons, for example, appear to be rather generic but may comprise complexes of different habitat types. Thirdly, there is some duplication between habitat and landscape categories. Some

Table I. Coastal landscape types, their location and description (www.coastalguide.org/typology: note that similar typologies appear in the literature, e.g. Davies 1980).

1a. Hard rock, cliffed coasts

Macro – meso-tidal Atlantic coasts of North and Western Europe and karstic areas of the micro-tidal Mediterranean & Black Seas. Sea cliffs, cliff islands, archipelagos, fjords and sea lochs, rias, rocky shores with caves, bay and pocket dunes, river mouths and small estuaries and embayments

1b. Hard-rock coastal plains

Micro-tidal shores of the Baltic including Sweden and eastern Denmark, the Mediterranean and Black Seas as well as meso-tidal shores of Scottish fjords. Skerry coasts, fjords, river mouths, arctic tidal plains, and karstic shores

2. Soft rock coasts

Meso – macro-tidal areas of the southern North Sea, southern Portugal and the micro-tidal southern Baltic and parts of the Black sea coast. Soft rock glacial cliffs, tidal bedrock plains, other friable sea cliffs with e.g. shale and sandstone. Soft rock coastal bedrock plains

3a. Tide-dominated sediment. Plains

Macro – meso-tidal areas Atlantic and North Sea and southern North Sea coasts including the Wadden Sea. Barrier shingle/dune coasts, sea lagoons, barrier shingle/dune islands, estuaries, freshwater tidal deltas and dune – wetland coasts

3b. Wave-dominated sediment. Plains

Micro-tidal zones of the Baltic, Mediterranean and Black Sea. Lagoons, Black Sea limans, river deltas, dune coasts, Baltic barrier-haff-delta coasts, German Baltic bodden coast

landscapes are dominated by a particular habitat. Overall, this apparent inconsistency is a consequence of asymmetric spatial heterogeneity at various spatial scales that has been ignored in the typology, probably for practical reasons.

We have chosen a larger-scale aggregation to arrive at a heterogeneous list of eight habitat types (see also Table III): rocky shores, cliffs, shingle beaches and kelp beds; wetland and dune complexes with adjacent sandy beaches; salt marshes; sandbanks and mudflats; seagrass beds; lagoons; subtidal sediments; and open sea pelagic zone. The grouping has been based on geographic co-occurrence, geological similarity as well as spatial extent and ease of demarcation.

3. Natural dynamics in coastal habitats

Section 2.2 differentiated between dynamics 'within' and 'between' habitats. The former reflects internal dynamics and the latter a transition into another habitat. Natural, internal, dynamics are coupled to physical forcing and occur at a range of temporal scales. The tides, for example, cause substantial, predictable changes in environmental conditions typically over ~6 – 13 hours. Distinct seasonality is apparent throughout Europe in coastal waters and on land. Seasonality, from an ecological perspective, is fairly predictable in terms of day length, light availability and/or temperature (e.g. Vermaat and Verhagen 1996, Marba et al. 1996). At longer temporal scales, weather patterns change over years and generate highly variable sequences of comparatively dry, wet, warm or cold years. The North Atlantic Oscillation is an important underlying forcing factor. Climate change, however, may lead to a decoupling of physical forcing and biotic responses (Phillipart et al. 2003). Variation at all these three scales has profound, nested impacts on the functioning of coastal ecosystems, and hence on the communities of living biota populating coastal habitats.

Transition to another type of habitat is probably the result of a substantial change in forcing factors, whether abiotic or biotic. A growing body of literature on the resilience of ecosystems, together with positive feedbacks and alternative stable states (e.g. Van de Koppel et al. 2001), suggests that the accumulation of individually small changes may also lead to a drastic change in ecosystem state, or the transition from one habitat type to another. An example of habitat

Table II. Distribution of major European coastal habitats over coastal landscapes (* = habitat may occur, F = habitat may occur to large extent; adapted from www.coastalguide.org/typology).

Landscape	Cl	Sh	Ke	Es	W	Du	Sb	Sm	Mf	La	Gr
1a. Hard rock, cliffed coasts											
sea cliffs, cliff islands, archipelagos	F	*	*	*	*						
Norwegian fjords and Scottish sea lochs	F	*	*	F	*						*
Atlantic rias	F	*	*	*	*	*	*	*	*		
rocky with caves, bay and pocket dunes	F	*	*	*		*	*				*
river mouths	*	*	*	F	*	*	*	*	*		
Atlantic and North Sea estuaries	*	*	*	F	*		*	*	*		
Karstic cliffs, Mediterranean and Black Seas	F	*	*								*
1b. Hard rock coastal plains											
Baltic skerry coasts	F	*	*			*					*
Baltic and Scottish fjords	*	*	*			*					*
river mouths	*	*	*		*	*					
Arctic tidal plains	*	*	*			*					
Karstic cliffs, Mediterranean and Black Sea	*										*
2. Soft rock coasts											
soft rock cliffs on tidal bedrock plains	F	*	*	*	*						*
high and low glacial cliffs	F	*	*	F	*						*
Atlantic rias	F	*	*	*		*					*
river mouths	*	*	*	F		*	*	*	*		*
barrier shingle coasts		F	*			*	*	*	F		*
Atlantic and North Sea estuaries			*	F				*	*		*
3a. Tide-dominated sediment, plains											
barrier shingle coasts		F	*	*	*	*	*	*	*	*	*
low earth cliff coasts		*		*	*	*	*	*		F	*
Atlantic and North Sea lagoons		*		*		*	*	*		F	*
barrier dune islands		*		*		F	F	*	F	*	*
Atlantic and North Sea estuaries				F	*	*	F	*	F		*
freshwater tidal deltas				F	F	*	*		*	*	*
barrier dune coasts				*	F	F	*		*		
dune-wetland coasts				*	F	F	*	*	*		
3b. Wave-dominated sediment, plains											
lagoons in micro-tidal zones		*		*	*	*	*	*	*	F	*
Black Sea limans		*		*	F	*	*	*	*	*	*
river deltas in micro-tidal zones				*	F	F	*	*	*	*	*
dune coasts in micro-tidal zones				*	*	F	*	*		*	*
Baltic barrier-haff-delta coasts				*	*	F	*			F	*
German Baltic bodden coast				*		*	*			F	*

Cl, sea cliff and rocky shore habitats; Du, dunes including sea dune habitats and machairs in Ireland, and sandy beaches; Es, estuary, marine and tidal habitats; Gr, seagrass beds including *Zostera* and Mediterranean *Posidonia* fields; Ke, kelp forests; La, lagoon habitats; Mf, mud and sand flats; Sb, sandbanks; Sh, stony banks and shingle habitats; Sm, salt marshes, steppes and meadows; W, wetland habitats.

transition is the drastic decline in seagrass beds across Europe (e.g. Giesen et al. 1990, Frederiksen et al. 2004a).

Mobile sediment may generate apparently cyclic transitions between different habitats, both on land and in the sea. Rare, extreme events, such as heavy storms and seismic movements of the Earth's crust, may cause considerable change in coastal habitats due to massive, incidental relocations of sediment. Seismic incidents are sufficiently frequent over longer time scales to be taken into consideration in the Mediterranean. Isostatic sea level rise, as well as coastal subsidence, is a further natural process that leads to gradual or abrupt transitions in coastal

Table III. Natural dynamics in major coastal and marine habitats of Europe.

	Dynamics	
Habitat type	Within habitat	Transitions between habitats
Cliffs, shingle beaches, kelp beds	Tidal, seasonal, interannual	Erosion; colonisation by vegetation; changes in macroalgal abundance of kelp with altered foodweb structure; changes in patterns of waves or currents
Wetland and dune complexes*	Tidal, seasonal, interannual	Changes in precipitation or hydrology
Salt marsh*	Tidal, seasonal, interannual	Changes in precipitation or hydrology; passing mobile dunes may alter vegetation
Sandbanks and mudflats*	Tidal, seasonal, interannual	Changes in precipitation or hydrology; changes in patterns of waves or currents
Seagrass beds*	Tidal, seasonal, interannual	Changes in patterns of waves or currents; increased turbidity will decrease light penetration; stronger hydrodynamics will lead to greater fragmentation of canopy
Lagoons	Seasonal, interannual	Sedimentation may lead to smothering; fracture of the barrier to the sea will disrupt quiet conditions; may be coupled to changes in barrier-disturbing storm frequencies
Subtidal sediments	Seasonal, interannual	Changes in composition of detritus rain from pelagic or coast may affect benthic fauna and fish; deep currents may change course
Open sea pelagic	Seasonal, interannual	Water temperature, nutrient loading gradients and turbulence spectra may lead to altered plankton and fish community compositions

*The interplay of sediment mobility and colonisation patterns of seagrass often leads to mosaics of these habitats, often in the form of wavelike bands (Marba and Duarte 1995, Frederiksen et al. 2004b). Similar patterns occur in saltmarsh-wetland-dune complexes where appreciable areas of open, moving sand occur (Van Dijk et al. 1999).

habitats. Succession in shore meadows of the northeastern Baltic is a good example (e.g. Cramer and Hytteborn 1987). Climate change effects will be discussed later.

Table III summarises both types of dynamics briefly for the eight habitat types identified in Section 2. Because of the erratic, unpredictable outcome in terms of habitat dynamics, seismic events have not been incorporated. It is also worth noting that the interplay of sediment mobility and colonisation patterns, for example by seagrasses, leads to mosaics, often in the form of wavelike bands (Marba and Duarte 1995, Frederiksen et al. 2004b) interspersed by appreciable areas of open, moving sand (Van Dijk et al. 1999).

4. Research findings on European coastal habitats

4.1. Approach

From the larger number of ELOISE projects, 43 were identified as contributing to our understanding of coastal habitat dynamics. Because the dominant criterion for funding is scientific quality (e.g. Herman et al. 2005), the distribution of research effort has not been even over coastal habitats (Figure 2). Our survey is based on an analysis of research objectives and published papers available from project websites, where available, and from the ELOISE database (http://www2.nilu.no/eloise). Projects may have contributed to our understanding about more than one habitat type. Most research has been devoted to understanding the natural dynamics of or anthropogenic changes in the pelagic zone (14 out of 43 projects).

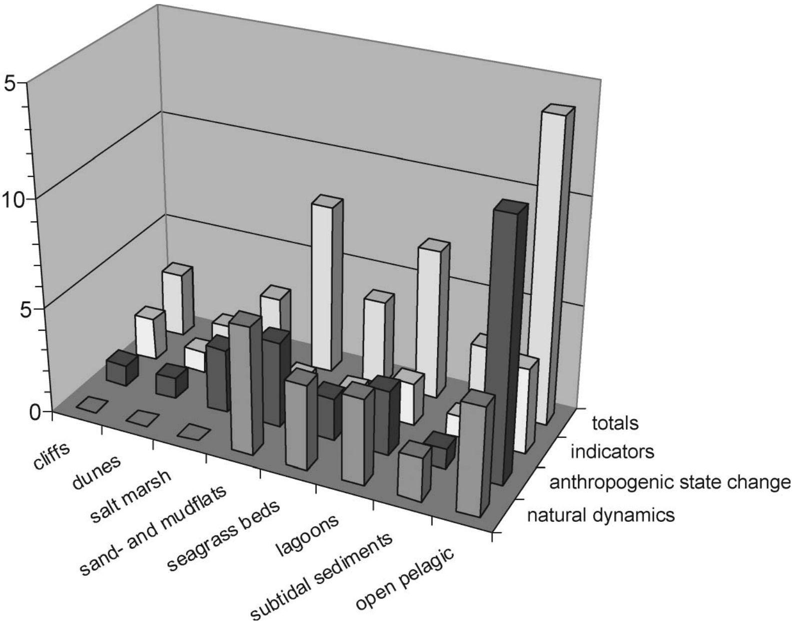

Figure 2. Number of ELOISE projects contributing to our knowledge of habitat types.

Several ELOISE projects, identified as relevant for habitat dynamics, nevertheless did not focus on a particular habitat. This was usually the case when the project scale was extensive and reached at or beyond the catchment scale of a regional sea, such as occurred in POPCYCLING, EUROCAT, DANUBS. Some of these projects have been listed under the open sea pelagic, since a model or assessment of the open water food web or water quality was involved. Other projects that did not allow a straightforward allocation to a particular coastal habitat were: RANR, TOROS, MAMCS, ANICE, MOE, SUBGATE, BASIS, BEAM, CHABADA, CLICOFI, COMET, DELOS, HUMOR, INCA, OROMA, STREAMES. See also Herman et al. (2005) for reference to projects that appear to be thematic outliers.

Project websites, summaries and notably published papers have been screened for the contribution of these projects to our understanding of habitat dynamics. Our findings are discussed per habitat type below, and summarised in Table IV. Section 4.10 identifies indicators and methods developed to reveal coastal habitat state change. Section 4.11 aggregates across projects and habitats.

4.2. Rocky shores, cliffs, shingle beaches and other hard-substratum coasts

ELOISE projects researching these coastlines have had two major foci. The first was the impact of eutrophication on seaweed communities attached to hard substrata. Experimental work showed that the impact of eutrophication was limited, largely due to high flushing rates (Barron et al. 2003), which is contrary to the expected pattern of a shift towards dominance by faster growing, chlorophytic forms based on more sheltered systems. The high water movement also led to substantial losses of particulate organic carbon (POC) as algal fragments. Most likely, physical stress dominates over nutrient stress on these wave- and current-battered rocky shores. A shift in species composition to more efficient nutrient competitors can be expected on less exposed coasts (e.g. Valiela et al. 1997). The second

Table IV. An aggregated overview of the contribution of ELOISE research projects to understanding coastal habitat types.

Habitat type	Understanding natural dynamics (fluxes, ecological processes, biogeochemistry)	Understanding anthropogenic state change	Indicators of habitat state change
Cliffs, shingle beaches, kelp beds		Due to flushing, eutrophication has little effect	Monitoring tools for cliff erosion
Wetlands and dune complexes			Composite vulnerability index for dunes
Salt marsh		Saltmarsh – mudflat interactions: sedimentation – erosion cycles, sediment trapping, burial sensitivity	EUROSAM: decision support tool
Sandbanks and mudflats	Zoobenthos – diatom interactions, self-organised spatial pattern, nutrient biogeochemistry, food webs	Zoobenthos species composition and numerical abundance	Zoobenthos composition
Seagrass beds	Natural seasonality in C, N, P fluxes and sequestration	Decreased colonisation depth with increased turbidity due to eutrophication	Colonisation depth, increased patchiness at upper, shallow limit
Lagoons	C, N, P fluxes	Eutrophication	Sediment anoxia, N/P ratio
Subtidal sediments	Mediterranean shelf sedimentation	Long-term changes in benthic and planktonic algal species composition	Incidence of anoxia
Open sea pelagic	Effects of turbulence spectra on plankton, redistribution sediment over shelves, food webs	Sequestering and fluxes of nutrients and DOC/POC, pelagic – sediment exchange, eutrophication related changes in taxonomic composition and food web path lengths, increased incidence of harmful algal blooms, comparative analysis of European pelagic and benthic metabolism	DOC, N/P ratio, plankton composition, chlorophyll

focus was on real-time monitoring of cliff erosion. Publications in the primary literature, dealing with this issue, are limited to date (Davidson et al. 2004).

4.3. Dunes, sandy beaches and associated wetland complexes

The ELOISE project DUNES has focused on this habitat type. It compiled a composite index of the vulnerability of coastal dune complexes to human interference and other threats that would cause degradation or loss (Williams et al. 2001), and provided a rapid assessment technique using remote sensing images. The project concluded that the drivers of dune degradation across Europe were primarily rising residential and tourist populations and secondary commercial, industrial as well as military development (Williams et al. 2001). Wetlands associated with the valleys between dune ridges have not been a separate study object. DUNES treated dune systems as landscapes, hence as habitat complexes and thus included indicators of natural dynamics (e.g. natural sand redistribution) and human disturbance (e.g. tourist-induced erosion). A total of 65 indicators nested in six categories ranging from dune geomorphology and beach condition to vegetation, pressure of use and protection measures were compiled into an aggregate and scaled Dune Vulnerability Index (DVI):

$$\mathrm{DVI} = (\mathrm{GCD} + \mathrm{VC} + \mathrm{MI} + \mathrm{HE} + \mathrm{AI})/5$$

where:

GCD = geomorphological condition of the dune system;
VC = vegetation condition;
MI = marine influence;
HE = human impact; and
AI = aeolian influence.

Clustering produced four groupings, with highly vulnerable dune complexes having a DVI >0.6 and low vulnerability systems having DVI <0.25. This index was compounded for 136 dune sites across Europe (France, Portugal, Spain and the United Kingdom). The data displayed, for example, substantial regional differences: recreational path lengths were associated with substantially larger areas of denuded dune vegetation in the Mediterranean than elsewhere (slope of linear regressions of denuded area versus path lengths was 7.5 and 4 $\mathrm{m}^2\ \mathrm{m}^{-1}$, respectively), and also the proportion devegetated of total dune area at a site was higher (slope of 0.4 versus 0.3 $\mathrm{ha\ ha}^{-1}$).

4.4. Salt marshes

Three projects have focused on the longer-term sustainability of salt marshes as a function of altered tidal as well as sedimentation regimes and climate change (ISLED, EUROSAM, TIDE). A fourth estimated the contribution of salt marshes to the carbon budgets of the continental shelf (BIOGEST). Gazeau et al. (2004) and Herman et al. (2005) provide a more elaborate review of the role of estuarine habitats in carbon fluxes. Salt marsh vegetation could accommodate substantial sedimentation rates (Day et al. 1999, Boorman et al. 2001) and salt marsh vegetation may well enhance sediment trapping sufficiently to overcome subsidence (Leendertse et al. 1997, Day et al. 1999, Marani et al. 2004). Day et al. (1999) concluded that 4 out of 7 salt marshes studied in the Venice lagoon would be able to cope with sea level rise in the coming 100 year as a result of sedimentation, pointing at the important effect of vegetation. In this respect, European salt marshes may differ considerably from sediment-starved North American marshes, in that there may be sufficient sediment available to keep up with sea level rise.

Processes at the seaward end of the marshes mostly determine salt marsh erosion and expansion. Erosion usually occurs as cliff erosion, and is a lateral process. Expansion occurs by plant colonisation of mudflats adjacent to the salt marsh. These processes are strongly influenced by changes in the position of the major gullies in estuaries (e.g. Boorman et al. 2001, Marani et al. 2004), but can also be an intrinsic feature of the natural dynamics of salt marshes (Van de Koppel et al. 2005). It is also in lateral erosion and expansion processes that the dynamics of salt marshes is strongly modified by coastal engineering works that lead to long-term, slow adjustments in sediment fluxes and budgets across bays and large coastal tracts (Thorin et al. 2001, Lefeuvre and Bouchard 2002, Nicholls and Klein 2005). Distinct interactions exist between salt marshes and adjacent mudflats, in terms of sediment carbon and nutrient fluxes, as well as in food web structure (e.g. Widdows et al. 2000, Brown et al. 2003). The EUROSAM project aggregated its findings into a decision support system intended for the 'non-specialist', which is briefly described by Brown et al. (2003).

4.5. Sandbanks and mudflats

Intertidal mudflats have been the subject of a number of intensive studies that combined spatial pattern and biogeochemistry, such as the ECOFLAT project (see also Herman et al. 2005). The project used a combination of field surveys, experimental approaches and hydrodynamic modelling, and showed that physical factors (tidal currents, sediment composition) were among the factors explaining best the spatial distribution of benthic communities (Herman et al. 2001; Ysebaert and Herman 2002). However, clear evidence was also found for an influence of benthic organisms on the stability of the sediments (Widdows et al. 2001, 2004). A stabilising effect of microphytobenthos was found, whereas macrobenthos in general had a destabilising effect on the sediment. The stabilisation of sediment by benthic algae, together with the observation that growth of benthic algae is improved on silt, led to interesting findings on self-organisation in algal mats covering these flats and spatial interactions across the estuary (e.g. Van de Koppel et al. 2001). Mudflat sedimentation may be affected by diatom films as well as macrobenthos activity (Widdows et al. 2001). Thorin et al. (2001) reported the existence of a major east–west gradient in riverine sediment input, swell-exposure, sedimentation balance as well as composition of mudflat benthos across the 240 km^2 bay of Mont St Michel. However, these authors had difficulty in explaining the higher macrobenthic density in the exposed, more sandy habitats of the eastern section, since food availability as well as disturbance regime co-varied.

Temporal changes in mudflat habitats may occur naturally at a number of time scales. The seasonal cycle in biophysical interactions may cause seasonal erosion–deposition cycles of mud (Herman et al. 2001). High temporal variability in sediment erosion and deposition can be due to (semi-)cyclic changes in hydrodynamics. Sand bars may migrate across tidal channels over periods of months to years, and hence benthic organisms encounter wholesale change in habitat conditions. At even longer time scales, estuarine morpho-dynamics is influenced by the estuarine sediment balance and sea level changes.

Human-induced changes can be caused by interference with estuarine morpho-dynamics, such as by dredging and the construction of sea defences. Dredging for sand as well as for bottom-dwelling fish and shellfish, such as cockles and mussels, leads to substantial physical disturbance of sandbanks and mudflats. Intertidal cockle exploitation in the Dutch Wadden Sea, for example, has led to serious debate on the balance between economic profit and conservation of nature and policy measures by the Dutch government (e.g. www.minlnv.nl/international/policy/fisheries).

Nutrient dynamics may drastically change the nature of the intertidal habitat. In comparatively sheltered systems, mudflats may become colonised by rooted seagrasses as well as accumulate attached and floating mats of macroalgae such as *Enteromorpha* and *Ulva*, a eutrophication-related phenomenon that will lead to drastic changes in sediment aeration and may cause mortality and changes in benthic community composition due to poor aeration (e.g. Flindt et al. 1997). For shallow and intertidal systems, extensive studies in the Dutch Wadden Sea (Leopold et al. 2004) largely confirm findings from elsewhere: the densities of shellfish and the larger polychaete infauna decline in favour of smaller, shorter-lived worms (cf. Ferns et al. 2000). This is thought to have reduced the food availability for migratory wader birds as well as eider ducks, adversely affected their survival, and may compromise efforts for their conservation.

4.6. Seagrass beds

The dynamics of seagrass beds largely depend on the factors determining their upper and lower depth limits, namely exposure to waves and light availability. Upper limits of intertidal seagrass beds are also imposed by low-tide exposure. Substantial effort (NICE, ROBUST) has been focused on the role of seagrasses in geochemical fluxes. Numerous studies in both projects documented the profound influence of seagrasses on the sediment nitrogen cycle. Seagrasses sequester most of the nitrogen in sediment and reduce the rate of microbial processes, as well as the reflux of mineral nutrients to the water (e.g. references in Herman et al. 2005). Evidence was found for enhanced ‘buffer capacity’ of sediments inhabited by seagrass, which constrained the emergence of eutrophication phenomena (De Wit et al. 2001). Overburdening of this buffer capacity led to sudden changes, such as increased dominance by macroalgae.

The M&MS project focused on seagrass as a key growth form in shallow coastal waters. The project produced an introductory booklet on seagrass monitoring and management that also addresses dynamics at a range of temporal and spatial scales. Natural temporal variability of seagrass beds relates to geophysical factors and the difficulties of recolonisation. Anthropogenic causes of decline are often related to eutrophication, and are well documented in the literature. Eutrophication acts through enhancement of periphytic growth, adverse light conditions due to shading by phytoplankton, and possibly even direct toxicity of high nutrient concentrations (e.g. Vermaat et al. 1997, Van Katwijk et al. 1997, Hemminga and Duarte 2000).

4.7. Lagoons

Research focussed on eutrophication and other human impacts, such as aquaculture, which led to an emphasis on biogeochemical fluxes. The Venice lagoon has been particularly well studied in a number of projects (e.g. ROBUST, TIDE). Research within PHASE showed that vertical turbulent mixing in the water column is most important for the intensity of benthic–pelagic exchange, both in systems characterised by dominant benthic filter feeders (Herman et al. 1999) and by seagrass meadows (e.g. Gacia et al. 2002). The project OAERRE has developed modelling tools for lagoons and other systems with limited exchange with the sea (Tett et al. 2003).

Overall, the intense human use has led to drastic changes in the range of benthic habitats present within lagoons. Increasing turbidity has led to the decline of rooted macrophytes and an increased abundance of floating mats of macroalgae. The increased organic content of sediments with associated increased oxygen demand has led to changes in macrofaunal composition.

Widespread hypoxic events have been reported (e.g. Plus et al. 2003), although recovery from these can be rapid (e.g. 1 – 3 years) if recolonisation from adjacent areas is possible.

4.8. *Subtidal sediments and open sea benthos*

The deeper seafloor that is beyond the reach of tidal emersion covers wide tracts of European continental shelves. Some research has been carried out within the framework of pelagic–benthic coupling, but only in a few projects. Trawling and dredging form an obvious disturbance that can be seen as a change in habitat conditions with adverse impacts on biodiversity, food web composition, and conservation values. There is consensus that overexploitation of fisheries is causing a change in the ecosystem composition of the north-east Atlantic Ocean and the Mediterranean and Black Seas (e.g. Frid et al. 2000; Trent and Nixon 2003). Open water (e.g. Heath 2005), benthic fish (e.g. Frid et al. 2000), and benthic invertebrates (e.g. Collie et al. 2000) communities are being affected.

4.9. *Open sea pelagic*

ELOISE research has contributed mostly to the understanding of pelagic food webs, plankton composition and biogeochemical pathways. Nutrient availability, which can be seen as a habitat condition, has changed greatly over large areas of coastal waters and the open sea (e.g. Herman et al. 2005), with consequences for pelagic food webs. The link between physical habitat dynamics of the open sea and human interference, including climate change, is not clear-cut. Turbulence spectra may well change with changing climate. However climate effects have become study objects only recently, and little can be related directly to habitat dynamics as yet.

4.10. *Indicators and methods to reveal coastal habitat state change*

Specific integrated monitoring or management information systems have been developed within ELOISE for dune and salt marsh systems (Tables IV, V). Unfortunately, no information could be traced on whether these systems have been implemented in current coastal zone management. It is not uncommon that tools developed for decision support remain poorly used (e.g. Janssen et al. 2005).

For intertidal as well as subtidal sediments, zoobenthic community composition has been proposed as an indicator system. This is in line with the requirements of the Water Framework Directive and comparable to methods developed for freshwater quality assessment (e.g. Ysebaert et al. 2002). For the pelagic, chlorophyll-nutrient loading models and the incidence of toxic blooms have been used as common indicators of habitat state both in the open sea as well as in waters with restricted exchange, such as lagoons and fjords (e.g. Tett et al. 2004, Windhorst et al. 2005). For seagrass habitats, maximum colonisation depth as well as changes in patchiness of meadows appear useful and operational indicators. These are presently in use in Scandinavian waters, as well as along the east coast of the USA (e.g. Krause-Jensen et al. 2003).

4.11. *Aggregation across projects and habitats*

The differential attribution of projects (Figure 2) is also reflected in the findings that bear relevance to habitat dynamics (Table VI). Table VI lists major findings in a topical, generic fashion, and hence can only be indicative in its depiction of research effort. Even so, the

Table V. Likely severity of major drivers (A) and extent of resultant state changes (B) for Europe's regional seas (adapted from Turner 2005).

	Atlantic Coast	Arctic	Baltic Sea	Black Sea	Caspian Sea	Mediterranean	North Sea
A. main drivers							
Climate change	+	++	+	++	++	+ locally++	+ locally++
Expansion of built environment	+	0	++	+	–	++	+
Trade, ports and related industry	+	0	++	++	++	++	++
Tourism	+	0	++	+ locally++	0	++	+
Fishing and aquaculture	++	++	++	++	++	++	++
Agriculture	+	0	++	++	++	+	+
B. environmental state change /impacts							
Sea level rise and coastal erosion	+	++	++	+	++	++	+ locally++
Contamination	+ locally++	+	+ locally++	++	++	+ locally++	++
Eutrophication	+ locally++	0	++	++	++	+ locally++	+
Biodiversity and habitat loss (incl. Invasive species)	+	+	+ locally++	++	++	+ locally++	+ locally++

++, very significant; +, significant; 0, minor to insignificant; (locally++), locally very significant.

Table VI. Expected habitat changes as a result of the drivers, associated pressures and resultant state changes from Table VI.

	Atlantic Coast	Arctic	Baltic Sea	Black Sea	Caspian Sea	Mediterranean Sea	North Sea
Cliffs, shingle beaches, kelp beds		move inland, erode	erode, coastal squeeze		erode	erode, coastal squeeze	erode, coastal squeeze
Wetlands and dune complexes		erode	lost	habitat lost		lost	coastal squeeze
Salt marsh		erode, move inland		habitat lost		lost	coastal squeeze
Sandbanks and mudflats		redistribute	submerge	species lost	species lost		species lost
Seagrass beds			↓area, less deep	↓area, less deep	↓area, less deep	↓area, less deep	
Lagoons			↑sediment anoxia	↑nutrient loading, ↑sediment anoxia	↑nutrient loading, ↑ sediment anoxia (E)	↑nutrient loading, ↑sediment anoxia	
Subtidal sediments	more trawling disturbance, ↑nutrient loading		more trawling disturbance	more trawling disturbance, ↑nutrient loading, ↑sediment anoxia	more trawling disturbance, ↑nutrient loading, ↑sediment anoxia	more trawling disturbance, ↑nutrient loading, ↑sediment anoxia	more trawling disturbance
Open sea pelagic			altered plankton composition	altered plankton composition	altered plankton composition	altered plankton composition	

attempt is useful, as it can be used to sketch the broad picture of our advances in understanding coastal systems from a habitat dynamics perspective. Most biogeochemical research has dealt with nutrient and/or carbon fluxes. Its contribution to our understanding of habitat dynamics has been limited to those occurring 'within' habitats.

Considerable advances have been made in understanding biogeochemical fluxes of pelagic and coupled benthic–pelagic ecosystem complexes, i.e. dynamics occurring at shorter time scales, such as within seasons (e.g. Herman et al. 2005). Our understanding of catchment–coast interactions has greatly improved (e.g. Behrendt et al. 2002, Lancelot et al. 2002), although often this cannot be translated directly into consequences for habitat dynamics. This larger-scale research has often involved the comparison of longer-term time scales and has, for example, led to the observation that nutrient loading (mainly phosphorus) to several of our northern seas has dropped over the last decade, in part because of policy implementation, and in part because of major political changes affecting agricultural practices, particularly fertiliser use, in central and eastern Europe.

However, the spatial scale of the biogeochemical studies was often small, say a few sampling sites in a habitat, whereas that of the catchment–coast work was large, say at 100s of km^2. A focus on habitat dynamics in the sense of structural change at the landscape scale remains an important challenge. Management at a specific habitat-scale may well require both up-scaling and down-scaling of research findings, probably not a trivial task, which has not been carried out within the framework of most ELOISE projects. Furthermore, the explicit connection to societal and socio-economic change has only been made in projects operating at the larger, catchment scale (such as EROS, BBCS, EUROCAT and DANUBS). In the next section, we ignore these scale considerations to a large extent, and carry out an attempt to extrapolate a global analysis of changes in drivers and pressures down into the habitat scale for a first and rough speculation on possible future changes in coastal habitats.

5. Drivers of coastal habitat change

The terms 'driver' and 'pressure' are taken from the DPSIR (Driver, Pressure, State, Impact and Response) framework. The DPSIR framework is a causal framework for describing the interactions between society and the environment and has been adopted by the EEA as a basis for analysing the interrelated factors impacting the environment. It is an extension of the Pressure–State–Response (PSR) model developed by the Organisation for Economic Cooperation and Development (OECD). DPSIR has been used in analysing nutrient abatement in the Baltic Sea (Turner et al. 1999) and catchment–coast interactions (Salomons 2004). Examples of drivers include consumer preferences, economic growth, the effects of globalisation, and climate change. Pressures comprise any human action, deliberate or incidental, that may cause an environmental state change. Examples include release nutrients and contaminants, as well as the effects of converting natural habitat to human purposes.

Major drivers of coastal change until 2050 have been identified by Turner (2005) and Nunneri et al. (2005) as: climate change, expansion of built environments, trade, ports and related industry, tourism, fishing and aquaculture, and agriculture. These drivers act together, often synergistically, to cause environmental state change with ultimate consequences for coastal habitats. Table V assesses the severity of these drivers and their potential role in environmental state change for the different European regional seas. Table VI translates these drivers, pressures and state changes into expected habitat changes. Expected changes are based, to a large extent, on our review of ELOISE findings.

Climate change, including the anthropogenic component, is a driver foreseen to have major effects in the coastal zone (see also Nicholls and Klein 2005). It is expected to have the most severe impacts in the Arctic and the Caspian and Black Sea. In the Arctic, the large scale disappearance of sea ice (Leontjev 2004) will lead to large-scale loss of habitat for arctic mammals and the food webs on which they depend (biodiversity loss). The loss of coastal ice will also enhance coastal erosion at these higher latitudes. In the Black Sea and Caspian Sea, freshwater influxes are expected to decrease substantially (Nunneri et al. 2005).

Sea level rise is foreseen (Nunneri et al. 2005) to lead to 'removal' or inland migration of sea cliffs, shingle beaches, sandy shores and salt marsh habitats due to enhanced erosion. These, therefore, will give way for aquatic habitats when natural re-alignment of the coast is impossible. Often, coastal squeeze will thus remove natural soft coasts until the armoured sea defence, hence typical coastal habitats will disappear.

Most drivers are related to human population growth and economic expansion (Turner 2005). Industrialisation, naval traffic intensity, fisheries, coastal aquaculture and port development as well as offshore mining for gas and oil all have increased greatly in the past decades, and probably will continue to do so. Together with increased tourism this has led to an increased urbanisation of the coastal zone (Nicholls and Klein 2005), accompanied by reclamation, increased armouring of coastal defences, and a narrowing of the zone where natural coastal processes may take place.

Tourism is expected to increase along Mediterranean and Baltic coasts (Nunneri et al. 2005). Fisheries and aquaculture will continue to have substantial impacts on coastal waters, despite considerable regulatory effort as regards the former. Aquaculture will probably expand into most European seas. Its impacts have been well studied, though not within ELOISE (e.g. LIFE QUALITY, cf. Read and Fernandes 2003). Agriculture is expected to intensify in the new member states of the EC and thus lead to increased nutrient loads into the Baltic and Black Seas (Salomons 2004). Future habitat losses were foreseen to be the most detrimental in the Black Sea and Caspian Sea.

6. Conclusions

'Habitat' has become a key component of European environmental and conservation policy. This review article has examined the contribution of ELOISE research to our understanding of coastal habitats and their dynamics. Research has addressed both natural process and anthropogenic sources of change. We have extended these research findings to identify challenges for future coastal zone management. In turn, these also pose challenges for future coastal research.

Before summarising our main findings and recommendations for further research, two points are made. The first is that, while ELOISE projects generally comprise a mix of disciplines, it is only in the last generation of ELOISE projects (e.g. DANUBS, EUROCAT) that the social sciences have been included. Their inclusion stems, in part, from the recent evaluation criterion of societal relevance. It also stems from recognition that the coastal zone provides extremely relevant challenges for undertaking social science research. Second, because research funding is based heavily on scientific quality, research has been distributed unequally over the research themes identified in the ELOISE science plan (Cadée et al. 1994; see also Ledoux et al. 2005 and Herman et al. 2005) and has not tended to respond to policy and management needs. Despite the emergence of 'habitat' as a key component of policy, few research projects within ELOISE explicitly addressed this concept in such a way that their products were relevant and available to policy-makers. There has been, perhaps inevitably, a mismatch between scientific quality, identified research needs and societal relevance.

ELOISE research has greatly increased our understanding of the biogeochemical processes in the near-coastal pelagic and its interactions with benthic environments. Important physical drivers of natural dynamics have been incorporated in habitat models of benthic systems. The biogeochemistry of nutrients, heavy metals and several persistent organic pollutants has been clarified substantially over the course of ELOISE. Effects of eutrophication have been comparatively well studied, particularly for the pelagic, and for benthic plants such as seagrasses and seaweeds. However, poorly known complex second-order interactions still hamper our predictive capacity of crucial phenomena, such as the possible existence of thresholds for habitat state transitions and the differential nutrient absorption capacity of food webs.

Major changes in drivers of change along the European coasts, such as climate change, increased urbanisation, trade and tourism, fisheries, aquaculture and agriculture, will lead to considerable changes in the extent and quality of coastal habitats. Different seas will experience different strengths of drivers, subsequent state changes and their impacts on habitat. Indicators monitoring these state changes have been developed in a considerable number of ELOISE projects.

Several habitats, notably the pelagic of the open coastal sea, lagoons, as well as tidal mud- and sand flats have been represented quite well in the ELOISE research portfolio. Hence for these we can draw on a sound knowledge base. Other European coastal habitats, such as cliffs, dunes, salt marshes and other coastal wetlands have been studied less extensively, and so are probably less well understood. For salt marshes and dune complexes, indicator and decision support models have been developed within ELOISE, based on existing knowledge. Overall, the Atlantic seaboard has received little attention compared with the other European seas.

Future European coastal research would certainly augment the effort reviewed here in a useful way. We identify four larger areas of research:

(1) *Comparative surveys of spatial pattern*. Larger-scale, comparative surveys of European seas have been carried out but to a limited extent only. An understanding of the overall relevance of observed patterns will be greatly enhanced by such a comparative approach. Larger-scale spatial variability such as habitat mosaics and their spatio-temporal dynamics have remained poorly investigated. These would enable firmer conclusions on state transitions within and among habitat types.

(2) *Fisheries and aquaculture*. The effect of fisheries on coastal food webs is comparatively well known, although data have not been collected within ELOISE. Those from aquaculture may be less well clarified, which is particularly relevant in view of the foreseen expansion of aquaculture into all European seas.

(3) *EC-wide stock-taking*. Stocktaking and assessment of habitat areas covering the coastal zone of Europe have been imbalanced so far, both with respect to countries as well as habitats. With the presently available CORINE and EUNIS typologies, the necessary defining stage is passed. Calibration among member countries as well as discussion on the level of aggregation for EC-wide stocktaking reviews requires attention and coordination between EEA, national authorities, and the coastal research community. This can complement and build on existing environmental surveys such as those of the EEA (cf. Ærtebjerg and Carstensen 2003).

(4) *Disciplinary integration*. Multidisciplinary assessment of interacting coastal issues with partners from natural and social sciences is relatively recent, both in ELOISE and in EC environmental research funding in general. Stakeholder involvement and analysis, the roles of government and other institutional organisations, law and socio-cultural contrasts, scenarios of future economic and policy conditions in Europe (particularly given expansion of the European Union) provide a sample of highly relevant research topics for the future.

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References

Barron C, Marba N, Duarte CM, Pedersen MF, Lindblad C, Kersting K, Moy F, Bokn T. 2003. High organic carbon export precludes eutrophication responses in experimental rocky shore communities. Ecosystems 6:144 – 153.

Behrendt H, Kornmilch M, Opitz D, Schmoll O, Scholz G. 2002. Estimation of the nutrient inputs into river systems—Experiences from German rivers. Regulators of Environmental Change 3:107 – 117.

Breitenmoser U. 1998. Large predators in the Alps: the fall and rise of man's predators. Biological Conservation 83:279 – 289.

Boorman LA, Hazelden J, Boorman M. 2001. The effect of rates of sedimentation and tidal submersion regimes on the growth of salt marsh plants. Continental Shelf Research 21:2155 – 2165.

Brown SL, Cox R, Feunteun E, Thorin S, Lefeuvre JC. 2003. Overview of the EUROSAM project and a decision support system. Continental Shelf Research 23:1617 – 1634.

Cadée N, Dronkers J, Heip C, Martin JM, Nolan C. 1994. ELOISE (European Land – Ocean Interaction Studies) Science Plan. Ecosystems research report no. 11, European Commission EUR 15608, Luxemburg.

Collie JS, Hall SJ, Kaiser MJ, Poiner IR. 2000. A quantitative analysis of fishing impacts on shelf-sea benthos. Journal of Animal Ecology 69:785 – 798.

Cramer W, Hytteborn H. 1987. The separation of fluctuation and long-term change in vegetation dynamics of a rising seashore. Vegetatio 69:157 – 167.

Davidson M, Aarninkhof SGJ, Van Koningsveld M, Holman RA. 2004. Developing coastal video monitoring systems in support of coastal zone management. Journal of Coast Research SI (in press).

Davies JL. 1980. Geographical variation in coastal development. Geomorphology texts 4. Longman.

Day JW, Rybczyk J, Scarton F, Rismondo A, Are D, Cecconi G. 1999. Soil accretionary dynamics, sea level rise and the survival of wetlands in Venice Lagoon: A field and modeling approach. Estuarine, Coastal and Shelf Science 49:607 – 628.

Den Hartog C. 1970. Seagrasses of the world. The Netherlands: North Holland.

Deshmukh I. 1986. Ecology and tropical biology. Oxford: Blackwell.

De Wit R, Stal LJ, Lomstein BA, Herbert RA, Van Gemerden H, Viaroli P, Cecherelli V, Rodrıguez-Valera F, Bartoli M, Giordani G, et al. 2001. ROBUST: The ROle of BUffering capacities in Stabilising coastal lagoon ecosystems. Continental Shelf Research 21:2021 – 2041.

Ferns PN, Rostron DM, Siman HY. 2000. Effects of mechanical cockle harvesting on intertidal communities. Journal of Applied Ecology 37:464 – 474.

Flindt M, Salomonsen J, Carrer M, Bocci M, Kamp-Nielsen L. 1997. Loss, growth and transport dynamics of *Chaetomorpha aerea* and *Ulva rigida* in the Lagoon of Venice during an early summer field campaign. Ecological Modelling 102:133 – 141.

Frederiksen M, Krause-Jensen D, Holmer M, Sund Laursen J. 2004a. Long-term changes in area distribution of eelgrass (*Zostera marina*) in Danish coastal waters. Aquatic Botany 78:167 – 181.

Frederiksen M, Krause-Jensen D, Holmer M, Sund Laursen J. 2004b. Spatial and temporal variation in eelgrass (*Zostera marina*) landscapes: influence of physical setting. Aquatic Botany 78:147 – 165.

Frid CLJ, Harwood KG, Hall SJ, Hall JA. 2000. Long-term changes in the benthic communities on North Sea fishing grounds. ICES Journal of Marine Science 57:1303 – 1309.

Gacia E, Duarte CM, Middelburg JJ. 2002. Carbon and nutrient deposition in a Mediterranean seagrass (*Posidonia oceanica*) meadow. Limnology and Oceanography 47:23 – 32.

Gazeau F, Smith SV, Gentili B, Frankignoulle M, Gattuso JP. 2004. The European coastal zone: characterization and first assessment of ecosystem metabolism. Estuarine, Coastal and Shelf Science 60:673 – 694.

Giesen WBJT, Van Katwijk MM, Den Hartog C. 1990. Eelgrass condition and turbidity in the Dutch Wadden Sea. Aquatic Botany 37:71 – 85.

Hanson CH. 1990. Estimated post-Messinian sediment supply and sedimentation rates on the Ebro continental margin, Spain. Marine Geology 95:395 – 418.

Heath MR. 2005. Changes in the structure and function of the North Sea fish foodweb, 1973 – 2000, and the impacts of fishing and climate. ICES Journal of Marine Science 62: 847 – 868.

Hemminga MA, Duarte CM. 2000. Seagrass ecology. Cambridge: Cambridge University Press.

Herman PMJ, Middelburg JJ, Van de Koppel J, Heip CHR. 1999. Ecology of estuarine macrobenthos. Advances in Ecological Research 29:195 – 240.

Herman PMJ, Ysebaert T, Heip C. 2005. Land – ocean fluxes and coastal ecosystems—A guided tour of ELOISE results. In: Vermaat JE, Turner RK, Salomons W, Bouwer L (eds). Managing European coasts, past present and future. Berlin: Springer.

Janssen MA, Goosen H, Omtzigt N. 2005. A simple mediation and negotiation tool for water management in the Netherlands. Landscape and Urban Planning. In press.

Klijn F. 1994. Ecosystem classification for environmental management. Dordrecht: Kluwer.

Krause-Jensen D, Pedersen MF, Jensen C. 2003. Regulation of eelgrass (*Zostera marina*) cover along depth gradients in Danish coastal waters. Estuaries 26:866 – 877.

Lancelot C, Martin JM, Panin N, Zaitsev Y. 2002. The north-western Black Sea: a pilot site to understand the complex interaction between human activities and the coastal environment. Estuarine, Coastal and Shelf Science 54:279 – 283.

Ledoux L. Vermaat JE, Bouwer L, Salomons W, Turner RK. 2005. ELOISE research and the implementation of EU-Policy in the coastal zone. In: Vermaat JE, Turner RK, Salomons W, Bouwer L (eds). Managing European coasts, past present and future. Berlin: Springer.

Leendertse PC, Roozen AJM, Rozema J. 1997. Long-term changes (1953 – 1990) in the salt marsh vegetation at the Boschplaat on Terschelling in relation to sedimentation and flooding. Plant Ecology 132:49 – 58.

Lefeuvre JC, Bouchard V. 2002. From a civil engineering project to an ecological engineering project: an historical perspective from the Mont Saint Michel bay (France). Ecological Engineering 18:593 – 606.

Leontjev IO. 2004. Coastal profile modelling along the Russian arctic coast. Coastal Engineering 51:779 – 794.

Leopold MF, Dijkman EM, Cremer JSM, Meijboom A, Goedhart PW. 2004. De effecten van mechanische kokkelvisserij op de benthische macrofauna en hun habitat. (In Dutch: The effects of mechanical cockle fisheries on benthic invertebrates and their habitat.) Concept final report EVAII. Ministry of Agriculture, Food Quality and Nature, The Hague, The Netherlands.

Marani M, Lanzoni S, Silvestri S, Rinaldo A. 2004. Tidal landforms, patterns of halophytic vegetation and the fate of the lagoon of Venice. Journal of Marine Systems 51:191 – 210.

Marbà N, Duarte CM. 1995. Coupling of seagrass (*Cymodocea nodosa*) patch dynamics to subaqueous dune migration. Journal of Ecology 83:381 – 389.

Marbà N, Cebrian J, Enriquez S, Duarte CM. 1996. Growth patterns of Western Mediterranean seagrasses: apecies-specific responses to seasonal forcing. Marine Ecology Progress Series 133:203 – 215.

Moss D, Wyatt BK. 1994. The CORINE biotopes project: a database for conservation of nature and wildlife in the European Community. Applied Geography 14:327 – 349.

Nicholls R, Klein RJT. 2005. Climate change and coastal management on Europe's coast. In: Vermaat JE, Turner RK, Salomons W, Bouwer L (eds). Managing European coasts, past present and future. Berlin: Springer.

Nunneri C, Turner RK, Cieslak A, Kannen A, Klein RJT, Ledoux L, Marquenie J, Mee L, Moncheva S, Nicholls RJ, et al. 2005. Group report: integrated assessment and future scenarios for the coast. In: Vermaat JE, Turner RK, Salomons W, Bouwer L (eds). Managing European coasts, past present and future. Berlin: Springer.

Philippart CJM, van Aken HM, Beukema JJ, Bos OG, Cadee GC, Dekker R. 2003. Climate-related changes in recruitment of the bivalve *Macoma balthica*. Limnology and Oceanography 48:2171 – 2185.

Plus M, Deslous-Paoli J, Dagault F. 2003. Seagrass (*Zostera marina* L.) bed recolonisation after anoxia-induced full mortality. Aquatic Botany 77:121 – 134.

Ponting C. 1991. A green history of the world. London: Sinclair-Stevenson.

Read P, Fernandes T. 2003. Management of environmental impacts of marine aquaculture in Europe. Aquaculture 226:139 – 163.

Salomons W. 2004. European catchments: catchment changes and their impact on the coast. Institute for Environmental Studies, Vrije Universiteit, Report R-04/01 (http://www.cs.iia.cnr.it/EUROCAT/publications/EuroCatSummary.pdf).

Schule W. 1993. Mammals, vegetation and the initial human settlement of the Mediterranean islands—A paleoecological approach. Journal of Biogeography 20:399 – 412.

Tett P, Gilpin L, Svendsen H, Erlandsson CP, Larsson U, Kratzer S, Fouilland E, Janzen C, Lee JY, Grenz C, et al. 2003. Eutrophication and some European waters of restricted exchange. Continental Shelf Research 23:1635 – 1671.

Thorin S, Radureau A, Feunteun E, Lefeuvre JC. 2001. Preliminary results on a high east–west gradient in the macrozoobenthic community structure of the macrotidal Mont Saint-Michel bay. Continental Shelf Research 21:2167–2183.

Trent Z, Nixon S. 2003. Fisheries impact habitats and ecosystems EEA indicator fact sheet FISH4. Copenhagen: EEA.

Turner TK, Georgiou S, Gren I-M, Wulff F, Barrett S, Söderqvist T, Bateman IJ, Folke C, Langaas S, Żylicz T, et al. 1999. Managing nutrient fluxes and pollution in the Baltic: an interdisciplinary simulation study. Ecological Economics 30:333–352.

Turner RK. 2005. Integrated environmental assessment and coastal futures. In: Vermaat JE, Turner RK, Salomons W, Bouwer L (eds). Managing European coasts, past present and future. Berlin: Springer.

Valiela I, McCLelland J, Hauxwell J, Behr PJ, Hersh D, Foreman K. 1997. Macroalgal blooms in shallow estuaries: controls and ecophysiological and ecosystem econsequences. Limnology and Oceanography 42:1105–1118.

Van de Koppel J, Herman PJH, Thoolen P, Heip CHR. 2001. Do multiple stable states occur in natural ecosystems? Evidence from tidal flats. Ecology 82:3449–3461.

Van Dijk PM, Arens SM, Van Boxel JH. 1999. Aeolian processes across transverse dunes. II: modelling the sediment transport and profile development. Earth Surface Processes and Landforms 24:319–333.

Van Katwijk MM, Vergeer LHT, Schmitz GHW, Roelofs JGM. 1997. Ammonium toxicity in eelgrass *Zostera marina*. Marine Ecology Progress Series 157:159–173.

Vermaat JE, Verhagen FCA. 1996. Seasonal dynamics in the intertidal seagrass *Zostera noltii* Hornem.: coupling demographic and physiological patterns. Aquatic Botany 52:259–281.

Vermaat JE, Agawin N, Duarte CM, Enriquez S, Fortes MD, Marba N, Uri J. 1997. The capacity of seagrasses to survive eutrophication and siltation, the significance of growth form and light use. Ambio 26:409–504.

Widdows J, Brinsley MD, Salkeld PN, Lucas CH. 2000. Influence of biota on spatial and temporal variation in sediment erodability and material flux on a tidal flat (Westerschelde, The Netherlands). Marine Ecology Progress Series 194:23–37.

Widdows J, Blauw A, Heip CHR, Herman PMJ, Lucas CH, Middelburg JJ, Schmidt S, Brinsley MD, Twisk F, Verbeek H. 2004. Role of physical and biological processes in sediment dynamics of a tidal flat in Westerschelde Estuary, SW Netherlands. Marine Ecology Progress Series 274:41–56.

Williams AT, Alveirinho-Dias J, Garcia Novo F, Garcia-Mora MR, Curr R, Pereira A. 2001. Integrated coastal dune management: checklists. Continental Shelf Research 21:1937–1960.

Windhorst W, Colijn F, Kabuta S, Laane RPWM, Lenhart HJ. 2005. Defining a good ecological status of coastal waters—A case study for the Elbe plume. In: Vermaat JE, Turner RK, Salomons W, Bouwer L (eds). Managing European coasts, past present and future. Berlin: Springer.

Wing SR, Wing ES. 2001. Prehistoric fisheries in the Caribbean. Coral Reefs 20:1–8.

Wolff WJ. 2000. The south-eastern North Sea: losses of vertebrate fauna during the past 2000 years. Biological Conservation 95:209–217.

Ysebaert T, Herman P. 2002. Spatial and temporal variation in benthic macrofauna and relationships with environmental variables in an estuarine, intertidal soft-sediment environment. Marine Ecology Progress Series 244:105–124.

Ysebaert T, Meire P, Herman PMJ, Verbeek H. 2002. Macrobenthic species response surfaces along estuarine gradients: prediction by logistic regression. Marine Ecology Progress Series 225:79–95.

Ærtebjerg G, Carstensen J. 2003. Chlorophyll-a in transitional, coastal and marine waters. EEA indicator fact sheet WEU13. Copenhagen: EEA.

Annex 1

Elaboration of acronyms, those in bold relate to research project (project websites may be accessed via http://www2.nilu.no/eloise)

BASIC	Baltic Sea cyanobacteria
BIOCOMBE	The impact of biodiversity changes in coastal marine benthic ecosystems
BIOGEST	Biogases transfers in estuaries
COASTVIEW	Video monitoring of littoral processes in support of coastal-zone management
COMWEB	Comparative analysis of food webs based on flow networks: effects of nutrient supply on structure and function of coastal plankton communities
CORINE	CoORdination of INformation on the Environment
COSA	Coastal sands as biocatalytical filters
DANLIM	Detection and analysis of nutrient limitation in coastal plankton communities across a hierarchy of temporal and physiological–systemic scales
DITTY	Development of an information technology tool for the management of European southern lagoons under the influence of river-basin runoff
DOMAINE	Dissolved organic matter (DOM) in coastal ecosystems: transport, dynamics and environmental impacts
DOMTOX	Importance of dissolved organic matter from terrestrial sources for the production, community structure and toxicity of phytoplankton
DPSIR	Driver, Pressure, State, Impact and Response framework
DUNES	Integrated management methods: monitoring environmental change in coastal dune ecosystems
EC	European Commission
ECOFLAT	The eco-metabolism of estuarine intertidal flat
EEA	European Environment Agency
ELOISE	European Land–Ocean Interaction Studies
EROS21	Biogeochemical interactions between the Danube River and the North-Western Black Sea
ESCAPE	Entangled sulphur and carbon cycles in *Phaeocystis* dominated ecosystems
EULIT	Effects of eutrophicated seawater on rocky shore ecosystems studied in large littoral mesocosms
EUNIS	European Nature Information System of the EEA
EUROSAM	European salt marshes modelling
EUROTROPH	Nutrients cycling and the trophic status of coastal ecosystems
F-ECTS	Feedbacks of estuarine circulation and transport of sediments on phytobenthos
HIMOM	A system of hierarchical monitoring methods for assessing changes in the biological and physical state of intertidal areas
ISLED	Influence of rising sea level on ecosystem dynamics of salt marshes
KEYCOPS	Key coastal processes in the mesotrophic Skagerrak and the oligotrophic Northern Aegean: a comparative study
METROMED	Dynamic of matter transfer and biogeochemical cycles: their modelling in coastal systems of the Mediterranean Sea

M&MS	Monitoring and managing of European seagrass beds
MOLTEN	Monitoring long-term trends in eutrophication and nutrients in the coastal zone
NICE	Nitrogen cycling in estuaries
NTAP	Nutrient dynamics mediated through turbulence and plankton interactions
OAERRE	Oceanographic applications to eutrophication in regions of restricted exchange
PHASE	Physical forcing and biogeochemical fluxes in shallow coastal ecosystems
POPCYCLING	Environmental cycling of selected persistent organic pollutants (POPS) in the Baltic region
PROTECT	Prediction of the erosion of cliffed terrains
ROBUST	The role of buffering capacities in stabilising coastal lagoon ecosystems
SIGNAL	Significance of external / anthropogenic nitrogen for central Baltic Sea N-Cycling
TIDE	Tidal inlets dynamics and environment