

Habitat dynamics at the coast-catchment interface: a digest from ELOISE projects

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Summary

(1) This synthesis summarises the contribution of research projects with the ELOISE cluster to the understanding of European coastal habitat dynamics. It applies 'habitat' as the key concept defining the ecosystems that cover Europe's coasts, since it is adopted by the European Community as formal currency in its directives on water and nature use, management and conservation. Classifications used by the EC have been aggregated into the following eight categories here (1) cliffs, shingle beaches, and associated kelp beds; (2) dune complexes with freshwater wetlands; (3) salt marsh; (4) sand-banks and mudflats; (5) seagrass beds, (6) lagoons; (7) subtidal sediments, and (8) open sea pelagic.

(2) Dynamics have been understood here as occurring 'within' and 'between' habitats. The former, internal dynamics are often coupled to physical forcing and occur at a number of temporal scales, from weeks (tide), to months (solar seasons) to longer temporal scales such as global weather patterns. The latter concern with transitions from one habitat into another, such as gradual succession or abrupt change following an incidental disturbance such as a severe storm or earthquake. Both types have been charted for the eight habitat categories used.

(3) For seven major European seas, the possible impact on the eight habitat categories has been reviewed in an aggregate DP-SIR analysis of the complex interplay of foreseen future changes (up to 2050) in major drivers and pressures that would lead to major state changes for the ecosystems along Europe's coast. These drivers were identified as 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 differently so in the seven seas. Often, when a fixed coastline prevents coastal migration inland, coastal squeeze and erosion will lead to a complete loss of coastal habitats, particularly saltmarshes and dune complexes in the Baltic, Black Sea and Mediterranean.

(4) Out of the larger number of ELOISE-funded projects, at least 43 have explicitly contributed to further our understanding of coastal habitat change, mostly focusing on the understanding of natural dynamics (13 projects) or human-induced state changes (23),

several others were designed to deliver indicators of habitat state change (13). Notably, these ELOISE projects have increased our understanding of the biogeochemical processes in the near-coastal pelagic, lagoons and mud- and sandflats. This digest concludes with specific recommendations for a future European coastal research programme and includes two exemplary cases.

Introduction

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 eastward 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). Inland catchment colonisation by sedentary farming societies will also have greatly altered the hydrology and sediment delivery of rivers to the sea for several millennia (e.g. Hanson 1990).

The impact of present day's modern society on coastal habitats is probably unprecedented and continues to increase in spatial extent as well as intensity, since coastal populations are expected to increase as are the impacts of economic activities and urbanisation on the coast and adjacent open sea (e.g. Nicholls and Klein 2004, Turner 2004). These foreseen developments are by no means restricted to the coast. They have led the European Community to issue the habitat directive (92/43/EEC), a legal framework at the level of the European Community, which is currently under implementation. The 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 as follows: 'natural habitats means terrestrial or aquatic areas distinguished by geographic, abiotic and biotic features, whether entirely natural or semi-natural,' (92/43/EEC). The EUNIS¹ website offers a different, more specified, text: 'Plant and animal communities as the characterising elements of the biotic environment, together with abiotic factors (soil, climate, water availability and quality, and others),

¹ EUNIS is the European Nature Information System of the European Environment Agency (EEA), developed and maintained by the European Topic Centre on Nature Protection and Biodiversity. EUNIS contains information on selected species, habitat types and sites, based on national data collected through EIONET (The European Environment Information and Observation Network coordinated by EEA) and from international organisations. EUNIS information is being used to support the NATURA2000 process, for EEA reports and for international co-ordination for example with the Bern Convention EMERALD Network and other conventions such as the Helsinki, OSPAR and Barcelona conventions. (<http://eunis.eea.eu.int/index.jsp>)

operating together at a particular scale.’ Confusion over delimitation of habitats is by no means improbable with definitions appearing in ecological textbooks such as ‘the spatial subdivision of the environment within an ecosystem into convenient units’ (e.g. Deshmukh 1986). A substantial literature exists on the definition of ‘habitat’ and related concepts, such as ecotope or biotope (e.g. Klijn 1994). Moss and Wyatt (1994) simply synonymise biotope to habitat in a paper describing the CORINE effort to create a harmonised European habitat classification and database. This CORINE classification is presently succeeded by the EUNIS habitat classification (<http://eunis.eea.eu.int/index.jsp>), which is substantially more comprehensive, certainly in terms of marine habitats (cf Fig 1).

The term ‘dynamics’ is taken here to reflect both internal dynamics, i.e. changes occurring within a habitat due to internal or external forces, where the habitat itself remains identifiable, as well as profound changes in the nature of a habitat leading to a transition into another type. The latter could be cyclic, reversible or irreversible. 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. Also 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) Transition of one habitat into another could be due to gradual succession, such as occurring on salt marshes that accrete with positive sediment trapping (Leenderse et al. 1997, Lefeuvre and Bouchard 2002). Cyclic habitat transitions can be illustrated by the accretion-erosion cycle associated with moving sand dunes, above as well as below water (e.g. Marbà and Duarte 1995).

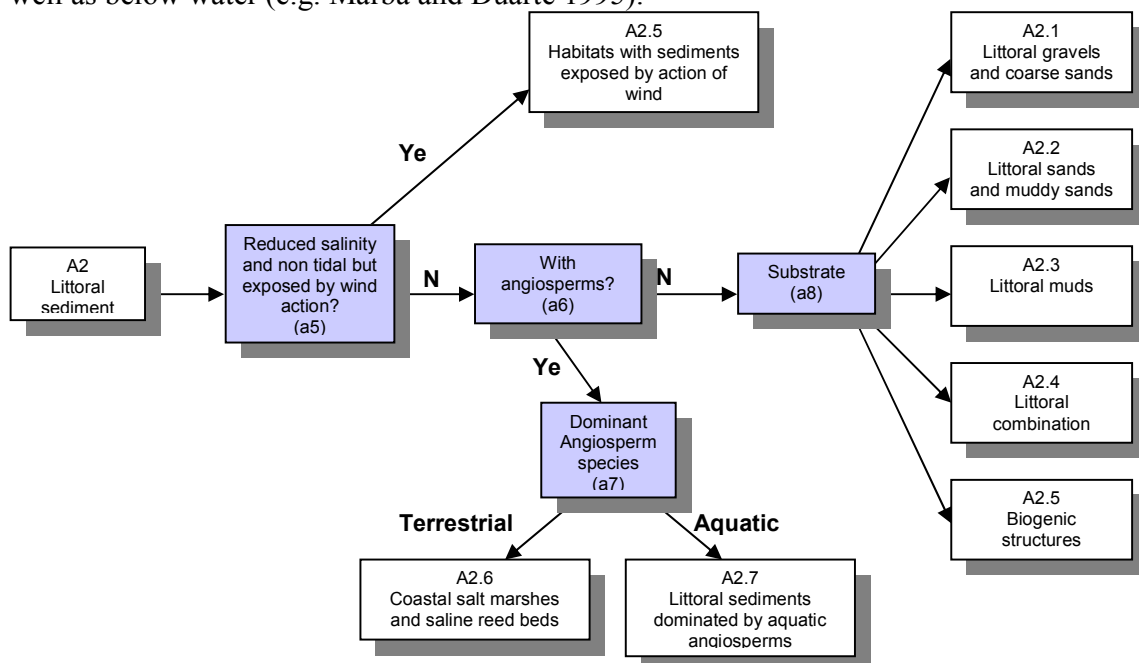


Fig 1. EUNIS habitat classification for a group of marine habitats, littoral sediments, to EUNIS level 2 (taken from <http://eunis.eea.eu.int/index.jsp>). A similar classification tree is developed for coastal habitats (main category B in EUNIS), including dunes, shingle and sandy beaches. The present digest aims to summarise new findings brought together in ELOISE research projects on the dynamics of coastal habitats. These dynamics will be understood here as natural, i.e. due to dynamic physical forcing, or man-induced, i.e. linked to important

drivers of global, societal and ecological change. This will be done for major coastal habitats as identified formally in EC-documents. We will first provide a survey of such coastal habitats and select the major habitats for each of Europe's coastal seas. The paper proceeds to identify the effects of major drivers on these habitats for each of these seas based on a recent scenario analysis (Turner 2004, Nunneri et al. 2004). We then continue to survey ELOISE projects for their contribution to understanding natural dynamics, anthropogenic state change and possible indicators of such habitat change for our breakdown of major coastal habitat types. We bring these together in two comprehensive tables. This digest is accompanied by two exemplary cases of coastal habitat change.

The habitat directive focuses on priority habitats that are geographically characteristic and/or in danger of disappearance and therefore have conservation urgency. In contrast, the present digest attempts to include all coastal habitats, including the open pelagic of the high sea and deeper demersal sediments that are not typically coastal in character.

Table 1. coastal landscape types, their location and description (from EUCC). Similar typologies appear in the literature (e.g. Davies 1980)

<p><i>1a. Hard rock, cliffed coasts</i> 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</p> <p><i>1b. Hard rock coastal plains</i> 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</p> <p><i>2. Soft rock coasts</i> 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</p> <p><i>3a. Tide-dominated sediment. Plains</i> 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</p> <p><i>3b. Wave-dominated sediment. Plains</i> 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</p>

Coastal habitat typology

A substantial number of coastal habitats has been formally defined in the Habitat Directive (directive 92/43/EEC) and are listed in the EUNIS catalog (see above). The EUCC has arranged them according to their abundance in various European coastal landscapes, since some habitats are ubiquitous and others have a restricted occurrence (www.coastalguide.org/typology). Different coastal landscape types have been identified

Table 2. distribution of major European coastal habitats over different coastal landscape types (adopted and adjusted from the EUCC classification) Legend: * habitat may well occur in this landscape: F: habitat usually occurs in appreciable extent

habitats landscape types	Cliff (Cl)	Shingle (Sh)	Kelp (Ke)	Estuary (Es)	Wet- land (W)	Dune (Du)	Sand bank (Sb)	Salt marsh (Sm)	Mud- flat (Mf)	Lagoon (La)	Sea- grass (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 & North Sea estuaries	*	*	*	F	*		*	*	*		
Karstic cliffs Mediterranean & Black seas	F	*	*								*
1b. Hard rock coastal plains											
Baltic skerry coasts	F	*	*			*					*
Baltic & Scottish fjords	*	*	*			*					*
river mouths	*	*	*		*	*					
Arctic tidal plains	*	*	*			*					
Karstic, Mediterr., Black seas	*										*
2. Soft rock coasts											
soft rock cliffs on tidal bedrock plains	F	*	*	*	*						*
high & low glacial sea cliffs	F	*	*	F	*						*
Atlantic rias	F	*	*	*		*					*
river mouths	*	*	*	F		*	*	*	*		*
barrier shingle coasts		F	*			*	*	*	F		*
Atlantic & North Sea estuaries			*	F				*	*		*

Table 2. continued

3a. Tide-dominated sediment, plains										
barrier shingle coasts	F	*	*	*	*	*	*	*	*	*
low earth cliff coasts	*		*	*	*	*			F	*
Atlantic & North Sea lagoons	*		*		*	*			F	*
barrier dune islands	*		*		F	F		*	F	*
Atlantic & 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 microtidal zones	*		*	*	*	*		*	*	F
Black Sea limans	*		*	F	*	*		*	*	*
river deltas in microtidal zones			*	F	F	*		*	*	*
dune coasts in microtidal zones			*	*	F	*		*	*	*
Baltic barrier-haff-delta coasts			*	*	F	*			F	*
German Baltic bodden coast			*		*	*			F	*

Cliffs (Cl): sea cliff habitats, shingle (Sh): stony banks and shingle habitats; kelp (Ke): kelp forests; estuary (Es): marine and tidal habitats; wetland (W): (temporary) wetland habitats; dune (Du): sea dune habitats and machairs in Ireland; sandbank (Sb): sandbanks; salt marsh (Sm): salt marshes, steppes and meadows; mud flat (Mf): mud and sand flats; lagoon (La): lagoonal habitats; seagrass beds (Gr): *Zostera* fields and Mediterranean *Posidonia* fields.

on the basis of predominant substrate, slope and prevailing tidal regime (Table 1). These serve as a landscape typology over which the habitat typology is cross-tabulated (Table 2). Particular coastal habitats are more prevalent in particular coastal landscapes. European seagrass beds, for example, can only be found on unconsolidated sediments, and stands of macro-algal kelp are abundant on hard rocks. From this tabulation, the most important habitats will subsequently be identified for the different European coastal seas, i.e. the Atlantic sea board, the Baltic Sea, the North Sea, the Mediterranean and the Black Sea. This breakdown by seas is then used to briefly sketch natural dynamics and downscale drivers for change and their effects to specific habitats.

The tabulation of habitat types (table 2) suggests that a distinction in hard-rock versus sedimentary coastlines has been very useful in identifying clusters of predominant habitats. Also, several habitats have rather similar patterns of occurrence across landscapes, hence probably often occur together. Examples are mudflats and sandbars, cliffs and shingle bars, as well as wetland and dune systems. This has a direct geomorphological/geo-genetical basis. The distribution of seagrass beds over the different landscape types in the table is not very distinct. Apparently, seagrass beds may occur along many coasts, which is confirmed in older literature (e.g. Den Hartog 1970) and on recent, internet-available GIS databases (see for example <http://stort.unep-wcmc.org/imaps/marine/seagrass/viewer.htm>).

Three further aspects need to be highlighted. Firstly, the pelagic and deep sea sediments of the open sea have been omitted from the typology, but can be added easily. The newer EUNIS-typology does include these habitats. Secondly, habitat types differ in their degree of homogeneity and spatial extent. Estuaries and lagoons, for example, appear to be rather generic and actually may comprise complexes of different, more homogeneous habitat types. Thirdly, a number of habitat qualifiers in the header row also appear in the landscape column. Apparently, some landscapes have been considered to be 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.

Natural dynamics in coastal habitats

We suggested differentiating between dynamics ‘within’ and ‘between’ habitats. The former reflecting 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 over ~6 – 24 hours, i.e. within a day, but also longer periods occur. Next, all across Europe distinct seasonality is apparent in coastal waters and on land. Seasonality, from an ecological perspective, is fairly well predictable with day length, light availability and/or temperature (e.g. Vermaat and Verhagen 1996, Marba et al. 1996). Climate change, however, may lead to an uncoupling of physical forcing and biotic responses (Phillipart et al. 2003). Thirdly, at larger temporal scales, weather patterns change between years and generate highly variable sequences of comparatively dry, wet, warm or cold years, the North Atlantic Oscillation being an important underlying forcing factor. 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. A substantial European research effort has been invested in better understanding these natural dynamics of coastal ecosystems.

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

the drastic declines in seagrass beds across Europe (e.g. Giesen et al. 1990, Frederiksen et al. 2004a) We will summarise both types of dynamics briefly here (Table 3) and have merged several habitats that appear to co-occur (see above, Table 2). Mobile sediment may generate apparently cyclic transitions between different habitats, both on land and in the sea (Table 3). Rare, extreme events, such as heavy storms and seismic movements of the earth crust may cause considerable change in coastal habitats due to massive, incidental relocations of sediment. Particularly in the Mediterranean, seismic incidents are sufficiently frequent over longer time scales to be taken into consideration. Because of the erratic, unpredictable outcome in terms of habitat dynamics, seismic events have not been incorporated into table 3. Isostatic sea level rise as well as coastal subsidence are additional natural processes leading to gradual or abrupt transitions in coastal habitats. Succession in shore meadows of the Northeastern Baltic are a good example. Climate change effects will be discussed later.

Table 3. Natural dynamics in major coastal and marine habitats of Europe. Habitats are regrouped from the EUCC typology (cf table 2) on the basis of co-occurrence or similarity in pattern. Complex processes that occur more than once have been abbreviated as acronyms (see below).

Habitat type	Dynamics	
	Within habitat	Transitions between habitats
Cliffs, shingle beaches, kelp beds	T,S,A	Erosion; colonisation by vegetation; changes in macroalgal abundance of kelp with altered foodweb structure; CWC for shingle
Wetlands and dune complexes*	T,S,A	CPH
Salt marsh*	T,S,A	CPH, passing mobile dunes may alter vegetation
Sand-banks and mudflats*	T,S,A	CWC; CPH
Seagrass beds*	T,S,A	CWC; increased turbidity will decrease depth penetration; stronger hydrodynamics will lead to an increased fragmentation of the canopy
Lagoons	S, A	Sedimentation may lead to infilling; possibly peat formation; fracture of the barrier to the sea will disrupt the quiet lagoonal conditions; may be coupled to changes in barrier-disturbing storm frequencies
Subtidal sediments	S, A	Changes in composition of detritus rain from pelagic or coast may affect benthic fauna and fish; deep currents may change course
Open sea pelagic	S, A	Water temperature, nutrient loading gradients and turbulence spectra may lead to altered plankton and fish community composition

Legend: T=tidal, S = seasonal, A=interannual; CWC = changes in patterns of waves or currents leading to changed patterns in sedimentation regime, i.e erosion, accretion, changing sediment texture; CPH = changes in precipitation or hydrology (altered river discharge) will affect erosion/accretion and vegetation composition; sandbanks and mudflats include sandy beaches and shallow, unvegetated sediments.

* 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).

Table 4. Aggregate DP-SIR analysis for European seas: prevalence of major drivers/pressures (A) the resultant state change (B), and expected habitat changes (C) (A and B adopted from Turner 2004)

	Atlantic Coast	Arctic	Baltic Sea	Black Sea	Caspian Sea	Medi-terranean	North Sea
<i>A. main driving pressures</i>							
climate change (CC)	+	++	+	++	++	+ (loc++)	+ (loc++)
built env expansion (BE)	+	0	++	+	-	++	+
trade, ports and related industry (P)	+	0	++	++	++	++	++
tourism (T)	+	0	++	+ (loc++)	0	++	+
fishing and aquaculture (F)	++	++	++	++	++	++	++
agriculture (A)	+	0	++	++	++	+	+
<i>B. environmental state change /impacts</i>							
sea level rise and coastal erosion (SE)	+	++	++	+	++	++	+ (loc++)
contamination (C)	+ (loc++)	+	+ (loc++)	++	++	+ (loc++)	++
eutrophication (E)	+ (loc++)	0	++	++	++	+ (loc++)	+
biodiversity and habitat loss (incl. invasive exotic impact) (B)	+	+	+ (loc++)	++	++	+ (loc++)	+ (loc++)
<i>C. expected habitat changes</i>							
cliffs, shingle beaches, kelp beds		move inland, erode (SE)	erode, coastal squeeze (SE)		erode (SE)	erode, coastal squeeze (SE)	erode, coastal squeeze (PT, BE, SE)
wetlands and dune complexes		erode (SE),	get lost (B, P, PE)	get lost (B, P, PE)		get lost (B, P, PE, T)	coastal squeeze (PT, BE, SE)
salt marsh		erode, move inland (SE)		get lost (B, P, PE)		get lost (B, P, PE, T)	coastal squeeze (PT, BE, SE)
sand-banks and mudflats		redistribute (SE)	submerge (SE)	species disappear (B, C)	species disappear (B, C)		species disappear (B, C)
seagrass beds			lower depth, area(E)	lower depth, area (E)	lower depth, area (E)	lower depth (E)	
Lagoons			more sediment anoxia (E)	incr. nutrient loading (F), more sediment anoxia (E)	Incr. nutrient loading (F), more sediment anoxia (E)	Incr. nutrient loading (F), more sediment anoxia (F, E)	
Subtidal sediments	more trawling disturbance (F), incr. nutrient loading (F)		more trawling disturbance (F)	more trawling disturb. (F), nutr loading (F), sediment anoxia (F, E)	more trawling disturb (F), incr.nutrient loading (F), sediment anoxia (F, E)	More trawling disturbance (F), incr. nutrient loading (F), more sediment anoxia (F, E)	more trawling disturbance (F)
open sea pelagic			altered plankton composition (E, F)	altered plankton composition (E)	altered plankton composition (E)	altered plankton composition (E)	

Notes: ++ = very significant; + = significant, 0 = minor to insignificant; (loc++) = locally very significant. Contamination = heavy metal accumulation, pesticides, persistent organic pollutants and their residues, oil and gas spills.

Major drivers and pressures: anthropogenic causes of coastal habitat change

Major drivers of coastal change have been summarised by Turner (2004), in an aggregate DP-SIR analysis for all European seas, setting a time horizon at 2050 (Table 4). These drivers act together in often complex synergy to lead to environmental state changes with ultimate consequences for coastal habitats. We broke down our analysis into three parts: driving pressures, environmental state changes and expected consequences for habitat change (Table 4).

Climate change, including the component due to human society, lists as a major driver that is foreseen to have major effects in the coastal zone (see also Nicholls and Klein 2004). Most drivers, however, are related to human population growth and economic expansion. 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. Increased development of the coastal zone is accompanied by reclamation increased armouring of coastal defences, and the narrowing of the zone where natural coastal processes may take place, a process identified as 'coastal squeeze'. Climate change is foreseen 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 will lead to wholesale loss of habitat for arctic mammals and the foodwebs they depend on (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 foreseen to drop greatly. Tourism is expected to notably increase along Mediterranean and Baltic coasts. 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 outside ELOISE (e.g. LIFE QUALITY, cf Read & Fernandes 2003). Agriculture is expected to intensify in the new member states of the EC and thus lead to increased nutrient loads into recipient seas (Baltic, Black Sea). Future habitat losses were foreseen to be the most detrimental in the Black Sea and Caspian Sea.

Sea level rise is foreseen 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.

Contribution of ELOISE projects to our understanding of coastal dynamics

Fund attribution has occurred largely on the basis of scientific quality (e.g. Herman et al. 2004), and hence the distribution of research effort has been unequally distributed over coastal habitats (Table 5). Most research has been devoted conspicuously to understanding the natural dynamics or anthropogenic changes in the pelagic (15 out of the 43 classified projects). Project web sites, summaries and published papers have been screened for the contribution of all these projects to our understanding of habitat

dynamics (Table 6). This table 6 lists major findings in brief statements and hence is characteristically minimal in its depiction of research effort. Still, the attempt appears worthwhile. The differential attribution of projects is also reflected in the findings that bear relevance to habitat dynamics. Most of the biogeochemical work has dealt with nutrient and/or carbon fluxes, its contribution to understanding habitat dynamics, hence, by nature must have been limited to those occurring ‘within’ habitats.

Table 5. Distribution of ELOISE research projects over coastal habitat types. The survey is based on an analysis of research objectives and published papers available from the ELOISE website database. ELOISE projects are represented by their acronym. A breakdown is attempted regarding the type of contribution made. Projects may have multiple entries, hence cross-tabulations do not add up. For each of these projects at least one key reference is presented in Annex 1.

Contribution to:	Understanding natural dynamics (fluxes, ecological processes, biogeo-chemistry)	Understanding anthropogenic state change	Indicators of habitat state change	Totals
Habitat type				
Cliffs, shingle beaches, kelp beds		EULIT	COAST-VIEW, PROTECT	3
Wetlands and dune complexes		DUNES	DUNES	1
Salt marsh		BIOGEST, EUROSAM, ISLED,	EUROSAM	3
Sand-banks and mudflats	NICE, F-ECTS, ECOFLAT, BIOCOMBE, COSA, ROBUST	BIOGEST, BIOCOMBE, ROBUST, ECOFLAT	HIMOM	8
seagrass beds	NICE, M&MS, ROBUST, PHASE	M&MS, ROBUST	M&MS	4
Lagoons	NICE, F-ECTS, ROBUST, PHASE	OAERRE, ROBUST, PHASE	DITTY, TIDE	7
Subtidal sediments	METROMED, PHASE,	MOLTEN	MOLTEN	3
Open sea pelagic	METROMED, KEYCOPS, BASIC, NTAP, DANLIM	ESCAPE, COMWEB, DOMTOX, POPCYCLING, BASIC, NTAP, DOMAINE, MOLTEN, EUROTROPH, DANLIM, METROMED, SIGNAL	ESCAPE, COMWEB, DOMTOX, EROS21	14

Note: several projects have not had a focus on a particular habitat. Often, this was because the project scale was extensive and reached at or beyond the catchment scale of a regional sea, such as occurred in POPCYCLING, EUROCAT, DANUBS. Sometimes these have been listed under the pelagic, since a model or assessment of the open water food web was involved. Other projects that did not allow a straightforward linkage 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 (2004) for reference to projects that appear to be thematic outliers.

Table 6. Contribution of ELOISE research projects to understanding coastal habitat types.

Contribution to:	Understanding natural dynamics (fluxes, ecological processes, biogeochemistry)	Understanding anthropogenic state change	Indicators of habitat state change
Habitat type			
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
Sand-banks and mudflats	zoobenthos-diatom interactions, self-organised spatial pattern, nutrient biogeochemistry, food webs	Zoobenthos species composition and numerical abundance	zoobenthos
seagrass beds	Natural seasonality in C, N, P fluxes and sequestration	Decreased colonisation depth with increased turbidity due to eutrophication	Colonisation depth
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 foodweb path lengths, increased incidence of harmful algal blooms (<i>Phaeocystis</i>), comparative analysis of European pelagic and benthic metabolism	DOC, N/P ratio, plankton composition

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 (see fx Herman et al. 2004). Also, our understanding of catchment-coast interactions has greatly improved (e.g. Behrendt et al. 2002, Lancelot et al. 2002). This has often involved the comparison of longer-term time scales, and has, for example, led to the observation that nutrient loading 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 in central and eastern Europe. Spatial scale, however, of the biogeochemical studies was often small, i.e. a few sampling sites

in a habitat, whereas that of the catchment-coast work by nature was quite large, i.e. at 100s of km of a catchment-sea complex. Management at the habitat-scale, thus, may well require both up-scaling as well as down-scaling of research findings, probably not a trivial task. 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).

Conclusions and way forward

ELOISE research has greatly increased our understanding of the biogeochemical processes in the near-coastal pelagic and its interactions with the benthos. Important physical drivers of natural dynamics have been incorporated in habitat models of benthic systems (HIMOM, ECOFLAT). 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. Poorly known complex second order interactions, however, 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 foodwebs.

Major changes in driving pressures that interact along the European coasts, such as climate change, increased urbanisation, trade and tourism, fisheries, aquaculture and agriculture, will lead to considerable changes in extent and environmental quality in coastal habitats. Different seas witness differences in strength of these societal pressures and their impacts (Table 4). Indicators required to monitor these state changes have been developed in a considerable number of ELOISE projects (Table 5). Integration of disciplines is only beginning to materialise in the last generation of ELOISE projects (DANUBS, EUROCAT). In addition, Ledoux et al. (2004) and Herman et al. (2004) have concluded that ELOISE research projects have been distributed unequally over the research themes identified in the ELOISE science plan (Cadée et al. 1994).

Several habitats, notably the pelagic of the open coastal sea, lagoons, as well as tidal mud- and sandflats have been represented quite favourably in the ELOISE research portfolio (Table 5). Hence for these we can draw on a sound knowledge base. Other European coastal habitats, such as cliffs, dunes, saltmarshes and other coastal wetlands have been studied less extensively, and thus probably are less well understood. For saltmarshes 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 within ELOISE compared to 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 to a limited extent only (fx COMWEB, EUROTROPH). 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, however, would enable firmer conclusions on state-transitions within and among habitat types.
2. *fisheries and aquaculture*. The effects of fisheries on coastal foodwebs are comparatively well-known, though data have not been collected within ELOISE. Those of 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*. Stock-taking and assessment of habitat areas covering the coastal zone of Europe has 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 stock-taking reviews requires attention and coordination between EEA, national authorities, and the coastal research community.
 4. *disciplinary integration*. Multidisciplinary assessment of interacting coastal issues with partners from natural and social sciences is developing in ELOISE only recently (see fx table 4). Here also stakeholder involvement mechanisms, the roles of government, institutional organisations, law and socio-cultural contrasts are worthwhile to be developed.

We suggest that subsequent ELOISE project clusters (a) build on achievements and tempts to cover identified gaps in content; (b) more carefully organise a mechanism that ascertains the EC-wide priority research issues to be resolved; and (c) develop a joint EU knowledge base on the dynamics of coastal habitats insofar as these are relevant for the implementation of EU environmental framework legislation vis-à-vis our notion of a sustainable provision of coastal resources and habitats to future generations of Europeans. A joint, comparative effort to assess the extent and state of European coastal habitats appears necessary. This can complement and build on existing environmental surveys such as those of the EEA (cf Ærtebjerg and Carstensen 2003).

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Annex 1. Key references for 33 ELOISE projects mentioned in Table 5 that contributed distinctly to understanding coastal habitat dynamics. Papers were taken from the ELOISE project database on <http://www2.nilu.no/eloise>. Projects that have no papers listed at this site are indicated with ‘-’.

BASIC: Gallon JR, Evans AM, Jones DA, Albertano P, Congestri R, Bergman B, Gundersen K, Orcutt KM 2002. Maximum rates of N-2 fixation and primary production are out of phase in a developing cyanobacterial bloom in the Baltic Sea. *Limnol Oceanogr* 47: 1514-1521

BIOCOMBE: -

BIOGEST: Frankignoulle M, Borges AV (2001) European continental shelf as a significant sink for atmospheric carbon dioxide *Glob Biogeochem Cycles* 15: 569-576

COASTVIEW: -

COMWEB: Olsen Y, Reinertsen H, Vadstein O, Andersen T, Gismervik I, Duarte C, Agusti S, Stibor H, Sommer U, Lignell R, Tamminen T, Lancelot C, Rousseau V, Hoell E, Sanderud KA (2001) Comparative analysis of food webs based on flow networks: effects of nutrient supply on structure and function of coastal plankton communities. *Cont Shelf Res* 21: 2043-2053

COSA: -

DANLIM: -

DITTY: -

DOMAINE: Mattsson T, Finer L, Kortelainen P, Sallantaus T (2003) Brookwater quality and background leaching from unmanaged forested catchments in Finland. *Water Air Soil Poll* 147: 275-297

DOMTOX: -

DUNES: Garcia-Mora MR, Gallego-Fernandez JB, Garcia-Novo F (2000) Plant diversity as a suitable tool for coastal dune vulnerability assessment *J Coast Res* 16: 990-995

ECOFLAT: Herman PMJ, Middelburg JJ, Heip CHR (2001) Benthic community structure and sediment processes on an intertidal flat: results from the ECOFLAT project. *Cont Shelf Res* 2:12055-2071.

EROS21: Lancelot C, Staneva J, Van Eeckhout D, Beckers JM, Stanev E (2002) Modelling the Danube-influenced north-western continental shelf of the Black Sea. II: Ecosystem response to changes in nutrient delivery by the Danube River after its damming in 1972. *Est Coast Shelf Sci* 54: 473-499.

ESCAPE: Simo R, Pedros-Alio C, Malin G, Grimalt JO (2000) Biological turnover of DMS, DMSP and DMSO in contrasting open-sea waters. *Mar Ecol-Progr Ser* 203: 1-11.

EULIT: 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.

EUROSAM: 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 *Cont Shelf Res* 21: 2167-2183.

EUROTROPH: Borges, A.V. and Frankignoulle, M (2003) Distribution of surface carbon dioxide and air-sea exchange in the English Channel and adjacent waters. *J Geophys Res –Oceans* 108 (C5): 3140.

F-ECTS: -

HIMOM: -

ISLED: Boorman LA, Hazelden J, Boorman M (2001) The effect of rates of sedimentation and tidal submersion regimes on the growth of salt marsh plants. *Cont Shelf Res* 21: 2155-2165.

KEYCOPS: Josefson AB, Forbes TL, Rosenberg R (2002) Fate of phytodetritus in marine sediments: functional importance of macrofaunal community. *Mar Ecol-Progr Ser* 230: 71-85.

METROMED: Karageorgis A, Anagnostou C, Georgopoulos D, Albuissou M (2000) Distribution of suspended particulate matter determined by in-situ observations and satellite images in the NW Aegean Sea (Greece) *Geo-Mar Lett* 20: 93-100.

M&MS: -

MOLTEN: Weckstrom K, Korhola A, Shemeikka P (2002) Physical and chemical characteristics of shallow embayments on the southern coast of Finland. *Hydrobiologia* 477: 115-127.

NICE: Sundback K, Miles A, Goransson E (2000) Nitrogen fluxes, denitrification and the role of microphytobenthos in microtidal shallow-water sediments: an annual study. *Mar Ecol-Progr Ser* 200: 59-76

NTAP: Peters F, Marrase C, Havskum H, Rassoulzadegan F, Dolan J, Alcaraz M, Gasol JM (2002) Turbulence and the microbial food web: effects on bacterial losses to predation and on community structure *J Plankton Res* 24: 321-331.

OAERRE: -

PHASE: Prins TC, Escaravage V, Wetsteyn LPMJ, Peeters JCH, Smaal AC (1999) Effects of different N- and P-loading on primary and secondary production in an experimental marine ecosystem. *Aquat Ecol* 33: 65-81

POPCYCLING: Haugen JE, Wania F, Ritter N, Schlabach M (1998) Hexachlorocyclohexanes in air in southern Norway. Temporal variation, source allocation, and temperature dependence. *Env Sci Tech* 32: 217-224 .

PROTECT:

ROBUST: De Wit R, Stal LJ, Lomstein BA, Herbert RA, van Gemerden H, Viaroli P, Cecherelli VU, Rodriguez-Valera F, Bartoli M, Giordani G, Azzoni R, Schaub B, Welsh DT, Donnelly A, Cifuentes A, Anton J, Finster K, Nielsen LB, Pedersen AGU, Neubauer AT, Colangelo MA, Heijs SK (2001) ROBUST: The ROLE of BUffering capacities in STabilising coastal lagoon ecosystems. *Cont Shelf Res* 21: 2021-2041.

SIGNAL: -

TIDE: -

Cases of coastal habitat dynamics

Two cases are presented here briefly to illustrate changes within a habitat or the transition from one habitat into another one. They are kept brief on purpose: no need for lengthy exposés. References are kept to a minimum and can be found in the main references list.

CASE 1 – interannual variability in patchiness of seagrass beds

Three of the four species of European seagrasses, *Zostera marina*, *Zostera noltii* and *Cymodocea nodosa*, cover shallow coastal sediments when water movement is not excessive and light penetrates sufficiently deep. The fourth, *Posidonia oceanica*, largely occurs in deeper Mediterranean waters, where this slow-growing long-lived species forms reefs of the decaying remnants of rhizome networks and covers wide expanses of the Mediterranean sea floor. All four species have been subject of substantial research (for example: a search on the Web of Science produced 502 papers for *Posidonia oceanica*, 140 for *Zostera noltii* and 208 *Cymodocea nodosa*). All seagrasses form ‘lawns’, meadows or beds that are partial to exclusive habitat to numerous organisms not present on sediments without such plants. Furthermore, these seagrass beds act as nutrient sinks, sediment traps and wave breakers through a number of mechanisms (e.g. Hemminga & Duarte, 2000). Areal extent and density of these seagrasses thus are important parameters for coastal management. Amongst others eutrophication has led to increased turbidity and hence reduced light availability to and depth penetration of seagrasses in many European waters but also elsewhere (cf Hemminga & Duarte, 2000). This has led to substantial reductions in areal extent, increased fragmentation as well as complete loss.

Maintenance of stands of the three shorter-lived species over longer time scales (in the order of > 10 years) depends on the successful establishment of new individual plants from seeds. Establishing seedlings, however, often fail to do so successfully outside the shelter of existing beds. Also, fragmented stands, expand more slowly and produce less seeds (Vermaat et al., 1987). All taken together, this may lead to a self-accelerating decline, probably starting when fragmentation has led to seagrass canopy covering less than 50% of the area. Frederiksen et al. (2004a, b) showed that apparently stable seagrass stands are subject to considerable interannual changes of local disappearance and recolonisation (40-60% in 7 years), particularly in sites exposed to strong water movement with a conspicuous sand bar geomorphology. In a fragmented meadow the majority of seagrass patches is often small (< 10 m², originating from a successful seedling) and has a high risk of extinction. Thus, we must conclude that such seagrass meadows depend on seedling establishment and early patch expansion as a critically sensitive phase. This phase can easily be disrupted by stochastic and predictable environmental adversity, such as ice scour, storm disturbance and high turbidity, and makes these stands susceptible to major declines. It took eelgrass (*Zostera marina*) more than 10 years to recolonise areas in Denmark that had been devoided after the wasting disease in the 1930ies. Initial, slow recolonisation from a few surviving stands occurred probably primarily from seeds.

The long-lived Mediterranean deep-water *Posidonia oceanica* is estimated to cover some 8% of the Mediterranean sea floor (Gazeau et al. 2003) and is observed to be declining widely (Marba & Duarte 1997). Because the decline occurred simultaneously at 15 sites studied along a 1000 km stretch of the Spanish coast, this decline was attributed to a global factor such as climate change and not to locally variable human interference. Superimposed on this overall decline, the authors identified human-induced decline in two sites.

Seagrass meadows have become recognised as habitats of importance. Coastal management thus needs to recognise the importance of water quality (notably light availability), hydrodynamics and sea-floor topography in their interaction with the dynamics and seasonal timing of recruitment of seedlings and establishment of new patches. Spatial extent and pattern dynamics are highly useful for a rational management-oriented monitoring. Increased patchiness or fragmentation of previously dense and homogeneous seagrass meadows should be considered as a serious indication of reduced vigour, just as decreased depth penetration. In open coastal waters where water and sediment movement is considerable, seagrass beds often are inherently heterogeneous, forming elongated bands shaped by moving sandbars.

CASE 2 – Bottom trawling and dredging as a physical disturbance

Both dredging for sand and fisheries with trawls or other means for bottom-dwelling fish and shell fish such as cockles and mussels lead to substantial physical disturbance of the sea floor. 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).

Consensus exists that over-exploitative fisheries are causing a change in the ecosystem composition of the north-east Atlantic Ocean, and the Mediterranean and Black Sea suggesting that fish stocks are being exploited at unsustainable rates (e.g. Frid et al. 2000; Trent & Nixon 2003). These changes involve communities of open water and bottom fish (e.g. Frid et al., 2000) as well as bottom invertebrates (e.g. Collie et al. 2000). For shallow and intertidal systems, extensive studies in the Netherlands' Wadden Sea (Leopold et al. 2004) largely confirm findings elsewhere: shellfish densities decline as well as those of larger polychaete infauna in favour of smaller, shorter-lived worms (cf Ferns et al. 2000). However, Leopold et al. (2004) could not find serious effects on sediment composition and had to cope with major temporal and apparently random variability. In addition, this is thought to have reduced the food availability to migrant wader birds as well as eider ducks, and hence their survival.

In short, trawling of the sea floor forms a major disturbance that affects biodiversity and foodweb composition.

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