Europe's seas are larger than its land area but most EU citizens are unaware of the nature and importance of their marine environment … or the footprint of their own economic activities on the sea.

"European Lifestyles and Marine Ecosystems" is a 15 -country €2.5 million project that, for the first time, has studied the relationship between our lifestyles and the state of the marine environment. There are "winners" and "losers" resulting from human activity; the "winners" are often nuisance species or those of low economic value.

Through a systematic and objective approach to modelling, we have examined scenarios of what the next 2-3 decades may hold for our seas. In some cases prospects are bright, but in others degradation will worsen unless we take urgent action to reduce our footprint.

ELME
European Lifestyles
Marine Ecosystems

SIXTH FRAMEWORK PROGRAMME

Marine Institute
UNIVERSITY OF PLYMOUTH

LOICZ

European Lifestyles and Marine Ecosystems

Exploring challenges for managing Europe's seas

2007

ELME
European Lifestyles
Marine Ecosystems

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Principal Investigators

L. Mee, M. Attrill: Marine Institute, University of Plymouth, UK

A. Gilbert: Institute for Environmental Studies, Vrije Universiteit, Netherlands

E. Garnacho, P. Kershaw: Centre for Environment, Fisheries and Aquaculture Science, UK

S. Knudsen: Department of Social Anthropology, University of Bergen, Norway

P. Cooper: University of Bath, UK

A. Farmer: Institute for European Environmental Policy, UK

J. Friedrich, K. Reise: Alfred Wegener Institute for Polar and Marine Research, Germany

A. Duarte: Analytical and Environment Group, University of Aveiro, Portugal

M. Zengin: Central Fisheries Research Institute - Trabzon, Turkey

S. Olenin: Coastal Research and Planning Institute, Klaipeda University, Lithuania

J. Albaiges: Consejo Superior Investigaciones Científicas, Spain

A. Trono: Department of Arts and Heritage, University of Lecce, Italy

L. Palmeri: Department of Chemical Processes Engineering, University of Padova, Italy

C. Gallastegui: Departamento de Fundamentos del Análisis Económico, University of the Basque Country, Spain

F. Wulff: Department of Systems Ecology, Stockholm University, Sweden

S. Back: Finnish Environmental Institute, Finland

J. Namiesnik: Gdansk University of Technology, Poland

N. Pirrone: Institute for Atmospheric Pollution of the Italian National Research Council, Italy

F. Pollehne: Institute for Baltic Research, Germany

M. Elliott: Institute of Estuarine and Coastal Studies, University of Hull, UK

C. Arvanitidis, C. Smith: Hellenic Centre for Marine Research, Greece

S. Moncheva: Institute of Oceanology, Bulgarian Academy of Sciences, Bulgaria

J. Weslawski: Institute of Oceanology, Polish Academy of Sciences, Poland

R. Prellezo: Instituto Tecnológico Pesquero y Alimentario, Spain

K. Hiscock: Marine Biology Association of the UK, UK

R. Mihnea: National Research Institute for Marine Research and Development, Romania

S. Bell: Nottingham Law School, UK

W. Pelczarski: Sea Fisheries Institute, Poland

Brochure design: DPC Design, University of Plymouth

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2007

Project core team

(full list of affiliated institutes on the inside back cover)

Prof Laurence Mee – Project Coordinator

Task Team coordinators:

Prof Martin Attrill and Dr Emma Jackson – Habitat change

Dr Alison Gilbert – Eutrophication

Dr Eva Garnacho and Dr Peter Kershaw – Chemical pollution

Dr Ståle Knudsen – Fisheries

Dr Philip Cooper – Social and economic drivers

Modelling team:

Dr Olivia Langmead

Dr Christopher Lowe

Abigail McQuatters-Gollop

Address for correspondence:

University of Plymouth Marine Institute

Marine and Coastal Policy Research Centre

Drake Circus

Plymouth

Devon, PL4 8AA

United Kingdom

Email: marineinstitute@plymouth.ac.uk

Report editors: Dr Olivia Langmead and Abigail McQuatters-Gollop

Assistance: Frankie Peckett and Javier Torres-Langmead

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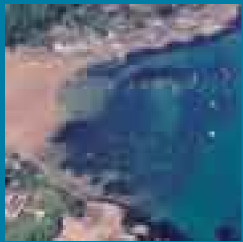

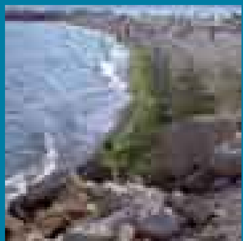

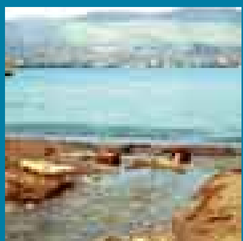

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Executive summary

Viewed from space, Europe's landmass is intertwined with the seas that virtually surround it. The area of Europe's seas exceeds that of its land and they have helped shape the history and economy of European peoples.

The past two decades have witnessed unparalleled changes in the European political and economic landscape, particularly resulting from expansion of the European Union, decline of the centrally planned Communist Bloc and pursuit of rapid economic growth. But despite numerous accounts of the declining state of the marine environment, few studies have attempted to link this situation with Europe's human lifestyles or to examine what the future may hold for the seas. The current project – European Lifestyles and Marine Ecosystems – was designed to explore this relationship.

Twenty eight institutions from 15 European countries participated in this work. We focused our studies on the four major European sea areas: the Baltic Sea, Black Sea, Mediterranean Sea and North-East Atlantic. We examined four cross-cutting environmental issues: habitat change, eutrophication (over-fertilisation of the sea), chemical pollution and fishing. For each issue and sea, we devised conceptual models linking economic and social drivers, environmental pressures and the state of the environment. As a 'proof of concept' where there were sufficient time-series data, we built innovative statistical models (Bayesian belief network simulations) and employed them to explore the consequences of a 'business-as-usual' scenario, along with four alternatives, for economic and social development in the coming 2-3 decades.

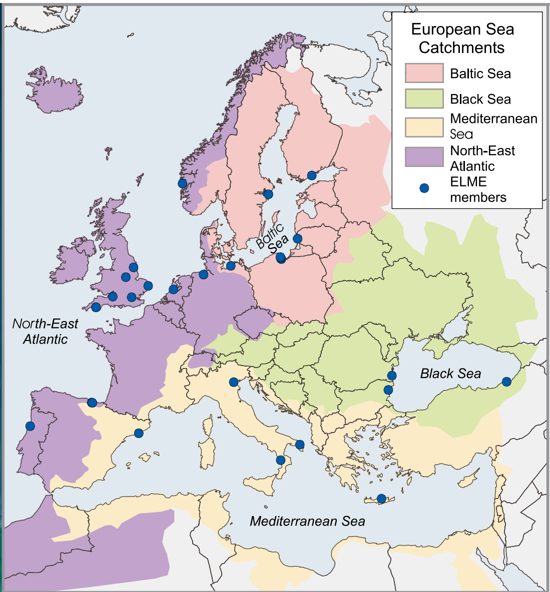
Our research has confirmed the serious state of decline of Europe's regional seas, particularly when the complex web of interactions between different human pressures is taken into account. In each sea, we identified components of the ecosystem that are 'winners' or 'losers' as a result of human activity. In almost every case the winners are either species that are low in the food chain or opportunistic, undesirable species. This situation will severely compromise future options for economic use of the sea and for the conservation of its biodiversity.

We explored the reason for these changes and the prognosis for the future. Eutrophication for example, continues to be a severe problem for the most enclosed seas (the Baltic Sea, Black Sea and the Adriatic within the Mediterranean Sea). It is partly maintained by historical phosphate and nitrogen loads (from agriculture and industrial/domestic effluent) that have accumulated in soils, aquifers and sediments and continue to leak into the sea. This may be further exacerbated by nutrient loads accompanying intensification of food production in Europe. This combination of pressures limits the scope for short-term remedial action and in the case of the Baltic Sea, short-term prospects for reducing eutrophication are particularly bleak.

The future condition of each sea is closely associated with the economic options that will be pursued in Europe, the transport of goods to and from other parts of the world and the European regulatory framework. Continued reduction of pollutants, such as chlorinated pesticides, is likely, but we are concerned about poorly monitored 'lifestyle' chemicals associated with household products. Changing economies and a more mobile labour force are likely to affect fisheries, though success or failure are currently clearly tied to the 'Total Allowable Catch' set through the Common Fisheries Policy. Our study illustrates how management of fisheries in isolation from the other environmental issues is unlikely to lead to overall sustainability.

The results of our study, summarised in the present document, examine the changing overall status of each regional sea, cross-cutting issues, emerging problems and the needs for future work. There are urgent challenges to be addressed if the concept of ecosystem-based management espoused in the draft EU Marine Strategy Directive and the Maritime Policy Green Paper is to be implemented. Our 'business-as-usual' scenario suggests that failure to take additional action to support the comprehensive assessment and management of each regional sea will result in continued degradation and loss of opportunity.

Introduction



Map of catchment locations for each European regional sea.

Europe is experiencing sweeping political and economic developments that are having profound consequences on its physical and social landscapes.

In less than twenty years, previously unimaginable changes have occurred; the Soviet Bloc disintegrated, globalisation became a reality, cyber technology spiralled and the European Union expanded to a 27 nation bloc with nearly 500 million people controlling 30% of the world economy. The EU now extends from the Atlantic seaboard to the Black Sea, from the Baltic to the Mediterranean, and large extensions of its frontiers are now in the seas that virtually surround it. Each unprecedented change exerts new pressures on the natural environment. But the same environment is expected to provide goods and services required to satisfy rising expectations of human welfare. Human lifestyles are inextricably linked to the state of natural ecosystems but these linkages are poorly understood.

In the terrestrial environment, wide public interest in negative consequences of development has triggered a relatively comprehensive suite of policies and laws designed to protect Europe's natural and built heritage. In the sea however, the changes are less visible and policies have been fragmentary and less well coordinated. European Union environmental policies largely disregard the integral nature of large marine ecosystems, focusing instead on the reduction of land-based sources of pollution (Water Framework Directive), fisheries management (Common Fisheries Policy), habitat protection (Birds and Habitats Directive) and a range of measures to limit the impact of shipping and port development. Nevertheless, a system of Regional Seas Conventions has evolved, most of which stemmed from initial concerns about marine pollution but have gradually expanded to react to other issues as they arose. In recognition of this disjointed approach to protection and the lack of a development policy for its seas, the European Commission is currently finalising a Marine Strategy Directive and a Maritime Policy (articulated in a Green Paper, currently under consultation).

Although a number of studies of Europe's seas have assessed their environmental problems, very few of these have explored the connections between the problems and their social and economic causes. Until now, there have been no systematic evaluations of potential future scenarios for the state of Europe's seas. Clearly, the future of our marine ecosystems is coupled to the welfare of the human population that surrounds them. An evaluation of the changing relationship between economic development and the state of our seas should help to develop sound policies for their sustainable use and conservation. The present project was designed as a means of filling this gap and contributing to a knowledge-based economy for Europe.

European Lifestyles and Marine Ecosystems (ELME) is a Framework Six project with the following overall objective: *Through improved understanding of the relationship between European lifestyles and the state of marine ecosystems, ELME will model the consequences of alternative scenarios for human development in post-accession Europe on the marine environment*. The project involves 28 institutions from 15 countries (see map for locations, full listing on inside back cover) encompassing a wide range of specialities in natural and social science. The basic approach of ELME is (1) to study the immediate and deeper economic and social causes of key problems on a catchment-wide scale, (2) to examine how social and economic drivers will change as a consequence of EU enlargement and other large scale policy processes, and (3) to model the likely consequences to the marine environment of a number of plausible scenarios for European development in the next 2-3 decades.

The present document summarises the key findings of this project. It discusses the methodology we have developed and presents regional conceptual models and analyses of a range of plausible future trends for key environmental issues. It then examines the findings for a number of cross-cutting issues that are closely related to human lifestyles and will require Europe-wide policy solutions.

ELME has been a challenging study employing innovative research strategies and modelling methods. Although we have collated a vast amount of information and are confident in our findings, this is not intended to be a comprehensive and exhaustive assessment but a 'proof of concept' that will contribute towards the 'joined-up' systems thinking needed to identify and surmount future challenges for sustainable development in Europe's marine environment. We will also be presenting detailed information on our findings through scientific papers in the forthcoming months.

The ELME Consortium is pleased to contribute to the sustainability debate in Europe and looks forward to comments and questions on its findings.

Approach and Methodology

ELME uses a multidisciplinary approach integrating relevant information on 1) current major state changes affecting Europe's marine ecosystems in four major sea areas (map opposite); 2) pressures on the environment producing these changes; 3) social and economic drivers leading to these pressures; and 4) plausible scenarios for social and economic change across Europe during the next 2-3 decades.

Spatial scales were set necessarily broad; investigations were framed at regional and sub-regional scales (specifically not at local level). An initial scoping study assigned the degree of impact of each environmental problem for each study region (table 1). High priority combinations were modelled in depth, but other combinations were explored during the course of the project. Results of these issue-based simulations formed the basis for regional seas models as the key environmental problems were brought together to constitute a region by region perspective.

The most plausible options for regional social and economic development were studied (see Scenarios) and applied to the models. By manipulating these models, it was possible to explore the major consequences of future alternative development scenarios on marine ecosystems.

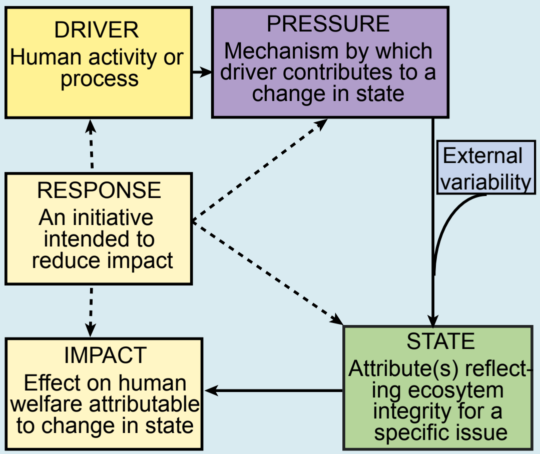
	Habitat loss	Eutrophication	Pollution	Unsustainable Fisheries
NE Atlantic	3	3	◇5	◇5
Baltic	2	◇5	4	4
Black Sea	4	◇5	2	4
Mediterranean	◇5	2	2	4

Priority: 5 = highest, 1 = lowest

◇ selected for module 1

Table 1. Initial scoping study of the degree of impact of specific issues in each of the study regions.

The DPSIR (Driver-Pressure-State-Impact-Response) framework was adopted to organise information relating to each environmental issue. Although various forms of this framework have been employed in previous studies, it was necessary to establish for ELME a single set of definitions for the DPSIR components. Informal versions of these definitions are shown right.



- **Drivers** – human activities that precipitate pressures on the natural environment
- **Pressures** – the manner through which drivers act upon states
- **States** – measures of ecosystem integrity
- **Impacts** – measures of human welfare (including indirect effects such as the knowledge that a particular species is endangered)
- **Responses** – effects of impacts on other DPSIR components through policy response

For example, fertiliser use (a driver) results in nutrient loading (a pressure) that may lead to eutrophication (a state). However, eutrophication (a state) may also act as a pressure on other state indicators (e.g. seagrass habitat).

Modelling approach

ELME uses stochastic techniques to model coupled socio-ecological systems, explicitly mapping impacts of socio-economic drivers on the marine environment. Specifically, Bayesian belief networks were used as they have two distinct advantages over mechanistic modelling: 1) They do not require specific understanding of the complex systems linking two variables as they calculate the likelihood of change in state of one variable given the state of another based solely on probabilities. 2) They can perform calculations where no data is available based on the opinion of specialists. The modelling method is outlined below:

- **Conceptual model** Groups of experts identified pressures (and their sectoral drivers) that can impact the thematic issue addressed. The pathways through which these could influence each other were laid out in a conceptual model. Prioritisation of key pathways was carried out to simplify models.
- **Populating the model** Time-series data were identified and provided (sources varied from meta-analyses to model-derived data); threshold values within data were identified either through consultation or analysis of the data. Variables where no data were available were assigned values generated via expert opinion.
- **The baseline prediction** The probable state of driving variables in 2025 was modelled as a 'business-as-usual' scenario (see Scenarios); this was used as the baseline for the other scenarios. Simulations were run by setting the value of each driver variable into this baseline state, and output was recorded as change in 'downstream' variables, ultimately resulting in changes in environmental states. Four alternative scenarios were run alongside the baseline scenario, and similarly applied to simulations as changes to the driver variables.

The Lifestyle Perspective

Understanding the pressures on marine ecosystems through economic drivers is a vital part of defining appropriate policy responses but it is equally necessary in this process to identify the underlying forces that motivate and shape the development of these drivers.

At the level of society as a whole, the size of the population and available technology each contribute to the nature and extent of the activities that make up the drivers. However, an important additional perspective comes from tracing economic drivers to their source in individual lifestyle - the choices a person makes as consumer or citizen within the constraints of their wealth, the available technology and the legal system.

The links between lifestyle, economic drivers and environmental change are illustrated in fig. 1. Within this representation, individuals' values are manifested in their lifestyle choices. As consumers, individuals make choices that directly result in pressures on the environment (e.g. removal of beach materials or organisms from the tidal zone as souvenirs or for personal collections) and, more often, others that are satisfied through production activities (e.g. coastal development to meet tourist and local recreational demand). While, as citizens, public political choices are made which could either enhance or diminish the environmental consequences of human activity.

Insofar as their values have dictated the desire for increasing personal consumption, rises in personal wealth and technological development have enabled Europeans to consume more and enjoy more choice over a range of goods and services. For example, in the case of food, choice has increased both in the availability of relatively cheap meat and in the range of exotic and non-seasonal fruits and vegetables. However, these benefits come at a cost to marine ecosystems that is not generally transparent to the consumer. Examples can be classified according to some key areas of lifestyle:

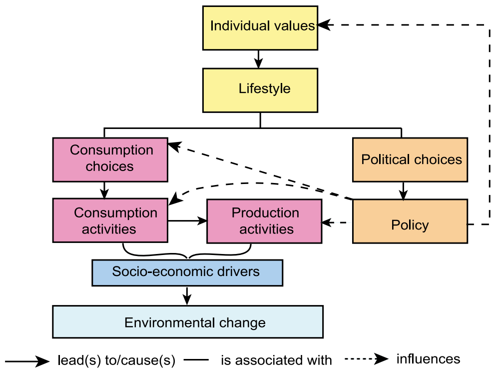


Fig. 1 The links between lifestyle and environmental change.

The home – Smaller household sizes with a stable or growing population mean more housing development. This can be a particularly acute issue in the coastal zone given the desire to live close to the sea and the capacity for greater distances between the home and the workplace, supported by increasing personal mobility and advances in telecommunications. Growing household numbers also have implications for increased energy consumption and water use.

Leisure – The attractiveness of coastal locations for recreation and leisure activities combined with the availability of relatively cheap transport, particularly international flights, enhance the demand for development in coastal zones. Marine-based leisure activities such as boating and diving have also become increasingly accessible.

Food – The demand for more animal protein in the diet that accompanies increasing wealth has wide-ranging consequences. Increasing consumption of meat is not only associated with more intensive rearing of livestock but also with use of fertilisers to produce feed crops, both leading to nutrient inputs to the aquatic environment, while continuing high levels of demand for fish, both for consumption and as feed for farmed species, directly affect stock levels. Furthermore, meeting the demand for exotic and non-seasonal fruit and vegetables relies on extensive transport networks.

Other goods and services – Globalisation has increased consumption opportunities in other markets besides those for food. Most notably, the demand for imported manufactured goods has been supported by relatively cheap labour in remote locations such as the Far East. Although this has accordingly shifted the environmental consequences of manufacturing to those locations, the need for transportation has risen and the waste-stream remains in Europe.

These examples only sketch the links between lifestyle and marine ecosystems. Production activities in certain sectors may have a number of environmental consequences. For example, in the transport sector, combustion of fossil fuels in all types of transport yields emissions that can damage the marine environment while growth in maritime transport also has direct effects such as creating demand for coastal development. This is to say nothing of the complex interactions that arise between sectors, such as transport and energy, which exacerbate the environmental effects of consumption choices.

The political choices that also manifest European lifestyles evidence some willingness by individuals to have their consumption choices tempered by environmental concerns. However, there is a challenge to policy making in defining where a democratically acceptable balance can be struck. By highlighting the fundamental role of lifestyle choices, this perspective identifies critical areas for future policy action, such as supporting better informed consumption decisions and designing economic instruments to directly influence those decisions.

Scenarios

Scenarios are essentially pictures or representations of potential future conditions.

They can provide a general overview, describing possible alternative states of the world, and be used to highlight differences in particular features of interest that result, but their usefulness does not depend on predicting the future, even if the assumed conditions materialised.

The ELME scenarios represent a synthesis of well-established precedents – primarily studies carried out by SRES, ACACIA, UKCIP, and AFMEC – since no individual study could meet all the needs of this project. This approach enabled the scenarios to be addressed at the geographical and temporal scales, and for issues, relevant to ELME while ensuring some consistency with these studies and thus supporting comparison of marine ecosystem effects with other environmental issues. However, the opportunity was taken to modify the precedents where it was thought that they could be more robust or realistic. Thus, the ELME scenarios (see fig. 2) are defined along two dimensions comparable to those employed in other studies but the communitarian scenarios in ELME are not necessarily represented as leading to or being driven by environmental improvement.

Fig. 2. The ELME scenarios.

The Baseline scenario depicts future trends based upon what we know now and expectations from a variety of sources, and is described relative to the present. The four alternative scenarios arising from the combinations of the scenario dimensions are then described relative to the Baseline. The title and slogan attached to the each alternative scenario are intended to capture the most distinctive features of each scenario.

At the heart of each of the alternative scenarios is a description of the underlying values and policies that define it, and their broad socio-economic implications, which are summarised below.

From these characterisations, narrative descriptions of changes in basic socio-economic variables (underlying drivers) and activity in driver sectors were developed for each scenario at a broad EU level. These were translated into a simple categorical (-/0/+) representation to indicate direction of change, for example, in the case of the driver sectors (right).

DRIVER SECTOR	Baseline	National Enterprise	Local Responsibility	World Markets	Global Community
	*	**			
Agricultural production	+	+	+	-	0/-
Energy: production [consumption	-[+	+[-	+[--	-[+	-[-
Fisheries production [capture effort	+[0	0[0/-	--[-	0[+	-[0
Household consumption	++	-	--	0	0/-
Industry	+	+	+	0	0
Tourism	++	-	--	0/+	-
Transport - terrestrial	+	-	--	++	0/+
- maritime	+	-	--	+	0/+
- air	+	-	--	+	-
Coastal development	+	+	-	0	-

*compared to present
**compared to Baseline (except regional differentiation)

National Enterprise
Values & Policy – Individualistic, high personal consumption, low taxes, market-based, but strong commitment to national culture and interests. Little concern for social equity or environmental protection. Sovereignty retained or taken back to national level, eroding EU status.
Economy – Priority of growth undermined by protectionist policies. Focus on meeting internal demand and security of supply. Trade diminished within EU but not as much as extra-EU. Considerable variation in regional development.

Local Responsibility
Values & Policy – Communitarian, co-operative self-reliance. High levels of public services funded by high local taxation. Strong emphasis on social equity and environmental protection at the local level. Local governance dominates other levels. EU becomes more diverse with regional autonomy and fragmented policy.
Economy – Slow growth, with increases in smaller scale production. Trade greatly diminished, but with some preference for intra-EU over external trade. Growth more even across communities.

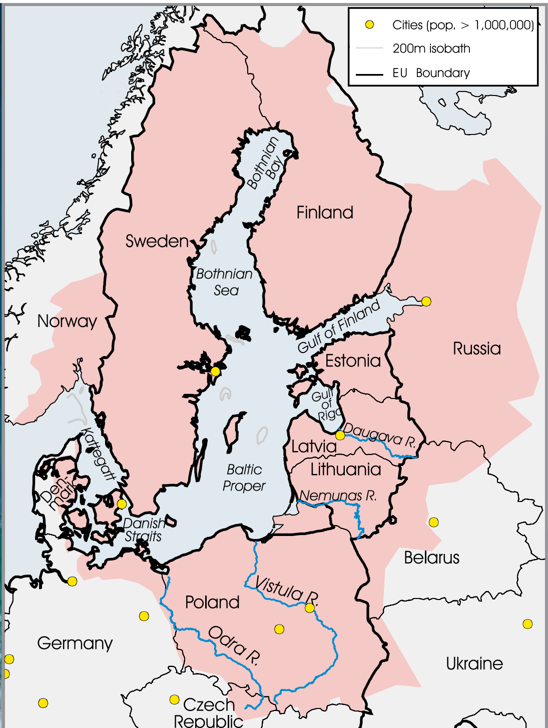
World Markets
Values & Policy – Libertarian, techno-centric, materialist consumerism. Presumption in favour of market provision. Growth more important than social equity, with environmental policy limited to correction/support of the market. Increased global interdependence and governance. Policy determined at trading bloc/international level.
Economy – Rapid growth, with dismantling of trade barriers increasing intra- and extra-EU trade. Service sector dominates others, with relative decline in agriculture and manufacturing.

Global Community
Values & Policy – Communitarian, with internationalist values and increasing globalisation of governance systems. Balancing of economic, social and environmental welfare, with preference for latter and willingness to accept high tax levels. Policy coordinated at EU and international level, but implemented at local level.
Economy – Growth constrained by social and environmental objectives. Growth in intra- and extra-EU trade, but with some inhibition through 'footprint' concerns. Development more evenly distributed.

In order to operationalise the scenarios for the purposes of the project, in particular modelling, the outcomes from the scenarios are defined in terms of a similar categorical representation of the direction of change in the immediate driver indicators. In this process, recognition was given to policy and technological developments that might decouple drivers from pressures so that historically observed relationships would not hold within the respective scenarios.

These EU-aggregate scenarios formed the basis for establishing variants for each regional sea.

Baltic Sea



Catchment map of the Baltic Sea.

The Baltic Sea is better seen as a large estuary where North Sea water and land drainage mix.

Near freshwater conditions can be found in the Bothnian Bay. Salinities increase through the Bothnian Sea, Baltic Proper and Danish Straits to reach near marine conditions in the Kattegatt. Freshwater input exceeds seawater input. Freshwater floats over the denser seawater, forming a sharp, vertical density gradient (pycnocline) between a less saline upper layer and a high saline deeper layer. Vertical mixing is constrained by the pycnocline. Lateral mixing is constrained because pycnoclines are deeper than the sills at basin entrances.

Sedimentation and remineralisation of algal blooms consume oxygen and so variable redox conditions occur in deep waters. However the occurrence of hypoxia (low oxygen) is determined less by eutrophication and more by meteorological conditions that drive saltwater inflow and determine the position of pycnoclines. During periods of major saltwater inflows, density gradients become stronger and the pycnoclines shift upwards. Oxygen consumption in the bottom waters leads to the spread of hypoxia and to massive release of phosphorus (P) and less efficient removal of nitrogen (N). Between periods of major inflows, the Baltic Sea becomes fresher and the increasingly fresh, upper mixed layer depresses the pycnocline. The area exposed to hypoxia contracts, improving conditions for benthic organisms as well as efficiently sequestering P and removing N.

The drainage basin of the Baltic Sea can be divided into a northern boreal part that drains into the Bothnian Bay and Bothnian Sea, and a southeastern part that drains into the rest of the Baltic. The northern watersheds are lowly populated and covered predominantly by forest and wetlands. River loads of nutrients and contaminants from human activities are generally low. The watersheds of the southeast are dominated by agriculture. The largest nutrient loads come from the Odra and Vistula rivers, draining Poland and its 40 million inhabitants, about half of the population of the entire Baltic Sea catchment. Industries also discharge into rivers and coasts, although much is being abated.

In contrast to the north-south division of the watersheds based on natural settings and landscape, an east-west distinction can be made for socio-political characteristics. Most riparian countries are now members of the European Union. Socio-economic disruption with the breakdown of communism in the early 1990s was expected to reduce nutrient fluxes to the Baltic, largely because fertiliser use and livestock densities decreased dramatically. Unfortunately, there has been little evidence of declining river loads.

Fishing has been a traditional activity in the Baltic Sea. Current levels of fishing for the most commercially important species are unsustainable. Stocks are declining due to overexploitation and environmental degradation. Eutrophication, which exacerbates the adverse effects of climate-driven hypoxia, is a key source of degradation.

Economic recovery and future development can be expected to change lifestyles and to affect anthropogenic pressures on the Baltic Sea. Trends in nutrient loads will, hopefully, reflect policies to improve waste water treatment and increase use of phosphorus-free detergents. However the 'wild card' for eutrophication is industrialisation of the agricultural sector, being fostered by a west-to-east shift in intensive livestock rearing. Accession of five former Eastern Bloc countries to the EU has increased use of Common Fisheries Policy (CFP) funds to further reduce fishing effort, mainly targeted on cod stocks, which may serve to rebuild those stocks.

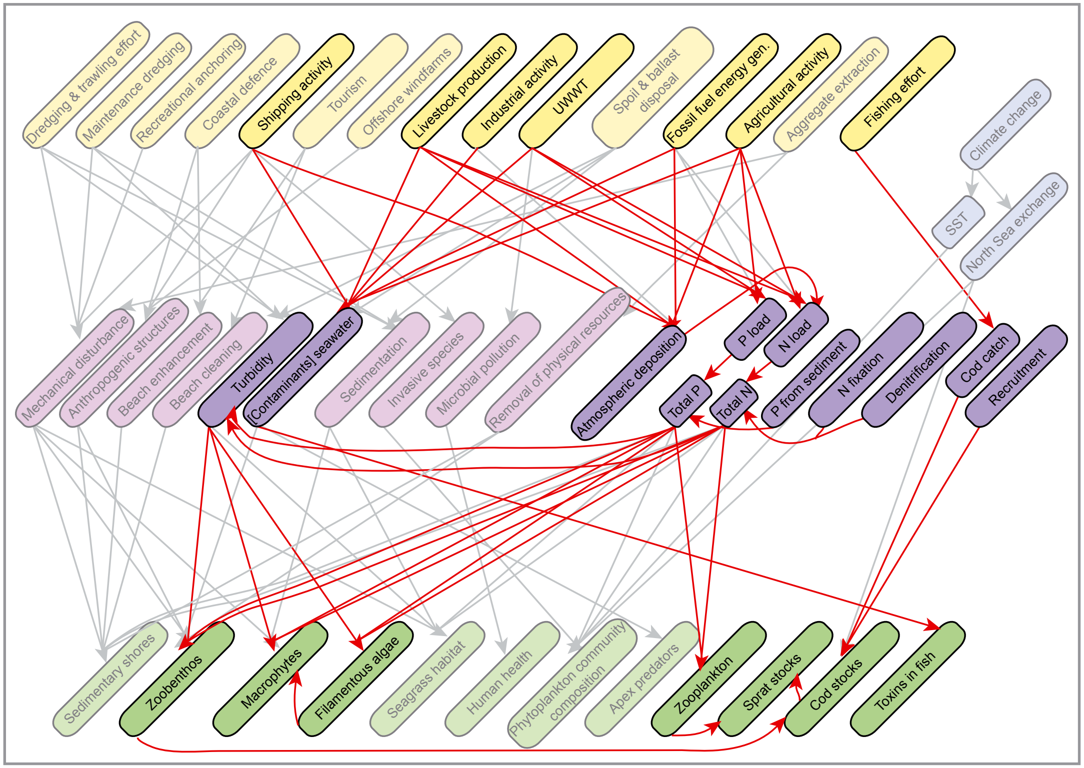
Baltic Sea simulation model

The Baltic Sea is hydrographically composed of distinct basins (see map opposite). The conceptual model presented here (fig. 3) is not representative of the whole sea, but specifically represents the Baltic Proper, a region for which comprehensive data are available. Macroalgae data from the Gulf of Finland were used because equivalent data from the Baltic Proper were not available; these two basins differ in their hydrology and ecology, and therefore the macroalgal pathway must be considered tentative.

The original conceptual model (fig. 3) was reduced based on data availability, importance of variables and pathways, and relevance to ELME. The resultant simulation model was constructed with an emphasis on eutrophication, the problem identified as the primary concern for the Baltic Sea (table 1). Fisheries and chemical pollution were included as issues of secondary importance; these components were simplified from the in depth issue-focused models (see following page).

Drivers: Variables were merged into a single proxy variable where one dataset representing multiple drivers existed (e.g. oil and chemical spills and discharge of toxins were replaced with the variable 'industrial activity'). Other elements present in the conceptual model (such as aggregate extraction and coastal urbanisation) were removed from the populated model due to insufficient data.

Pressures: Because eutrophication is the priority issue in the Baltic Sea, the simulation model focuses on nutrient-related pressures which drive changes in the eutrophication influenced state variables. Turbidity is used as a measure of eutrophication (adequate data on cyanobacteria were not available) as well as a pressure which regulates light available to macrophytes. Chemical pollution and fish recruitment were included because they act as pressures on aspects of fish health (e.g. toxicity, food supply).



States: Cod (*Gadus morhua*, a large demersal fish), sprat (*Sprattus sprattus*, a small planktivorous fish) and zooplankton biomass were included to illustrate changes in pelagic community structure and therefore have implications for trophic interactions. Benthic indicators (filamentous algae presence, zoobenthos biomass, and macrophyte depth limit) are similar measures of benthic ecosystem health. The level of chemical contamination in fish stocks is an indicator of fish health, but also has human health implications.

Fig. 3 Baltic Sea conceptual model with the simulation model embedded within it (red arrows show pathways between variables included in the simulation model, while grey arrows indicate where linkages were made conceptually but were not included). Yellow indicates anthropogenic driver variables; blue indicates exogenous climatic driver variables; purple indicates pressures, while green indicates ecological state variables.

Baltic Sea

Cod case study

Cod (*Gadus morhua*) is the most important species for both offshore and coastal commercial fisheries in the Baltic Sea. Of the five main commercial fish species in the Baltic, only cod stocks are in a precarious state. This is due to heavy exploitation (including high unreported catch) and insufficient recruitment caused by the long-term unfavourable environmental conditions for the reproduction of this species.

The cod model (fig. 4) shows the importance of economic and human activities for the management of the cod fishery in the Baltic. These activities result in the regulation of fishing effort through two methods, fishing effort undertaken (consisting of number of vessels and days at sea) and Total Allowable Catch (TAC) legislation. These factors, of which TAC is the most influential, determine the number of cod landings. The number of landings is the primary factor influencing the cod state variables (cod length, spawning stock biomass (SSB), and recruitment). However, interactions do exist between other Baltic fishery stocks and cod landings and recruitment.

The Baseline scenario shows a decrease in fishing effort through reduced fleet capacity, although TAC remains the same. This reduced fishing effort results in a reduction in the catch of cod, and consequently the average length of the cod stock and SSB increase. Sprat (*Sprattus sprattus*), another commercially important species, shows a decline in stock due to competition with, and predation by cod. Under both the National Enterprise and Local Responsibility scenarios TAC is increased, while the capacity of the fishing fleet is reduced. Because TAC is more influential than fleet capacity, these scenarios result in unsustainable levels of exploitation of cod and so declines in cod stocks and size occur.

The World Markets scenario shows an increase in TAC combined with an increase in capacity of the fishing fleet. This results in large scale overexploitation and collapse of cod stocks. In this scenario sprat stocks increase, so an expansion in this fishery may occur.

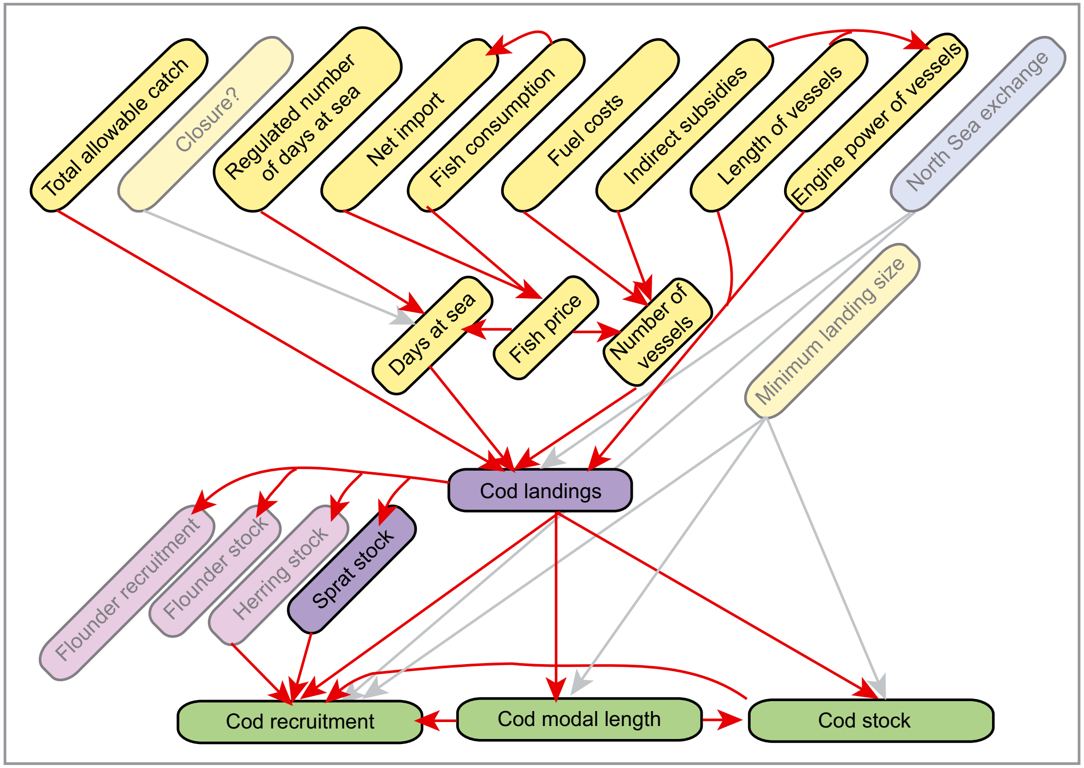


Fig. 4 Conceptual model of cod (*Gadus morhua*) in the Baltic Sea with the simulation model embedded within it (colours follow those used in the regional model).

The Global Community scenario, which resembles the Baseline scenario, shows a strong recovery in cod stock and size due to reduced TAC and fishing capacity. Sprat stocks are reduced through the large increase in population of cod, as in the Baseline scenario.

Pesticides case study

Pesticide contamination is one of the most important marine chemical pollution issues affecting the Baltic Sea. Pesticides are transported from municipal, agricultural, and industrial sources. The amount of pesticides applied is particularly high in the southern Baltic which is surrounded by a large proportion of arable land. Because of the Baltic's estuarine character, pesticides such as Dichloro-Diphenyl-Trichloroethane (DDT) persist in waters despite bans or restrictions on their usage. These persistent contaminants are a particular concern due to their bioaccumulative behaviour, which results in greater concentrations of contaminants in higher trophic levels (such as birds and fish).

Few datasets measuring pesticide contamination of Baltic water, sediments, and biota exist and available datasets contain large spatial and temporal gaps. To overcome these data limitations, the simulation model was populated almost exclusively through expert opinion.

The model (fig. 5) illustrates the introduction of pesticides to the water column through agriculture, industrial activity and the re-suspension of historical pesticides from the sediment through disturbances created by shipping activity. Pesticides are taken up from the water column by biota. Simulations show that in the Baseline scenario, although pesticide application to farmland remains constant and shipping increases, a decline in industrial discharges results in an overall decrease in pesticide concentrations in the environment and therefore in biota. All other scenarios, except National Enterprise, result in a further decrease in pesticide concentration in the Baltic ecosystem. National Enterprise however, shows that although industrial discharges and shipping activity remain as today, pesticide use and its consequent discharge into the environment is increased, resulting in elevated concentrations of these contaminants in the environment.

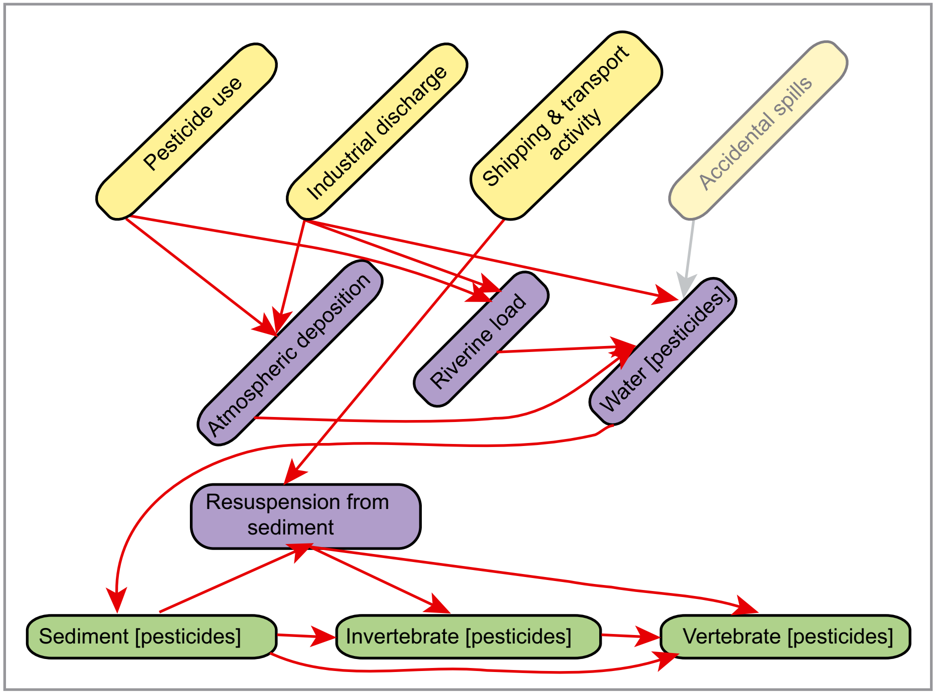


Fig. 5 Conceptual model of pesticides in the Baltic Sea with the simulation model embedded within it (colours follow those used in the regional model).

Open pesticide tomb near Skorzewo (Northern Poland), empty glass containers of pesticides are clearly visible

Baltic Sea

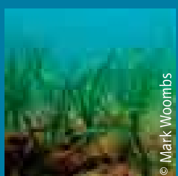
Winners

Filamentous algae and cyanobacteria profit from greater nutrient availability

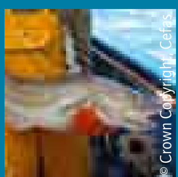
Zoobenthos, such as the blue mussel, is abundant in coastal areas where flushing redistributes organic matter and prevents the development of hypoxia

Sprat are less sensitive than cod to hypoxia, and subjected to lesser fishing pressure

Losers



The maximum depth where eelgrass and bladder wrack can be found declines as they are shaded by increased algal growth



Cod stocks are threatened as a result of complex interactions between natural, climate-driven variability, which can be exacerbated by eutrophication and overfishing

Key results and interpretation

Modern lifestyles have increased pressures on the naturally variable Baltic Sea environment. Agriculture, industry, limited waste water treatment, fossil fuel combustion and fishing have caused ecosystem deterioration. Nutrients, particularly phosphorus, are accumulating and exacerbate hypoxia from climate-driven stagnation. Fishing pressure compounds the effects of natural variability on recruitment. Shifts in competitive balances are occurring that favour undesirable species.

Of the four themes in ELME, eutrophication is the most pressing for the Baltic Sea. Eutrophication stimulates algal growth, and generally benefits pelagic over benthic ecosystems. For the Baltic, this means that cyanobacteria in open waters and filamentous algae in coastal waters flourish. Macrophytes in coastal zones lose out to algae through shading.

The Baltic Sea, unlike the other European regional seas, suffers from cyanobacterial blooms, a phenomenon more typical of eutrophic freshwater environments. Two of the quantitatively most important species, *Aphanizomenon flos-aquae* and *Nodularia spumigena*, form successive blooms between May and October in the open Baltic Proper. These species are 'diazotrophic', able to circumvent nitrogen limitation by fixing atmospheric N. They outcompete other algae under conditions of high dissolved phosphorus availability relative to nitrogen, which occur when vertical mixing returns dissolved phosphorus in hypoxic bottom waters to the surface. This reflux of phosphorus can exceed anthropogenic loads by a factor of three. The specifics of this P-pump are not yet well understood and the simulations have included it only indirectly. Effects on other parts of the pelagic food web are also still largely unknown. Concerns have been raised about shifts in phytoplankton composition due to changes in relative nutrient availability, and subsequent effects on zooplankton.

The occurrence of drifting algal mats as a result of eutrophication is increasingly reported. Dense growths of unattached filamentous algae, such as *Pilayella littoralis, Sphacelaria* sp., *Dictyosiphon tortilis*, *Ectocarpus siliculosus* and *Enteromorpha* spp., have been identified covering both hard substratum and sediments in shallow water (<15 m). Algal mats adversely affect benthos by fostering hypoxia and causing development of hydrogen sulphide in sediments. The depth limit of eelgrass (*Zostera marina*) and bladder wrack (*Fucus vesiculosus*) has declined due to shading from pelagic algal growth (fig. 6).

For benthic communities, the increased rain of organic matter has different effects depending on the prevalence and persistence of hypoxia. The area affected by hypoxia during long stagnation periods has increased from about 10,000 km^2 in the early 20^{th} century, to about 40,000 km^2 today; the increase seems attributable to anthropogenic eutrophication. However, hypoxia in the deep Baltic is primarily caused by climatic events, eutrophication merely exacerbates it. Deep basins are benthic deserts. At the basin fringes, zoobenthos profit from the rain of organic matter under moderate eutrophication and good flushing but succumb to persistent hypoxia under extreme eutrophication and poor flushing. In coastal zones where seawater mixing redistributes organic matter and hypoxia does not occur, zoobenthos biomass has increased during modern times.

Fish stocks show a general trend towards declining cod and increasing sprat. Cod lay eggs in deeper, saltier water than sprat, and so are more vulnerable to hypoxia. The two species have different food preferences, with the abundance of prey species related to climatic conditions. Sprat also prey on cod larvae, and so the two stocks are interdependent. Recruitment is highly variable as a result of complex interactions between climate and fishing pressure. Eutrophication aggravates adverse environmental conditions caused by climate.

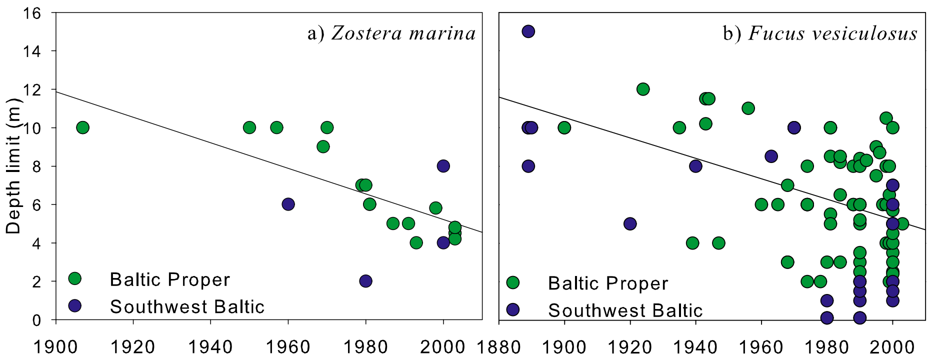


Fig. 6 Long-term trends in depth limit of (a) eelgrass (*Zostera marina*) and (b) bladder wrack (*Fucus vesiculosus*). Note that the trend for *Fucus* is less clear, possibly suggesting a more complex response to eutrophication such as competition with filamentous algae.

There are considerable data on the Baltic Sea. Unfortunately, data and understanding of the most crucial determinant of environmental quality – climate-driven hypoxia – is limited. This factor could not be included in the simulations. Outcomes may indicate improvements that, under favourable climatic conditions, are feasible but could easily be overridden by adverse climatic conditions.

The Baseline scenario is based on the most probable future lifestyle for the region (see right). The outcome suggests that policy measures can succeed in reducing fishing pressure and anthropogenic loads of nutrients and contaminants. Nutrient loads decline despite anticipated increases in intensive livestock and transport activity. However subsequent improvements in the state of the Baltic Sea are limited. Cod stocks and contaminant levels in fish show improvements. Eutrophication indicators do not, presumably because phosphorus is accumulating and is being kept biologically available.

The future success of policy measures to restore ecological states in the Baltic Sea must be considered highly doubtful. Firstly, it will be severely constrained by the overpowering influence of the natural environment. Secondly, extreme measures are needed to reduce anthropogenic sources of nutrients even further than past policy has achieved. Thirdly, because past anthropogenic loads of nutrients have been locked into sediments and catchments, even stringent measures may not overcome this system 'memory'.

The outcomes for the more extreme scenarios indicate that Local Responsibility provides the best option for improving environmental conditions in the Baltic Sea. This scenario reduces or stabilises key drivers behind the deteriorating environment. Cod stocks however do not recover under this scenario due to the lack of cohesive protection between countries to protect the fishery. Global Community shares amelioration of eutrophication symptoms with Local Responsibility through reduced loads of nutrients. However both outcomes should be considered somewhat optimistic given that the simulations do not include climate-driven natural variability. Global community sees a more regionally-based, holistic management of the cod fishery resulting in increases in cod stocks, partly at the expense of sprat stocks.

World Markets, with lifestyles fuelling greater transport activity and intensive livestock production, achieves the least improvement in environmental conditions. Lack of fishing regulation results in the continued collapse of cod stocks. Sprat stocks increase due to lack of predation from cod and increased food in the form of plankton. Fishing pressure increases under National Enterprise so cod stocks decline, while eutrophication increases as a result of increased and intensified agricultural activities.

Scenario outcomes

Outcomes of the Baseline scenario and four alternative scenarios from the Baltic Sea simulation model are shown below. The driver component determines the conditions that forced the simulation for each scenario, while pressures and states are the responses to these combinations of drivers. Arrows indicate the direction of changes relative to the current situation.

↑ Large increase
↗ Increase
→ Stable
↘ Decrease
↓ Large decrease

		Current Trend	Baseline Scenario	Scenarios (relative to current)			
				National Enterprise	Local Responsibility	World Markets	Global Community
DRIVERS	Industrial discharge	→	↘	→	↓	↓	↓
	Fishing effort	↗	↘	↗	↗	↑	↓
	UWWT	↘	↘	→	↘	→	↘
	Agricultural activity	→	→	↗	↘	↗	→
	Fossil fuel en. gen.	↘	↘	→	↓	→	↓
	Shipping activity	↗	↗	→	→	↑	↗
	Livestock prod.	↗	↗	↗	→	↑	↗
PRESSURES	P Load	↗	↘	↗	↓	↗	↓
	N Load	→	↘	↗	↓	↗	↓
	Total P	↗	↗	↑	↑	↑	↑
	Total N	→	↘	↗	↓	↗	↓
	Atmos. N depos.	→	↘	↗	↓	↗	↓
	P from sediment	↗	↗	↑	↗	↑	↗
	N fixation	→	↗	↑	↑	↑	↑
	Turbidity	↗	↘	→	↘	↗	↘
	Recruitment	↘	↘	↗	↗	↓	↘
	[Contam.] seawater	↗	↘	↗	↓	↗	↓
STATES	Zoobenthos	→	↘	↗	↗	↗	↓
	Zooplankton	→	↘	↓	↓	↗	↓
	Macrophytes	↘	↘	↘	↑	↘	↑
	Filament. algae	↗	↗	↑	↑	↑	↑
	Cod stocks	↘	↗	↘	↘	↓	↗
	Sprat stocks	↗	↘	↗	↗	↑	↓
	Toxins in fish	↗	↘	↗	↓	↗	↓

Black Sea

Catchment map of the Black Sea.

Coastal defence at Mamaia, Romania

Fishermen at Varna, Bulgaria

The Black Sea is a semi-enclosed brackish sea with significant annual water temperature oscillations and a permanent 'dead' anoxic zone below 200 m depth.

Except in the northwest, the continental shelf generally does not extend more than a few kilometres from the coast. The shallow northwestern shelf receives input from the Danube and Dnieper rivers which transport water from much of Europe and Russia. The Black Sea drains a catchment area containing large proportions of 15 countries, covering a land area of 2,000,000 km^2, and receiving waste water from more than 100 million people.

Saltwater balance is maintained through the regular inflow of highly saline water through the Bosporus Strait. Compared to other European seas, the Black Sea has a low number of species but high organic production which supports large stocks of pelagic fish species such as anchovy (*Engraulis encrasicolus*), sprat (*Sprattus sprattus*, *Clupeonella clutriventris*) and bonito (*Sarda sarda*).

During recent decades anthropogenic activities have dramatically impacted the Black Sea ecosystem. High levels of riverine nutrient input during the 1970s and 1980s caused eutrophic conditions including intense algal blooms resulting in hypoxia and the subsequent collapse of benthic habitats on the northwestern shelf. Intense fishing pressure also depleted stocks of apex predators contributing to an increase in small planktivorous fish which are now the focus of fishing efforts. In addition to eutrophication and overfishing, the Black Sea's ecosystem changed even further with the introductions of the comb jelly *Mnemiopsis leidyi* and the sea snail *Rapana venosa*. *Mnemiopsis* outcompeted small fish while also preying on their larvae and eggs, thereby further altering the structure of the pelagic food web; *Rapana* destroyed mussel communities, but has also become an important target species for Black Sea fisheries. Since the collapse of the Soviet Union, the Black Sea has in some respects begun to recover. The economic decline of the surrounding socialist republics resulted in the decrease in nutrient loading which allowed the pelagic and benthic ecosystems to start to return to their previous states. However, recovery has been non-linear, with different species dominating the benthic and pelagic realms.

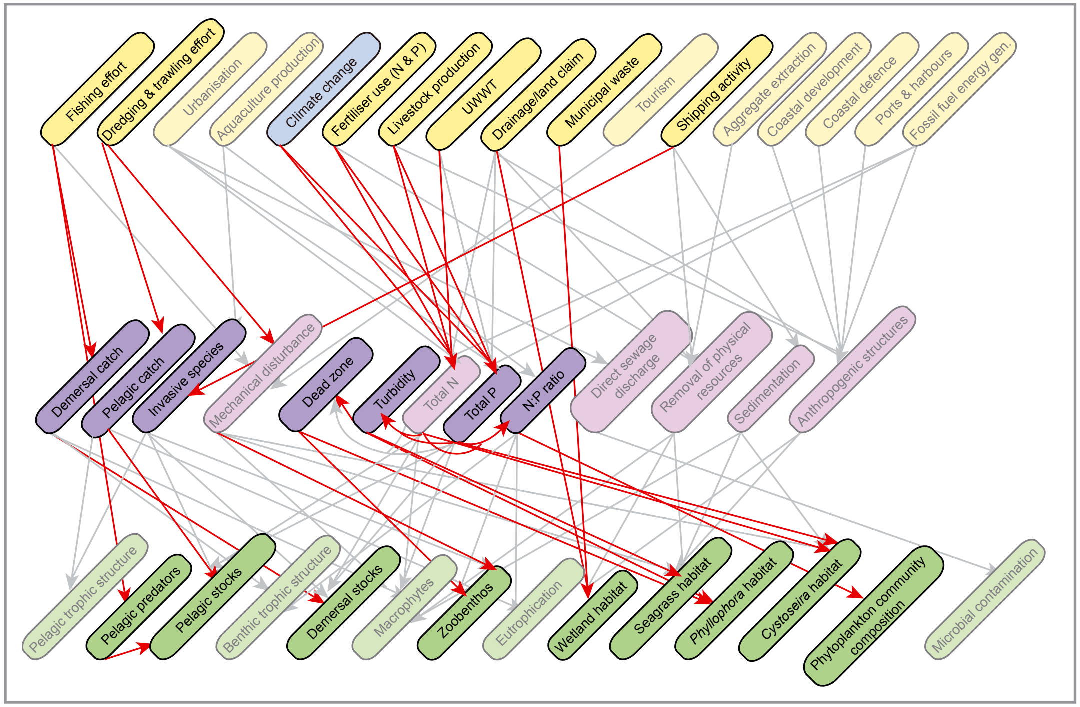
Since the disintegration of the Soviet Union the Black Sea region has experienced increased trade accompanied by complex and shifting politics, including issues created by the development of new nations and the control of oil and gas pipelines. The Black Sea is also experiencing increased shipping traffic, and with the economies of the previous communist states now in a period of expansion and growth, industries such as tourism, urbanisation and infrastructure development are again increasing pressure on the Black Sea coastal zone. Few international agreements regulating activities and resource use in the Black Sea exist. However, with the recent addition of Bulgaria and Romania to the EU and membership negotiations with Turkey underway, the Black Sea is now of interest to the EU, a position creating both new challenges and opportunities for the management of this volatile sea.

Black Sea simulation model

The Black Sea model is based on the northwestern shelf, with key variables relating to nutrients, turbidity and phytoplankton coming from the Romanian coast. Fisheries data, however, are for the entire sea.

Drivers: The number of driver variables in the conceptual model was reduced for the simulation model (fig. 7). This was because either: 1) they were considered to be subordinate (e.g. aggregate extraction, aquaculture and fossil fuel energy generation), or 2) no indicators and/or time-series datasets could be identified (e.g. coastal defence, port and harbour development, coastal development and urbanisation). For some variables, proxy data were used (fishing capacity (gross tonnage of fleet) was used as a proxy for fishing effort and dredging and trawling effort, and total agricultural area (in Romania) was used as a proxy for drainage/land claim, but this was only considered a good indicator up until 1989). Finally, in the absence of better information, quantity of municipal waste dumped was assumed to be a function of amount generated.

Pressures: Some pressure variables were removed (such as mechanical disturbance) and driver variables were connected directly to ecological state variables as no regionally representative indicator data were available. A time-series of the frequency of introductions by date introduced was used as an indicator of invasive species (see Invasive species box). Turbot (*Scophthalmus maximus*) landings represents demersal catch while anchovy (*Engraulis encrasicolus*) and sprat (*Clupeonella cultriventris, Sprattus sprattus*) landings represent pelagic catch. Data on the area of hypoxia were used to populate the formation of the dead zone variable. Turbidity (Secchi depth) and nutrient data were from Romanian waters, although total nitrogen was removed as data were unreliable. The nitrogen-related drivers (fertiliser use, livestock production) were connected directly to the state variables (turbidity, nutrient ratio).



States: Anchovy and sprat spawning stock biomasses (SSB) represent pelagic stocks, and turbot SSB represents demersal stocks. The pelagic predator variable is comprised of mackerel (*Scomber scombrus*), bonito (*Sarda sarda*), and bluefish (*Pomatomus saltator*) biomass. Expert opinion was gathered to populate variables for loss of wetland, seagrass and *Cystoseira* (brown macroalgae) habitat as there are no comprehensive time-series data available. Metadata analyses were used to populate *Phyllophora* (red macroalgae) habitat and zoobenthos; indicators were spatial extent and mussel biomass respectively. Phytoplankton community composition was indicated by % diatoms and 'other' phytoplankton (not diatoms or dinoflagellates) at Constanta, Romania.

Fig. 7 Black Sea conceptual model with the simulation model embedded within it (red arrows show pathways between variables included in the simulation model, while grey arrows indicate where linkages were made conceptually but were not included). Yellow indicates anthropogenic driver variables; blue indicates exogenous climatic driver variables; purple indicates pressures, while green indicates ecological state variables.

Black Sea

Invasive species

Shipping traffic through the Bosporus Strait

The introduction of non-native species to the Black Sea is a critical and escalating issue (fig. 8). Heavy anthropogenic stresses such as nutrient loading and overfishing have increased the susceptibility of the Black Sea ecosystem to species invasions. The most extreme example of an invasive species prospering in the Black Sea occurred with the accidental introduction of the comb jelly, *Mnemioposis leidyi*, in the late 1980s. *Mnemiopsis* outcompeted small fish and consumed their eggs and larvae, thereby reducing the abundance of small fish as a food source for higher trophic levels and dramatically disturbing the pelagic food web. *Mnemiopis* had no natural enemies until another gelatinous species, *Beroe ovata*, was introduced in 1997, which decreased the biomass of *Mnemiopsis* significantly.

Rapana venosa prey on smaller native mussel species

Rapana venosa, a non-native species of sea snail, was accidentally introduced to the Black Sea in the late 1940s. *Rapana* have few natural predators in the Black Sea and its excessive predation on native mussel stocks has lead to their disappearance in some regions. Interestingly, *Rapana* have also become an important commercial species in the Black Sea and are now fished throughout coastal waters. A similar situation occurred with the grey mullet, *Mugil soiuy*, which was released into the neighbouring Sea of Azov as a fishery species. *Mugil* migrated to the Black Sea where it now replaces several depleted native species as a commercial target.

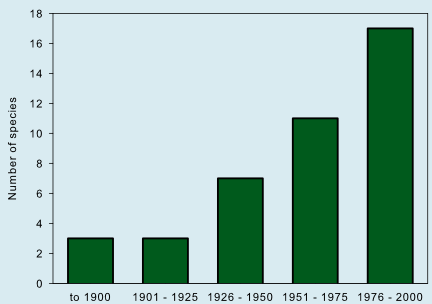


Fig. 8 Trend in introduction of alien species to the Black Sea (after EEA 2002).

Adaptive fisheries case study, Samsun, Turkey

During the last 30 years there has been an inflow of impoverished workers into fisheries in the province of Samsun, Turkey. Samsun's fisheries have expanded due to harbour construction, state subsidies, poor enforcement of fishing regulations, high consumer demand and the fact that fishers are allowed to switch liberally between different kinds of gear and fishing locations. The uncontrolled growth of Samsun's fisheries has resulted in the decline of fish stocks (such as turbot, whiting and mullet) and the economic and ecological unsustainability of the fishery. However, the accidental introduction and establishment of the sea snail *Rapana venosa* (see Invasive species box) resulted in a new period of fishery expansion during the 2000s as the fishery adapted to exploit this new target. Fishers now frequently alternate between fishing for demersal and pelagic fish stocks and dredging for *Rapana*. Unfortunately, this practice is harmful to the ecosystem and demersal fisheries as *Rapana* are illegally dredged during summer when trawl and dredge fisheries are closed for stock replenishment. *Rapana* are not consumed locally (unlike demersal fish species landed at Samsun). Landings are processed and exported to the Far East, an example of globalisation in fisheries. Unlike most EU fisheries, Samsun's fisheries continue to expand. Uniquely, Samsun offers a fishing 'frontier' for the poor; few regulations are in place and little capital is needed to enter the fishery.

Vessels from the fleet at Samsun, Turkey, with bags of *Rapana venosa* in foreground

Rapana venosa being processed onshore prior to export

Samsun's fisheries offer opportunities for impoverished workers

Key results and interpretation

The Black Sea environment has been subjected to the pressures of modern lifestyles; in the past these have caused catastrophic collapses in ecological systems. This ecosystem stress is primarily a result of agricultural activity, but limited waste water treatment, fishing and shipping have also contributed. Eutrophication of the northwestern shelf of the Black Sea is the result of nutrient enrichment, largely from the Danube and other incoming rivers, but aggravated by the loss of nutrient-retaining wetland habitats. Fishing pressure has caused trophic cascades in pelagic systems and damaged benthic habitats. Invasive species now occupy key niches in many Black Sea communities.

Eutrophication is the most pressing of the four ELME themes in the Black Sea. Nutrients from land-based sources stimulate algal growth and generally benefit pelagic over benthic ecosystems. Symptoms of eutrophication spread over the northwest shelf during the 1970s. Pelagic production increased and changes were observed in phytoplankton and zooplankton communities. Impacts on higher trophic levels may have occurred, but were confounded by overfishing and invasion by species such as the comb jelly, *Mnemopsis leidyi* (see Invasive species box). Enhanced phytoplankton productivity resulted in reduced light penetration to Zernov's *Phyllophora* field, an assemblage of the red alga *Phyllophora nervosa* attached to bivalves such as *Mytilus galloprovincialis* and *Modiolus phaseolinus*. Deposition of organic matter from the enriched water column then created extended periods of hypoxia, resulting in the loss of more than 5000 km² of bivalves and drastically reducing biofiltration (fig. 9).

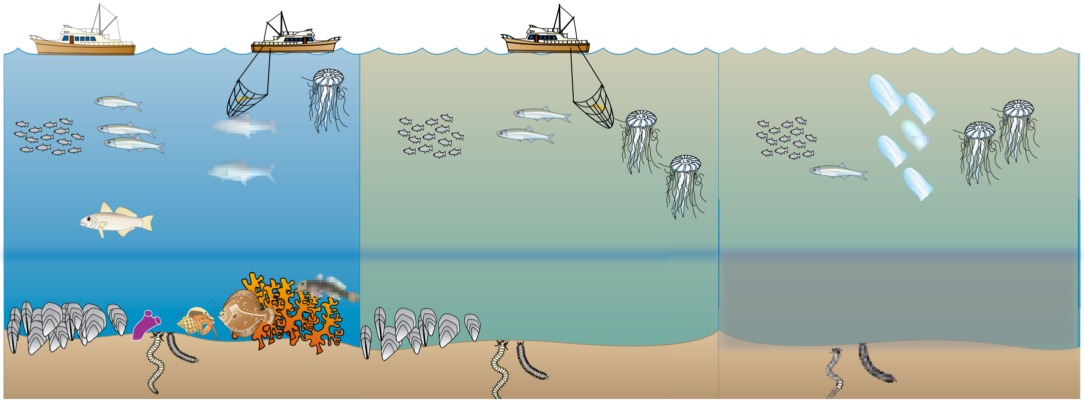


Fig. 10 Schematic diagram of eutrophication and its effects on benthic and pelagic habitats of the northwestern Black Sea shelf. Three stages are represented: pre-eutrophication (pre-1970s), eutrophication (1970s-80s) and severe eutrophication compounded by hypoxia (1990s).

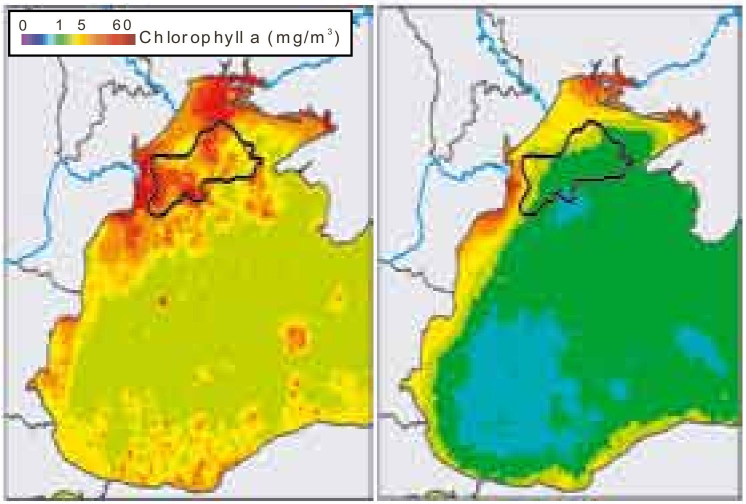


Fig. 9 Maximum extent of Zernov's *Phyllophora* field prior to eutrophication superimposed over phytoplankton productivity (chlorophyll concentration) on the northwestern shelf of the Black Sea in July 1979 (left) and July 2002 (right).

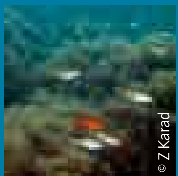
These two phases resulted from exceeding two thresholds of resilience in the benthic system (fig. 10, also see p. 43). After the collapse of centrally planned economies in Eastern Europe in the early 1990s, the ecosystem began to respond to the decrease in anthropogenic pressures. Nutrient loads declined which led to clear signs of improved environmental quality, such as fewer hypoxic events and re-establishment of benthic communities, although not necessarily with the original species.

Coastal communities such as wetland, seagrass and *Cystoseira* habitats have also declined over the last three decades. Large areas of the Danube Delta were reclaimed; losses were concurrent with government subsidies to enhance agriculture. Expert opinion gathered for this project estimated that nearly half of the total wetland area present in 1960 has been lost since. This has implications for nutrient and sediment retention and contributes to coastal erosion. Seagrass (*Zostera marina* and *Zostera noltii*) and *Cystoseira* beds, like all benthic communities in coastal Black Sea waters, have suffered from eutrophication. This has led to catastrophic losses of *Cystoseria*, <1 % of the reference level (1960) in Romanian and Ukrainian waters remains. Localised losses of seagrass habitat have also

Black Sea

Winners

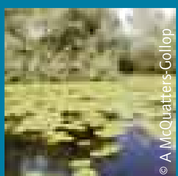
Invasive species such as the comb jelly, *Mnemiopsis*, have changed the Black Sea food web



Eutrophic conditions provide ample food for small planktivorous fish like anchovy and sprat

Losers

Overfishing has removed many large predatory fish, such as mackerel, bluefish and swordfish from the Black Sea



Over 2.5 million hectares of Black Sea wetlands have been lost due to agricultural land claim and coastal development

Winner or loser?

Phyllophora habitat has been severely impacted by eutrophication, but regulation of nutrients may allow recovery

occurred due to coastal construction causing increased turbidity and direct exploitation (for animal feed and fertiliser).

Black Sea fisheries have experienced drastic changes since the 1970s, including continued increase of fishing effort and the redistribution of fishing capacity from ex-Soviet nations to Turkey. Many species have effectively disappeared from catches in the Black Sea (such as tuna, *Thunnus thynnus*; swordfish, *Xiphias gladius*; and mackerel, *Scomber scombrus*). Stocks of small pelagic species such as sprat (*Sprattus sprattus* and *Clupeonella cultriventris*) and anchovy (*Engraulis encrasicolus*) have been more resilient and form the basis for an industrial fishery. In the southern Black Sea, bonito (*Sarda sarda*) and bluefish (*Pomatomus saltatrix*) stocks collapsed but have since undergone recovery. Demersal fisheries have

Bivalves (*Mytilus galloprovincialis* and *Modiolus phaseolinus*) create a highly diverse habitat

expanded as the target has changed from fish stocks such as the almost depleted turbot (*Scophthalmus maximus*), mullet (*Muglidiae*) and whiting (*Merlangius merlangus*) to the invasive sea snail *Rapana venosa* (see Invasive species box). This is a unique case of a fisheries expansion where most are declining and has led to concurrent social changes (e.g. influx of new fishers to the sector) in fishing communities such as Samsun on the Turkish Black Sea coast (see Samsun case study).

Under the Baseline scenario the exploitation of environmental resources (fishing, shipping and agriculture) increases due to the continued economic development of post-Soviet countries. However this effect is partially ameliorated by an increase in infrastructure development, represented here by the proportion of the population connected to secondary and tertiary urban waste water treatment. These changes in infrastructure and resource exploitation also result in the degradation and loss of wetlands through drainage, reclamation, and by smothering with municipal waste. Nutrient loads from sewage decrease, but increased nitrogenous fertiliser usage and growth in intensive livestock farming result in an overall increase in nitrogen (but not phosphorus) entering the Black Sea. Phytoplankton utilise the excess nitrogen to bloom thereby increasing turbidity; light is then unable to reach macroalgal (*Cystoseira, Phyllophora*) and seagrass beds, and these subsequently die. The decomposition of these benthic plants results in lowered oxygen concentrations and a hypoxic dead zone forms killing flora and fauna associated with these habitats. Ecological pressure from these factors along with increased fishing activity also results in the stocks of target species becoming further depleted.

Under the National Enterprise scenario, increased exploitation of natural resources places further pressure on the environment. Increased nutrients result in a further increase in turbidity, larger hypoxic areas and greater degradation of benthic plants. Again, increased pressure from fishing effort along with damage to fish nursery habitats result in the collapse of fish stocks. The World Markets scenario suggests greater movement of materials through the region, strengthening the influence of transportation on the ecosystem. For example, the increase in shipping activity increases the likelihood of introduction of invasive species to the Black Sea through ballast water. Again, natural

Municipal waste dumping in wetlands causes habitat degradation

stocks do not decrease further although recovery is not expected.

Despite some alleviation of eutrophication symptoms, three questions remain: 1) What impact will further loss of nutrient-retaining wetlands have on eutrophication? 2) To what degree have benthic communities recovered with recent alleviation of anthropogenic pressure? 3) Will original habitats return, or will communities be dominated by opportunistic/invasive species? The answers to these questions are tied to the economic recovery of the region, and in the case of Romania and Bulgaria, accession to the EU. This regional harmonisation provides the opportunity to regulate future nutrient loads which may allow recovery of the northwestern shelf ecosystem to its pre-eutrophic state.

resources are heavily exploited to meet demand of materials for trade; this results in increased nutrient concentrations, increase in hypoxic area and subsequent loss of benthic plant habitats. Although fishing effort increases, it is at a lower rate than under National Enterprise due to increased fish imports; however fish stocks again decline. Both Local Responsibility and Global Community show expected environmental use to be similar to the present but with improved waste water treatment. These scenarios simulate a slight increase in status of benthic plant habitats resulting from a reduction in hypoxic area. As fishing effort remains constant relative to the current situation,

Dead fish washed ashore in Romania following a hypoxic event in July 2001

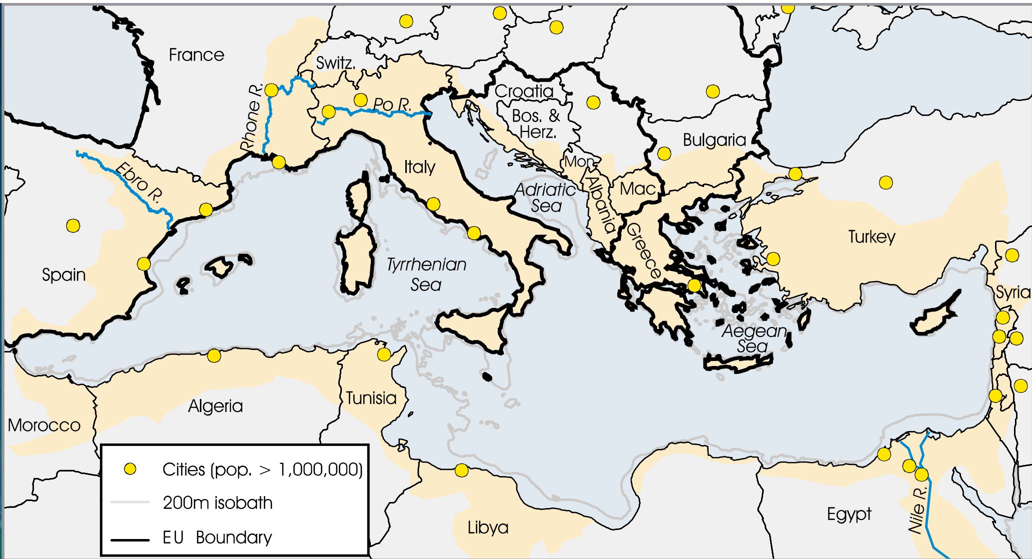
Scenario outcomes

Outcomes of the Baseline scenario and four alternative scenarios from the Black Sea simulation model are shown below. The driver component determines the conditions that forced the simulation for each scenario, while pressures and states are the responses to these combinations of drivers. Arrows indicate the direction of changes relative to the current situation.

- ↑ Large increase
- ↗ Increase
- → Stable
- ↘ Decrease
- ↓ Large decrease

		Current Trend	Baseline Scenario	Scenarios (relative to current): National Enterprise	Local Responsibility	World Markets	Global Community
DRIVERS	Dredge & trawl effort	↘	↗	↑	→	↗	→
	Shipping activity	↗	↗	→	→	↑	↗
	Fishing effort	↘	↗	↑	→	↗	→
	Drainage/land claim	↗	↗	→	→	↑	→
	Municipal waste	↘	→	↗	↘	→	↘
	Livestock prod.	↘	↗	↗	→	↑	↗
	N fertiliser use	→	↗	↑	→	↗	→
	P fertiliser use	↘	→	↗	↘	→	↘
	UWWT	↗	↗	→	↗	→	↗
PRESSURES	Total P	↘	→	↗	↓	↗	↓
	Turbidity	↗	↗	↑	↘	↑	↘
	Dead zone	↘	↗	↑	↘	↗	↘
	N:P ratio	↗	→	↘	↗	↘	↗
	Invasive species	↗	↗	→	→	↑	↗
	Demersal catch	↘	↘	↓	→	↘	→
	Pelagic catch	→	↘	↓	→	↘	→
STATES	*Cystoseira* hab.	↗	↘	↓	↗	↗	→
	Seagrass hab.	↗	↘	↓	↗	↓	↗
	Phyllophora hab.	↘	→	↘	↗	→	↗
	Pelagic predators	↘	↘	↓	→	↘	→
	Pelagic stocks	↘	↘	↓	→	↘	→
	Wetlands hab.	→	↘	↓	↗	↓	↗
	Demersal stocks	↘	↘	↓	→	↘	→
	Zoobenthos	↘	↘	↓	↗	↘	↗
	Phytopl. com. comp.	↘	→	↗	↘	↗	↓

Mediterranean Sea



Catchment map of the Mediterranean Sea.

The Mediterranean region is traditionally recognized as a crossroads of marine routes, biota and civilizations. As a semi-enclosed sea, restricted communication with the open ocean is a major factor affecting its sedimentary dynamics, physical oceanography and nutrient regime.

Four major rivers drain into the sea (the Po, the Rhone, the Ebro and the Nile) with a combined catchment of over 3.5 million km^2, carrying substantial amounts of agricultural and industrial wastes. Although the Mediterranean is the most oligotrophic of Europe's regional seas, coastal eutrophication is a growing problem.

The Mediterranean Sea is an international biodiversity hotspot with many unique species and natural resources. EU Mediterranean fishery catches have decreased since the mid 1990s, coincident with a decline in catches of top predators (e.g. tuna, *Thunnus thynnus*, and swordfish, *Xiphias gladius*) and an increase in catches of small pelagic fish and molluscs. This suggests the occurrence of trophic changes, probably as a response to both fisheries exploitation and coastal eutrophication. Resource management and conservation in the Mediterranean is particularly challenging due to its distinctive political and geographic boundaries. The northern Mediterranean rim is mainly comprised of EU countries while the remainder of the Mediterranean is surrounded by non-EU nations, both African and European. Successful management of the marine ecosystem therefore relies on pan-Mediterranean coalitions, e.g. the Barcelona Convention, Euro-Mediterranean Partnership (EMP) and the General Fisheries Commission of the Mediterranean (GFCM).

Tourism is a major industry in the Mediterranean. Each summer the population of coastal areas increases by 30% due to the large influx of international tourists; numbers are expected to double over the next 20 years. This growth in tourism is increasing pressure on waste water treatment facilities, and demand for coastal development and transportation, and is resulting in sedimentary beach degradation.

Improvements in urban waste water treatment are leading to declines in domestic water consumption and nutrient discharges in EU Mediterranean countries; however, the situation is very different in the remaining Mediterranean states. Increasing coastal populations and inadequate sewage networks have resulted in increased point source pollution and localised coastal eutrophication events in non-EU areas. Treatment of waste water for many emerging lifestyle chemicals (e.g. flame retardants, antimicrobials and surfactants) remains inadequate across the Mediterranean.

Chemical and petrochemical industries, metallurgy, waste treatment plants, paper mills, and tanneries are all significant sources of pollution. Considerable division occurs between the EU and non-EU Mediterranean countries in terms of industrial development (the latter show a faster rate). Industrial contamination within the region reflects the aforementioned sectors (e.g. PAHs, heavy metals) but toxic and biocumulative chemicals such as tributyltin (TBT) are also a problem. The use of TBT, a biocide in antifouling paints, is now restricted; however its persistence in the system is an example of the lasting impact of the Mediterranean shipping sector on habitat and species loss.

Mediterranean Sea simulation model

The Mediterranean model is based on the northwestern region of the sea since most data for driver variables originate from EU states (Spain, France, Italy and Greece). However, fisheries landings and habitat data are for the entire Mediterranean marine ecosystem.

Drivers: The number of driver variables in the conceptual model was reduced for the simulation model (fig. 11). This was because they were either considered to be subordinate (e.g. commercial anchoring, fossil fuel energy generation, land reclamation, ship oil/ballast disposal, aggregate extraction, discharge of contaminants and road transport), or because no indicators and/or time-series datasets could be identified although their importance was recognised (e.g. coastal defence and seawall/marina development). Some variables were not possible to quantify directly and proxies were used (e.g. tourist arrivals were used as a proxy for tourism which encompassed a range of activities including beach cleaning, regeneration and use of temporary structures, such as beach furniture). Similarly, fishing capacity (gross tonnage of fleet) was used as a proxy for fishing effort. Times-series data for urbanisation (% urbanised area in the coastal zone) was almost absent and had to be interpolated from three data points (1975, 1990 and 2000).

Pressures: Data were not available for the majority of pressure variables (aside from fish catch). This meant that pathways in the simulation model connected driver variables directly with environmental state variables. Contaminants within the model were restricted to PAHs, but this pathway was later removed as the relationship identified conceptually was not supported by data, indicating decoupling (see PAH pollution box). Conceptually, nutrients are a key pressure in many pathways through the model, but no comprehensive nutrient data exist. To overcome this problem, driver variables were connected directly to the state variable coastal eutrophication, which was populated with a metadata analysis frequency distribution of eutrophication events. Demersal catch is landings of hake (*Merluccius merluccius*), bogue (*Boops boops*) and mullet (*Mullus* spp.), small pelagic catch is sardine (*Sardina pilchardus*), anchovy (*Engraulis encrasicolus*) and *Sardinella* spp. and large pelagic catch is bluefin tuna (*Thunnus thynnus*), bonito (*Sarda sarda*) and swordfish (*Xiphias gladius*).

States: Seagrass meadows and sedimentary shores were selected to represent coastal habitats. Other habitats were also considered important but could not be included due to the lack of time-series data (maerl reef, deep water coral reef and submarine sediment habitats). Fish stock data (e.g. spawning stock biomass or recruitment) are available for very few Mediterranean species, so the Fishing-in-Balance index

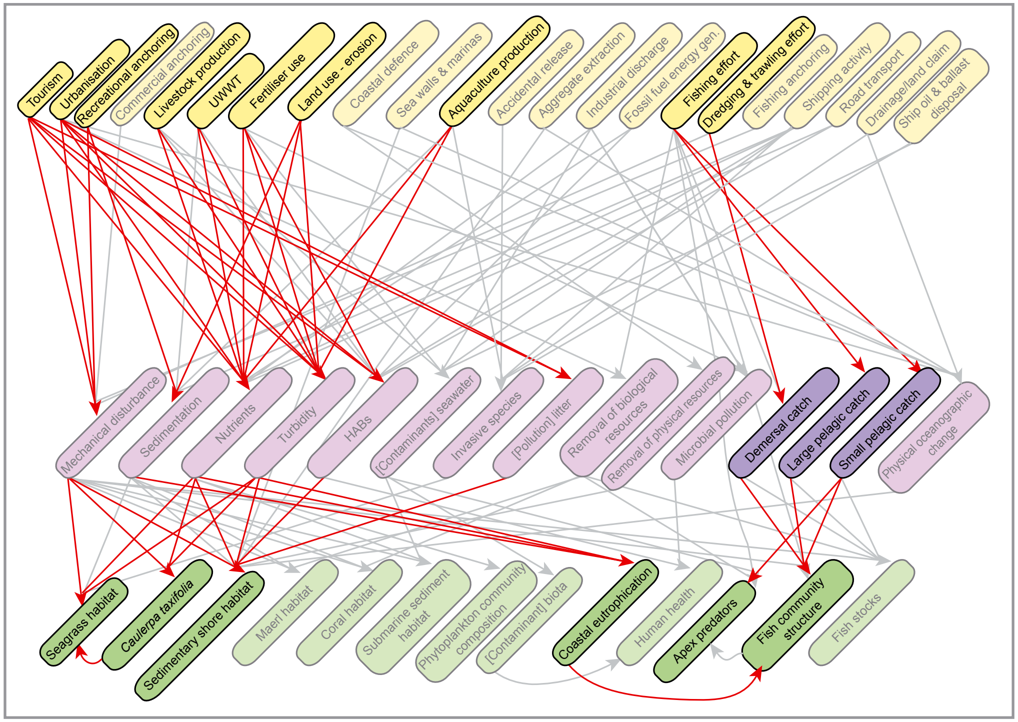


Fig. 11 Mediterranean Sea conceptual model with the simulation model embedded within it (red arrows show pathways between variables included in the simulation model, while grey arrows indicate where linkages were made conceptually but were not included). Yellow indicates anthropogenic driver variables; blue indicates exogenous climatic driver variables; purple indicates pressures, while green indicates ecological state variables.

(FiB) was used as an indicator of catch-compensated fish community composition. Dolphin (*Delphinus delphinus*) stranding frequency (as a % of total cetacean strandings) was used as an indicator for apex predators. Effects of contaminants on biota or human health were not included for reasons outlined above.

Mediterranean Sea

Northern Adriatic case study

Although relatively nutrient poor, eutrophication hotspots are found throughout the Mediterranean Sea (see fig. 30, p. 42). Primary production is phosphorous-limited with productivity generally increasing from west to east. An analysis of published literature indicates that eutrophication is worsening (fig. 12). This is mostly attributed to inadequate sewage networks and a rapid increase in population growth in non-EU regions. Although the Nile drains the largest catchment, the Aswan High Dam prevents large quantities of water (and therefore nutrients) from entering the Mediterranean, which has resulted in the eastern African coast becoming one of the most nutrient deficient areas. In contrast, the northern Adriatic, a shallow, semi-enclosed basin, is one of the most eutrophic areas, receiving a third of all freshwater discharge entering the Mediterranean. The northern Adriatic region is intensely affected by anthropogenic activities; the Po River alone drains water from a 71,000 km^2 catchment containing 16 million inhabitants.

Increased nutrient discharge to the northern Adriatic during the 1970s led to eutrophication-induced algal blooms and hypoxia. During the 1980s, riverine P-loads decreased as a result of banning phosphorus in detergents and improved waste water treatment. Because the northern Adriatic is phosphorus-limited, the reduction in phosphorus inputs significantly reduced the occurrence of eutrophic events. However, agriculture-related N-loads continue to rise and, as a result of this decoupling, the ratio of nitrogen to phosphorus is also increasing.

The model simulation (fig. 13) suggests that eutrophication is likely to decrease in the northern Adriatic under the Baseline, Local Responsibility, and Global Community scenarios and increase under the scenarios that include increased anthropogenic pressure (National Enterprise and World Markets). Although the model simulation adequately explains expected trends in the state variables, simulations are less certain when applied to pressures. Because the model was highly simplified in order to be adequately populated, some important processes that could help to better explain the variability of nutrient loads and concentrations were excluded (such as nutrient release from the sediments).

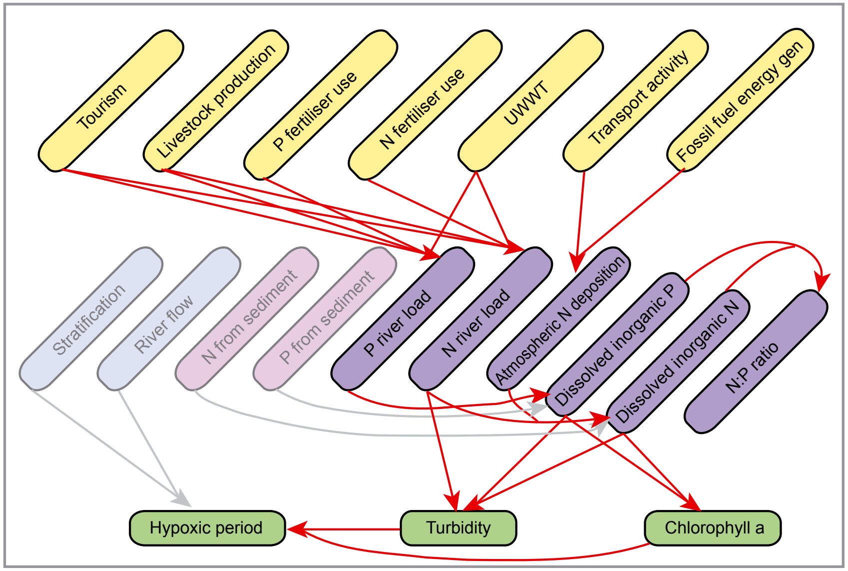


Fig. 13 Conceptual model of the northern Adriatic with the simulation model embedded within it (colours follow those used in the regional model).

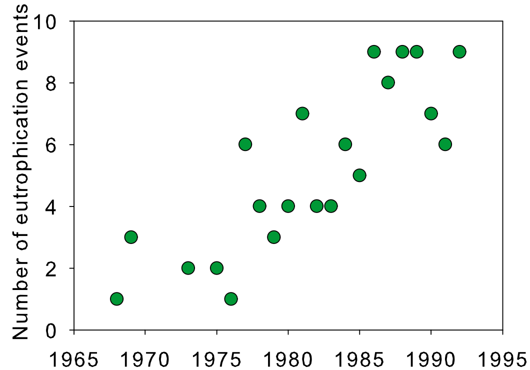
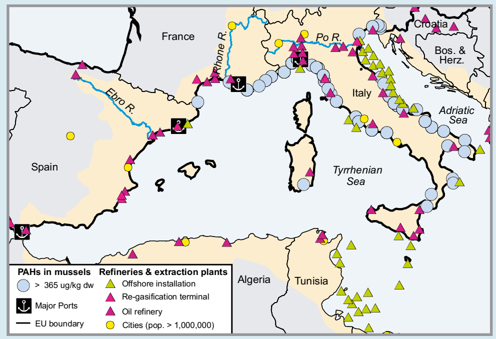


Fig. 12 The frequency of eutrophication events is rising in the Mediterranean Sea (after UNEP/FAO/WHO 1996).

PAH pollution

Polycyclic aromatic hydrocarbons (PAHs) are a group of organic contaminants released into the environment through fuel combustion, oil processing, and accidental oil spills. In the Mediterranean, occurrence of high concentrations of PAHs in mussels is spatially correlated with oil refineries and installations.



Seagrass case study

A fringe of seagrass (primarily *Posidonia oceanica*) is found on most Mediterranean coasts. These biogenic habitats play a crucial role in stabilising sediments, maintaining water quality and protecting sedimentary shores from erosion. Furthermore, seagrass meadows are the most important fish production areas in the Mediterranean. ELME estimated a total loss of 44,625 ha of seagrass over the last 100 years, which equates to an average of more than one hectare of seagrass lost per day (although the rate is increasing). However this estimate does not consider recovery of the habitat and is likely to be an underestimation since much of the habitat remains unmapped and unstudied (e.g. North African coast).

Changes to the state of seagrass habitat result from a complex series of interacting pathways which ultimately affect seagrass through three key pressures (fig. 15): 1) mechanical disturbance, 2) smothering (via increased sedimentation or direct dumping of sediment onto seagrass beds) and 3) reducing light to the plants. One of the main impacts of light limitation is reduction of the lower depth limit at which seagrasses can grow. Mechanical disturbance damages seagrass beds by removing plants and damaging rhizomes. This source of loss has increased over the past three decades, mainly from trawling and anchor/mooring damage, despite bans on these activities in the vicinity of seagrass beds in many parts of the Mediterranean. Furthermore, such activities have been linked to the spread of the invasive algae *Caulerpa*. Initially introduced from aquaria in 1984, *Caulerpa* has spread rapidly. It occupies a similar niche to seagrass and may outcompete seagrass in damaged or degraded beds, creating a permanent barrier to recovery. Aquaculture has also led to seagrass loss, commonly from smothering by waste food and faeces under fish cages, but also through phytoplankton blooms and increased turbidity from the addition of nutrients to the system. The cage structures themselves may also cause shading. The main pathway of loss from the urban sector is through the release of sewage, which again adds nutrients but can also impact seagrasses directly through smothering and increased turbidity. However, the importance of this driver has decreased since the 1970s, probably due to improved waste water treatment.

Alarmingly, under the Baseline scenario (assuming full compliance to policy) the decline of *Posidonia oceanica* is likely to continue, despite improvements in urban waste water treatment and a decline in trawling and dredging fleets. This is mainly due to increases in finfish aquaculture and coastal urbanisation. An extension of current upward trends in livestock production and fertiliser use continue loading coastal systems with nutrients. Local Responsibility is the sole scenario that is likely to lead to an improvement in *Posidonia* state, due to a steep decline in destructive fishing practices and a decrease in the drivers causing nutrient enrichment and turbidity. National Enterprise would have devastating effects on *Posidonia* with all of the major causes of seagrass decline showing increasing trends or continuing at current levels.

Since 1990 PAH concentrations in Mediterranean biota have declined (fig. 14), although shipping traffic and oil imports have increased. This decoupling is likely to be a result of the successful implementation of pollution prevention and control measures in industry and maritime sectors.

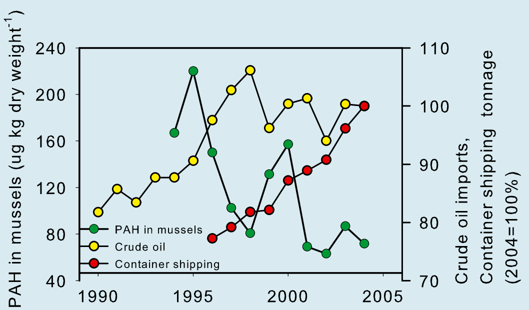


Fig. 14 Decoupling of PAH contamination from oil imports and shipping.

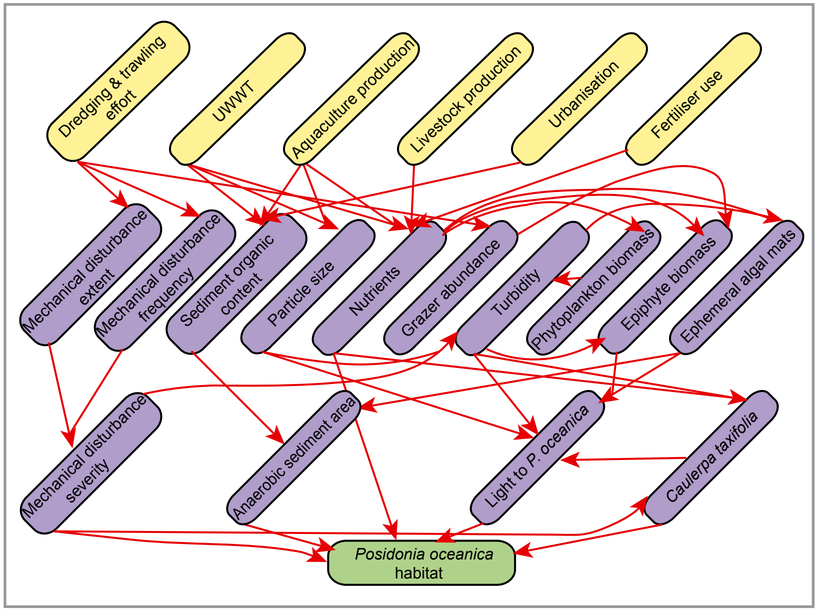
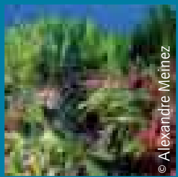


Fig. 15 Conceptual model of impacts on *Posidonia oceanica* habitat with the simulation model embedded within it (colours follow those used in the regional model).

Mediterranean Sea

Winners



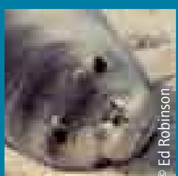
Invasive seaweed replaces native seagrass in degraded meadows

Losers

Turtles are victims of fishing bycatch and disruption of breeding habitat from increased beach tourism

Aquaculture, increased turbidity and trawling contribute to seagrass habitat degradation

Predatory pelagic fish stocks such as swordfish and bluefin tuna are threatened by overfishing and aquaculture activities



Endemic monk seals suffer from reduced prey due to fisheries overexploitation and loss of breeding sites from tourist encroachment

Key results and interpretation

The Mediterranean's status as an international biodiversity hotspot is increasingly compromised by human activity (see fig. 11), elevating habitat and species destruction to this sea region's priority issue. Mediterranean habitats commonly suffer from the establishment of invasive species, coastal development, eutrophication, fishing and aquaculture.

A small, but increasing fraction of species found in the Mediterranean are exotic and have been introduced by humans (e.g. via shipping, aquaculture). Some of these alien species (e.g. seaweeds *Caulerpa taxifolia* and C. racemosa) have become invasive, thriving in their new environment and competing with, and sometimes displacing, native species. Over the past 20 years *Caulerpa* has invaded damaged or degraded seagrass beds across the Mediterranean; the area affected is estimated to double annually. *Caulerpa's* spread has been augmented by activities such as anchoring by recreational vessels and demersal fishing which damage seagrass beds. Moreover the presence of *Caulerpa* is a permanent barrier to seagrass recovery.

Recent coastal development at Bodrum, Turkey

Over the past three decades, one of the primary causes of permanent loss of habitat in Mediterranean coastal zones has been coastal development driven by increased coastal populations and tourism. Impacts have been particularly severe on sedimentary shores where development has hardened the coast or claimed land from the sea, or where activities impair suitability as a habitat. For example, increased beach tourism has altered the nesting behaviour of turtles.

Coastal eutrophication events in the Mediterranean have increased during the past three decades, driven primarily by inadequate urban waste water treatment (only 16% of Mediterranean cities with populations over 10,000 have tertiary treatment), agricultural practices and at a localised scale, aquaculture (see northern Adriatic case study). A common symptom of eutrophication is massive algal blooms which reduce the light available to seagrass, retarding growth and in some cases resulting in the reduction of the lower depth limit of these plants. Eutrophication can also cause hypoxia, leading to the death of benthic organisms.

The Mediterranean EU fishing fleet has decreased since the mid 1990s, whilst non-EU fleets have increased. Target and non-target species are heavily impacted by non-specific fishing gears. Benthic species are caught as bycatch and killed by large towed gears. Other

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species are affected indirectly when prey availability is reduced by overfishing. Populations at risk from fishing and showing signs of decline over the past decade include large pelagic fish (e.g. swordfish and tuna), elasmobranchs (rays and pelagic sharks), seabirds, marine turtles, and marine mammals (including monk seal and cetaceans). The mean trophic level and Fishing-in-Balance Index (FiB) have decreased since the mid 1990s, demonstrating impacts on the food web. Additionally, seagrass habitats are at risk from destructive demersal fishing activities such as trawling and dredging, and anchoring of recreational vessels, which damage and remove seagrass. Trawling in the vicinity of seagrass beds is now banned in many parts of the Mediterranean but most reports of seagrass habitat decline identified in this study were due to illegal trawling.

The Baseline scenario indicates continued ecosystem degradation. Improvements in UWWT and declines in dredging and trawling effort are not sufficient to halt the damage to seagrass habitats, which are under increased pressure from aquaculture- and agriculture-driven coastal eutrophication. Fishing effort stabilises under this scenario, although a decline in dredging and trawling may suggest a shift to pelagic methods. Catches of small and large pelagic fish stabilise at current levels (high and low, respectively). The FiB index indicates a reversal in the trend of fishing down the food web, ultimately evident as a levelling of the decline in apex predators.

Under the Local Responsibility scenario, there are improvements in some state variables such as sedimentary shore and seagrass habitats although there is an increase in coastal eutrophication. This is because most nutrient-related drivers decline (except for aquaculture production). A decline in destructive fishing practices and a decrease or levelling of drivers responsible for nutrient enrichment and turbidity halt decline of seagrass habitat and allow some recovery. Large pelagic landings increase under this scenario as reduced fishing effort prevents overfishing. Under the World Markets scenario, where some of the drivers are similar to current, a decline in trawling but an increase in fishing effort results in a continued decline in the FiB index, an increase in small pelagic catch, and a decline in apex predators (due to interactions with fishing gear and depletion of prey). There is a steep decline in the state of sedimentary shores as tourism increases.

Under the National Enterprise scenario sedimentary shore degradation and FiB stabilise at current levels, concurrent with a stabilisation in coastal urbanisation, tourism and fishing effort. However National Enterprise results in the intensification of agriculture and aquaculture which lead to severe coastal eutrophication, declines in the state of seagrass habitat, and an increase in *Caulerpa*. Coastal eutrophication also increases under the Global Community scenario due to increased livestock production, although fertiliser use and aquaculture production stabilise. Global Community also results in the stabilisation of sedimentary shore degradation, decreased area of *Caulerpa*, and an increase in the FiB index. These changes occur as the result of decreased dredging and trawling and stabilised fishing effort, coastal urbanisation, and tourism.

Scenario outcomes

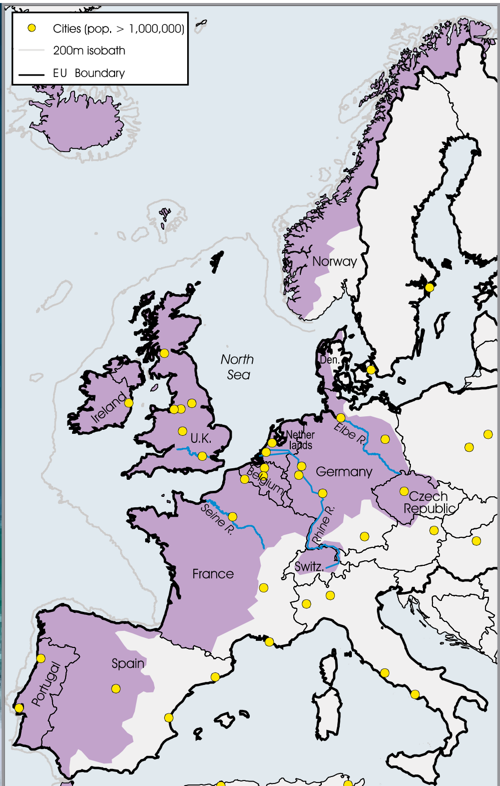
Outcomes of the Baseline scenario and four alternative scenarios from the Mediterranean Sea simulation model are shown below. The driver component determines the conditions that forced the simulation for each scenario, while pressures and states are the responses to these combinations of drivers. Arrows indicate the direction of changes relative to the current situation.

Legend	
↑	Large increase
↗	Increase
→	Stable
↘	Decrease
↓	Large decrease

		Current Trend	Baseline Scenario	Scenarios (relative to current)			
				National Enterprise	Local Responsibility	World Markets	Global Community
DRIVERS	Recreat. anchoring	↗	↗	→	→	↑	→
	Dredge & trawl effort	↘	↘	→	↓	↘	↓
	Fishing effort	↘	→	→	↘	↗	→
	UWWT	↗	↗	→	↗	→	↗
	Aquaculture prod.	↗	↗	↑	↗	→	→
	Livestock prod.	↗	↗	↗	→	↗	↗
	Fertiliser use	↘	↗	↑	→	↑	→
	Tourism	↗	↗	→	→	↑	→
	Urbanisation	↗	↗	→	↘	↑	→
PRESSURES	Demersal catch	↗	↗	→	↑	→	↗
	Small pelagic catch	↗	→	→	↘	↗	→
	Large pelagic catch	↘	→	→	↗	↘	→
STATES	Sed. shore hab.	↘	↘	→	↗	↓	→
	Caulerpa taxifolia	↗	↗	↑	↘	↘	↘
	Coastal eutrophic.	↗	↗	↑	↗	↗	↗
	Seagrass hab.	↘	↘	↓	↗	→	→
	Fish com. structure	↘	↗	→	↑	↘	↗
	Apex predators	↘	→	→	↗	↘	→

Mediterranean Sea

North-East Atlantic



Catchment map of the North-East Atlantic.

The North-East Atlantic exhibits a variety of physical and biological characteristics, ranging from open ocean to shallow coastal waters. Within the North-East Atlantic, the North Sea is a semi-enclosed area, strongly influenced by human activities

The southern region of the North Sea is generally shallow (<40 m) with strong tidal mixing and significant freshwater inputs from rivers draining Central Europe. Circulation is driven by tides and wind, with an overall anti-clockwise flow. The water column remains well mixed near the southern coast but in deeper water seasonal thermal stratification results in localized oxygen depletion. The northern region is generally deeper (50-200 m), reaching 700 m in the Norwegian trench with seasonal stratification occurring throughout. Strong currents along frontal regions enhance the eastward transport of nutrients, contaminants and plankton.

Inflow from the North Atlantic brings warm, salty, nutrient-rich water to the North Sea. Southern waters receive additional anthropogenic inputs of nitrogen and phosphorus, especially from intensive agricultural production. Although beneficial for some shellfish species, increased coastal nutrients have contributed to eutrophication in some areas. Recent declining trends in inputs have not been matched by near-shore chlorophyll concentrations, suggesting other factors, such as climate change, may be important.

The North Sea is a productive ecosystem, supporting a long-established and diverse fisheries sector. Fisheries are controlled by the Common Fisheries Policy (CFP), but this has failed to prevent the overexploitation of many fish stocks, despite the introduction of technical measures (e.g. Total Allowable Catch (TAC), closed areas, minimum mesh sizes). The discarding of bycatch supports large populations of scavenging seabirds while abundance of small seabirds dependent on sandeels (*Ammodytes* sp.) has declined. In addition, the ecosystem is subject to considerable natural variability, which interacts with fisheries resulting in large fluctuations in fish stocks that are subject to substantial uncertainty in terms of forecasting and planning suitable management actions.

Over 160 million people live in the North Sea catchment. Much of the coastline and many of the estuaries bordering the southern North Sea are highly industrialised, leading to a variety of pressures. In addition, significant areas of former wetland have been reclaimed for agriculture or other development. This has resulted in the phenomenon known as 'coastal squeeze', a condition exacerbated by sea level rise. These factors combine to increase pressure on existing coastal defences, and may have significant impacts on the large populations of wading birds and waterfowl. Coastal waters receive a great variety of organic and inorganic contaminants. Increased controls have reduced many direct inputs but new manufacturing processes and products have resulted in the emergence of novel chemicals, which may have unexpected effects, such as endocrine disruption, on marine organisms. Estuarine sediments often contain a legacy of past industrial practice. Dredging and disposal to maintain navigation or create port facilities leads to the re-distribution of contaminants. This region represents one of the most heavily utilised shipping routes in the world, increasing the risk of introducing alien species.

Channel dredging for shipping navigation is a key activity in North Sea coastal areas

The North Sea has a long history of oil and gas exploitation. More recently, offshore wind farms have become a feature of the southern North Sea. Additionally large quantities of sand and gravel are routinely extracted to support the construction industry. Such activities have significant impacts on the ecosystem.

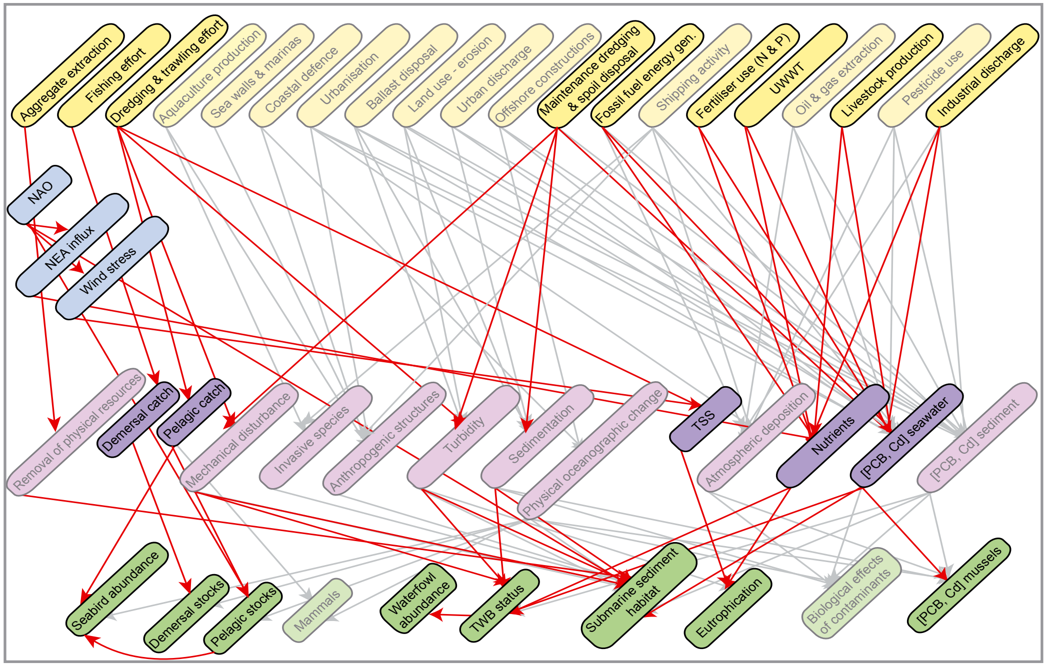


Fig. 16 North-East Atlantic conceptual model with the North Sea simulation model embedded within it (red arrows show pathways between variables included in the simulation model, while grey arrows indicate where linkages were made conceptually but were not included). Yellow indicates anthropogenic driver variables; blue indicates exogenous climatic driver variables; purple indicates pressures, while green indicates ecological state variables.

North Sea simulation model

Rather than attempting to capture the entire North-East Atlantic region, this model is restricted to the North Sea. Focusing on this semi-enclosed region also allows for comparability with other regional seas modelled within ELME. Furthermore there is greater data availability for the North Sea than for other areas of the North-East Atlantic.

Drivers: The conceptual model constructed for the North Sea is highly complex but the number of driver variables was reduced for the simulation model (fig. 16). This was done for four reasons: 1) they were considered to be subordinate (e.g. aquaculture, ballast disposal, oil/gas extraction, shipping and pesticide use), 2) no indicators and/or time-series datasets could be identified (e.g. coastal defence, seawalls and marinas, urbanisation and urban discharge), 3) there were no trends in the data (e.g. land use changes) or 4) variables were aggregated (e.g. maintenance dredging and spoil disposal were aggregated and shipping activity was used as a proxy). Exogenous climatic drivers are included here (North Atlantic Oscillation, North Atlantic seawater influx and wind stress) as they play a key role in regulating total suspended solids (TSS) and nutrients.

Fleet capacity (total tonnage) was used as a proxy for both fishing effort and dredging and trawling effort, as better indicators (such as days at sea, vessel gear type, total fleet power) were not available. Fertiliser usage was split between nitrogen and phosphorus as these data had different trends.

Pressures: Two contrasting contaminants were selected to illustrate the problems of chemical pollutants: a group of organic compounds (PCB_7) and a metal (cadmium). Riverine inputs were used as a proxy for seawater contaminant concentrations and sediment contamination concentrations were removed to overcome difficulties in data availability. Equally, data were not readily available to populate sedimentation and physical oceanographic change variables, so these were removed and driver variables were connected directly to environmental state variables. Fish catch was divided into pelagic (herring, *Clupea harengus*; sandeel, *Ammodytes* sp.) and demersal (plaice, *Pleuronectes platessa*) landings.

States: Two habitats (transitional water bodies (TWB) and submarine sediments) were selected based on data availability and representativeness. The indicator for TWB was an index constructed from turbidity and dissolved oxygen measurements for four North Sea estuaries (Elbe, Humber, Rhine and Thames), while zoobenthos biomass was used as the indicator for submarine sediments. Spawning stock biomass (SSB) was used to populate pelagic (herring; sandeel) and demersal (plaice) stock variables. The indicator for seabirds was an index constructed from reproductive success data for five sandeel-dependent species (European shag, *Phalacrocorax aristotelis*; black-legged kittiwake, *Rissa tridactyla*; common guillemot, *Uria aalge*; razorbill, *Alca torda*; Atlantic puffin, *Fratercula arctica*). The indicator for waterfowl was an index constructed from abundance data for five species (bar-tailed godwit, *Limosa lapponica*; redshank, *Tringa totanus*; dunlin, *Calidris alpine*; knot, *Calidris canuta*; curlew, *Burhinus oedicnemus*; shelduck, *Tadorna tadorna*).

North-East Atlantic

Climate exacerbates eutrophication

A significant increase in chlorophyll, an indicator of phytoplankton biomass, was observed in open and coastal North Sea waters during the 1980s (fig. 17). This change was related to a climate-driven, region wide regime shift. Since the regime shift, chlorophyll has remained at a higher level in both open and coastal waters. In the coastal North Sea, chlorophyll continues to increase.

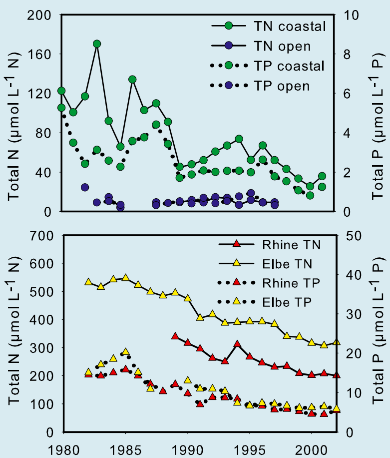


Fig. 18 Total nitrogen (TN) and total phosphorus (TP) have decreased in the Elbe and Rhine rivers resulting in decreased nutrient concentrations in the coastal North Sea (after McQuatters-Gollop et al. 2007).

Usually an increase in chlorophyll is associated with an increase in nutrients; however that is not the case in the North Sea. Instead, nutrient levels in coastal waters and in the Elbe and Rhine rivers are declining from their previously high levels (fig. 18). This is largely due to changes in agricultural practices and European policy directives.

The decline in coastal nutrient concentrations has been coincident with increased SST (fig. 19a) and a period of positive NAO, an important regulator of climatic variability (fig. 19b). During the same period, inflow of clear water from the North Atlantic (fig. 19c) also increased resulting in greater water transparency of coastal North Sea waters (fig. 19d). The clearer water and warmer SST create a longer growing season and better access to light; conditions which enable coastal phytoplankton to more effectively utilise high levels of nutrients already existing in coastal waters. In other words, due to climatic variability, coastal North Sea waters are increasingly sensitive to eutrophication.

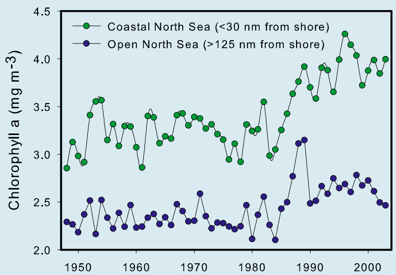


Fig. 17 The 1980s regime shift caused increased chlorophyll in North Sea waters (after McQuatters-Gollop et al. 2007).

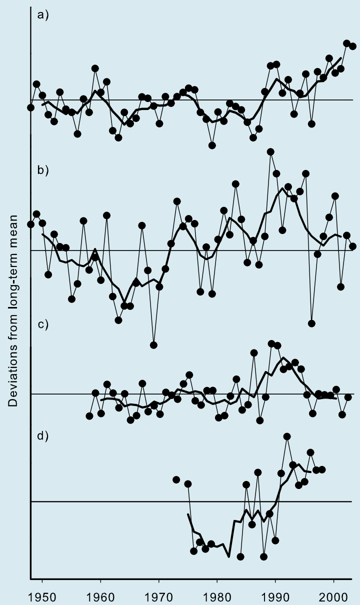


Fig. 19 Changes in (a) North Sea SST, (b) the NAO, (c) Atlantic inflow to the North Sea, and (d) water clarity of coastal waters have occurred in recent years (after McQuatters-Gollop et al. 2007).

Lophelia pertusa case study

Deep waters of the North-East Atlantic are the primary habitat for *Lophelia pertusa*, an important cold water coral. As biodiversity hotspots, *Lophelia* reefs provide hard substrata, nursery areas for juvenile fish and habitat for a wide variety of species. However, due to its slow growth rate, recovery of this key biogenic organism from damage is particularly lengthy.

Cold water deep sea coral reefs were only discovered within the last decade so no time-series data are available regarding their health. Therefore a non-traditional method for modelling the effects of anthropogenic activities on this sensitive ecosystem was required. The model structure (fig. 20) was developed based on current research on the impacts of anthropogenic activities on deep sea coral reefs and expert opinion was elicited by questionnaire to assess the potential severity of each activity on *Lophelia* reefs. Findings suggest the most damage to *Lophelia* reefs is likely to occur due to deep water fishing activities, especially trawling. Oil and gas exploitation may also impact *Lophelia* reefs. Other drivers not included in this simulation model (climate change, chemical contamination and waste disposal) may also harm *Lophelia* reefs both directly and by influencing larval recruitment to reefs.

Lophelia pertusa reefs are biodiversity hotspots

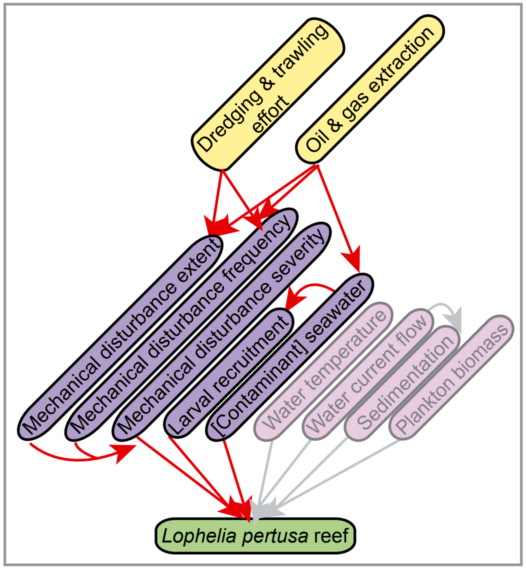


Fig. 20 Conceptual model for *Lophelia pertusa* biogenic reef habitat with the simulation model embedded within it (colours follow those used in the regional model).

The Baseline scenario suggests a reduction in mechanical disturbance of the seabed as oil and gas exploitation decrease, although trawling activities continue at their current rate. Unfortunately, the simulation model is not sensitive enough to discriminate between the localised and relatively infrequent disturbance caused by oil and gas exploitation and the long-term, frequent and extensive disturbance caused by trawling activities, and therefore provides an overly optimistic scenario for *Lophelia*. The Local Responsibility and Global Community scenarios reduce pressure on *Lophelia* reefs through reductions in both dredging and trawling activities and oil and gas exploitation. The National Enterprise scenario predicts an increase in trawling activities and a resultant decline in *Lophelia*, while the World Markets scenario results in continued increases in both drivers and consequently further degradation of reef habitat.

Basque trawl fishery case study

Approximately half of the Basque trawl fleet's catch from the Bay of Biscay consists of hake (*Merluccius merluccius*). This overexploited species is also targeted by other European fleets and has recently become the focus of recovery policy measures. Initial research indicated that a reduction in fleet capacity is needed to increase sustainability of the hake fishery. However, the economic costs of downsizing the trawl fleet make this difficult. Fish price is a possible mechanism through which incomes in the sector may be improved while reducing pressure on hake stocks.

Basque trawler landings account for a small percentage of hake catch in the Bay of Biscay. Therefore, changes to the Basque fishery have a limited influence on the total stock and increased fishing effort (days at sea, number of vessels) results in more landings. This is unlike the Baltic cod fishery where increased effort results in greater pressure on cod stocks and their eventual depletion (see Cod case study). The hake simulation model thus focuses on the management of fishing effort through political and institutional regulation (fig. 21). Regulated number of days at sea and Total Allowable Catch (TAC) have the greatest influences on hake landings. Fish price (set by demand and imports) and cost of fishing (fuel price, amount of investment, available subsidies) determine the profitability of the fishery.

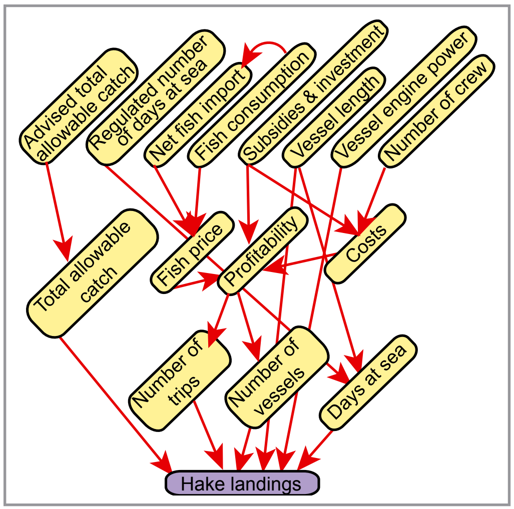


Fig. 21 Conceptual model for Basque trawl fishery with the simulation model embedded within it (colours follow those used in the regional model).

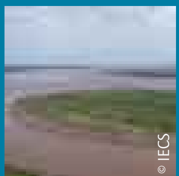
The Baseline scenario suggests heightened protection of fish stocks using financial instruments. The amount of available investment funding is decreased and TAC is reduced. These drivers result in decreased fishing effort and fishery employment, consequently reducing hake landings. However fish consumption rises; demand is met through imports.

Under the World Markets scenario TAC is sharply decreased, and although fish consumption increases, demand is satisfied through imports. Fishery employment declines and so hake landings decrease. Under the National Enterprise scenario, fish consumption also increases, but there is no increase in fish imports and TAC remains at the current level. Instead, fishing effort rises to maximise hake landings. Under the Local Responsibility and Global Community scenarios, fishery funding decreases. TAC and the number of days at sea are greatly reduced resulting in a considerable reduction in fishing effort.

North-East Atlantic

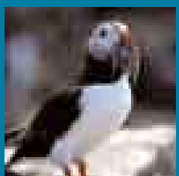
Winners

The changing climate favours phytoplankton growth



Transitional water bodies are improving with decreasing loads of nutrients and contaminants and wetland restoration

Losers



Declines in breeding success of seabirds have been linked to a decrease in the abundance of sandeels

Plaice is one of several demersal fish species which have been overexploited

Benthic fauna is removed as demersal fishing bycatch

Key results and interpretation

Modern lifestyles have increased pressure over much of the North-East Atlantic, particularly the semi-enclosed North Sea. The North Sea catchment is affected by anthropogenic activities resulting from heavy industrial development, high population density and intensive agriculture while the sea itself is subject to fishing, aggregate extraction, oil and gas exploitation, transport and tourism.

Dredging and spoil disposal have negative impacts on marine ecosystems

Of the four themes in ELME, fishing pressure is the most widespread in the North-East Atlantic region. Scientific advice and policy measures have been insufficient in preventing the overexploitation of several species. The North Sea in particular has experienced a substantial decline of demersal fish stocks, such as plaice (*Pleuronectes platessa*), cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) over the past few decades. These species are dangerously overexploited and rebuilding stocks may depend on a significant reduction in fishing mortality. In addition, fishing affects submarine habitats and seabird populations. Heavy fishing gears can have a destructive impact on benthic fauna, particularly for sessile long-lived organisms (though modified selective trawling gear may reduce bycatch by up to 75%). Diving seabirds, such as Atlantic puffin (*Fratercula arctica*), arctic tern (*Sterna paradisaea*), shag (*Phalacrocorax aristotelis*) and black-legged kittiwake (*Rissa tridactyla*) have suffered poor breeding success in recent years as the result of the decreased availability of sandeels (*Ammodytes* sp.), a key prey. Sandeels are the largest single component of North Sea commercial fisheries and overexploitation together with climatic variability has led to declines in abundance. Conversely, fishing discards and offal are a key food source for scavenging seabirds, such as great skua (*Catharacta skua*) and great black backed gull (*Larus marinus*) in the northern North Sea. Measures that reduce fishing discards will have negative consequences for these animals. The abundance of all of these species depends on a complex combination of anthropogenic pressures and natural variability. Removal of a key species may be irreversible and reduction in fishing pressure does not guarantee recovery (see p. 43) as other species may replace target stocks.

Eutrophication is also a major concern in some regions of the North-East Atlantic, although this is restricted to semi-enclosed seas and coastal waters, such as the southern North Sea. Increased primary production persists despite reductions in nutrient inputs, illustrating the complex relationship between productivity, natural variability and human pressures, and demonstrating the need to take these factors into account when predicting future trends (see Climate box, p. 28; Emergent issues, p. 38). The manner in which climate change and natural variability may influence the future North Sea ecosystem is not yet confirmed. Climate change is likely to increase water temperatures, resulting in worsening eutrophication in the southern North Sea, and benefiting warm water species at the expense of colder water forms. The impact on lower trophic levels is difficult to predict but this will ultimately influence the success of target fisheries species. Greater winter precipitation and more episodic flooding events will also influence the supply of nutrients and contaminants to the coastal zone. However, as the mechanisms behind these changes are not entirely understood, their effects on and interactions with the ecosystem are uncertain.

The status of North Sea transitional water bodies (TWB) has improved in recent years because of developments in urban waste water treatment and wetland restoration projects. However, in some cases an improvement in TWB water quality has been accompanied by a decrease in the abundance of some shellfish and water fowl with declines in organic enrichment.

Sandeels are a key prey for many North Sea fish and bird species

Shipping activity has increased significantly in the North-East Atlantic, with larger vessels requiring new port facilities and increased dredging of navigation channels. These activities have resulted in loss of habitat and redistribution of contaminated sediments. Additionally, alien species have been introduced through ship ballast water and the coastline has been physically impacted by accidents. Organotins continue to be used as antifoulants on large vessels, and historic contamination can be reintroduced to the water column through dredging, resulting in significant levels of endocrine disruption in several species (see Emergent issues, p. 39).

Chemical pollution is also a concern in the North-East Atlantic. An enormous number of contaminants exist in the marine environment, many without adequate data or knowledge of their effects on biota. However riverine concentrations of most metals and organic contaminants (such as PCBs and cadmium) have begun to decline as a result of regulation. The extent to which this is reflected in biota is unclear, due to variations in bioavailability, local conditions and a legacy of past contamination in sediments. The biological effects of many newly created substances introduced into the marine environment are also poorly known (see Emergent issues, p. 39).

Under the Baseline scenario a reduction in nutrient inputs continues but eutrophication increases, due to climatic effects. Implementation of the CFP results in some improvements in demersal fish stocks. TWB status increases, in part due to decreases in contaminants and nutrients, a subsequent decline in waterfowl abundance occurs. Model prediction of eutrophication is not reliable due to the unpredictable and confounding influence of climate (see Climate box).

With the Local Responsibility and Global Community scenarios, fisheries are more sustainable, allowing the recovery of some stocks. This benefits diving seabirds, whereas those supported by discards may suffer a decline. The likely introduction of protected areas safeguards biogenic reefs and other rare habitats that provide nursery areas for fish. Continuing improvements in gear selectivity reduces bycatch of benthic organisms. Nutrient inputs decrease, improving TWB status at the expense of some wildfowl.

Under the World Markets scenario fisheries will be unsustainably exploited, with consequent impacts on seabirds, non-target species and submarine sediment habitats. Increased transport will require further dredging, increase the risk of introduction of alien species and lead to increased contamination (e.g. oil, organotins). Less stringent legislation may lead to higher loadings of some contaminants. Similar patterns are also observed under the National Enterprise scenario.

The *Prestige* oil spill heavily impacted beaches in northwestern Spain in 2002

Scenario outcomes

Outcomes of the Baseline scenario and four alternative scenarios from the North Sea simulation model are shown below. The driver component determines the conditions that forced the simulation for each scenario, while pressures and states are the responses to these combinations of drivers. Arrows indicate the direction of changes relative to the current situation.

↑ Large increase
↗ Increase
→ Stable
↘ Decrease
↓ Large decrease

				Scenarios (relative to current)			
		Current Trend	Baseline Scenario	National Enterprise	Local Responsibility	World Markets	Global Community
DRIVERS	UWWT	↗	↗	→	↗	→	↗
	Industrial discharge	↘	↘	→	↓	↓	↓
	Fossil fuel en. gen.	↘	↗	↑	↘	↑	→
	N fertiliser use	↘	→	↗	↘	↗	→
	P fertiliser use	↘	↘	→	↓	→	↘
	Livestock prod.	↗	→	→	↘	→	→
	Dredg. & spoil disp.	↗	↗	→	↘	↑	↗
	Dredg. & trawl effort	↘	→	↗	↘	→	↘
	Fishing effort	↘	→	→	↘	↗	→
PRESSURES	[PCB] seawater	↘	↘	→	↓	↘	↓
	[Cd] seawater	↘	↘	↗	↓	↗	↓
	Total nitrogen	↘	↘	↗	↘	↗	↘
	Total phosphorus	↘	↘	→	↓	→	↘
	TSS	↘	→	↗	↘	→	↘
	Demersal catch	↘	↘	→	↓	↘	↓
	Pelagic catch*	→	→	→	↗	↘	→
STATES	[PCB] mussels	↘	→	→	→	→	→
	[Cd] mussels	↘	↘	↗	↓	↗	↘
	Eutrophication	↗	↗	↘	↑	↘	↑
	TWB status	↗	↗	↘	↗	↑	↑
	Waterfowl abund.	↘	↘	→	↘	↓	↓
	Submarine sediment hab.	↘	↘	↘	↗	↓	↘
	Demersal stocks	↘	↗	→	↑	↗	↑
	Seabird abundance	↘	→	→	↗	↘	→
	Pelagic stocks*	→	→	→	↗	↘	→

*trend for sandeels is ↗ and herring ↘

Discussion: Joined-up thinking

Eutrophication is a problem impacting areas of every European sea. Increases in intensive farming efforts, industrial livestock production, construction of inadequate sewage systems and rising fossil fuel use (which releases nitrogen into the atmosphere), all lead to nutrient emissions into watersheds.

Food production is the largest human source of nitrogen to our seas, and a major source of phosphorus. The way we produce our food is critically important for the future state of Europe's seas.

Changing lifestyles affect eutrophication

Demands on land use are closely linked to affluence. Studies have suggested that increased personal income leads to changes in diet, generally favouring greater protein consumption. There is a clear relationship between average household expenditure and the per capita consumption of animal protein (including dairy products, meat and fish) for European countries (fig. 22). Acceding countries aspire to high and stable economic growth and as they become more affluent, household expenditure and protein consumption increase. As an example, the per capita protein consumption in Portugal grew by 50% in the 13 years following accession whereas that of Romania fell 10% in the same period. It seems likely that demand for animal protein will grow rapidly across Central and Eastern Europe in coming decades. The additional consumption can be met by increasing the amount of land farmed, intensifying farming (e.g. greater use of fertilisers) or by importing animal products. Typical vegetarian diets require less than a third of the agricultural land area than does the average European diet. A shift in EU-15 countries towards a meat consumption pattern similar to that of the USA would require an approximately 17% increase in agricultural land. Without major changes in agricultural practice greater protein consumption will raise nutrient discharges to water bodies. Our research has demonstrated the importance of understanding these connections if deterioration of Europe's seas is to be prevented.

A second key diet-related trend is the intensification of farming, particularly livestock production. For example, in the EU-12 pig farming is a growing sector that is shifting towards fewer holdings with larger numbers of animals (fig. 23). Evidence is also beginning to emerge of major investments in animal production units in Eastern Europe. Pig production units often import fodder from outside the EU, thus decoupling protein production from European farming. Waste from large poultry and pig farms resulted in approximately 94,000 tonnes of ammonia released into the air in EU-25 countries in 2004; much of this will eventually find its way into the aquatic environment.

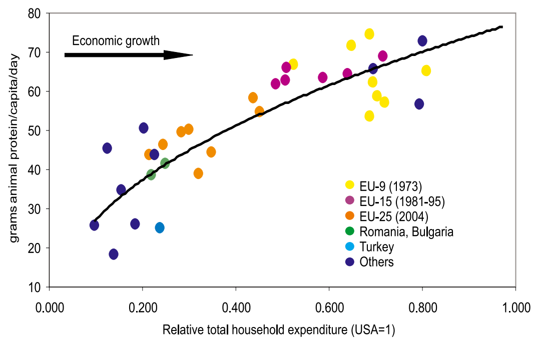


Fig. 22 European protein consumption as proportion of household expenditure.

With intensification of agriculture and livestock production in Eastern Europe, coupled with increased consumer demand for animal protein (and also vegetable oils and fats), there are legitimate concerns that nutrient discharges to the Black Sea and Baltic Sea will also increase. Such an increase could accelerate eutrophication and reverse recent improvements resulting from both the economic recession that occurred in many Eastern and Central European countries following the collapse of communism, as well as the control of point source nutrient discharges.

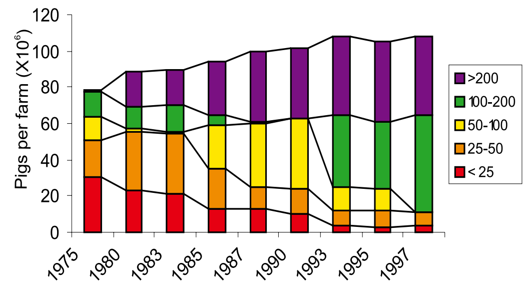


Fig. 23 The trend toward intensification of farming is illustrated by an increase in large pig farms in European countries.

Nutrient balances across Europe's regional seas

Our regional sea models strongly suggest that the semi-enclosed Baltic Sea, Black Sea and northern Adriatic are particularly vulnerable to increased nutrient discharges. By reinterpreting previous studies, we developed nutrient balances for nitrogen and phosphorus in each of the seas (fig. 24), comparing contemporary load estimates with historical 'pristine' and 'eutrophic' states where possible. These balances demonstrate the importance of the sea floor as a source and sink for nutrients, effectively enabling nutrient retention in the system, and also the importance of exchange with neighbouring water bodies. In the case of the Baltic, the huge reservoir of phosphorus accumulated in the sediments currently provides the largest source of this nutrient to the water column. Net export of phosphorus to the North Sea is relatively small and is more than

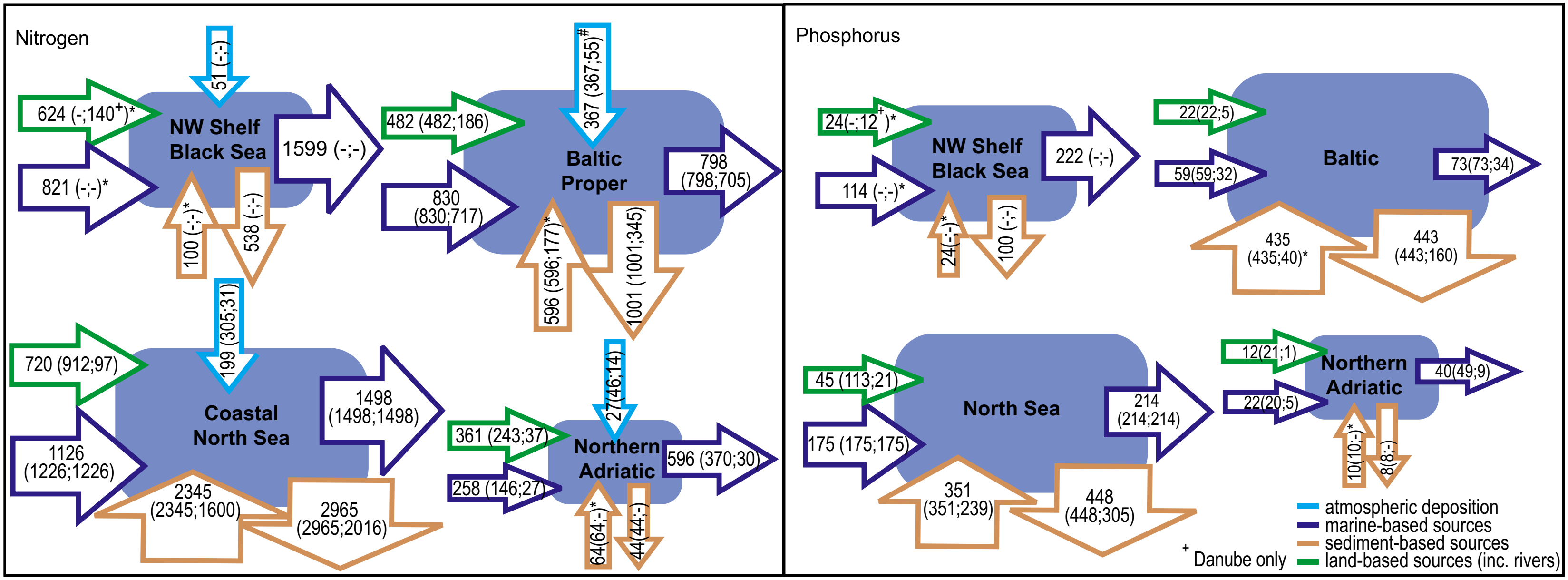


Fig. 24 Nutrient budgets for the four regional areas compared. All values are fluxes of TN or TP in thousands of tonnes per year, except fluxes evidenced by * that are DIN or DIP. Values between brackets respectively show fluxes during eutrophication and pre-eutrophication conditions. When an estimate was not possible, no value (-) is shown. Blue areas are proportional to basin surfaces.

balanced by sources from land. Even if terrestrial nutrient inputs were controlled in order to be in balance with exports, it would take many years to deplete sedimentary reservoirs and eliminate eutrophication.

The sensitivity of the other regional seas to nutrient discharges from human sources also depends on the efficiency of removal. On the northwestern shelf of the Black Sea, nutrients may be lost to the anoxic deep sea (phosphorus) or through denitrification (nitrogen). Terrestrial discharges of nutrients in the 1980s overwhelmed these processes and caused catastrophic eutrophication (see p.17). To a lesser extent, the same situation occurred in the northern Adriatic. In contrast, the North Sea is relatively well flushed and, aside from shallow coastal areas, is less likely to suffer from eutrophication.

Overall, the northern Adriatic and Black Sea are somewhat phosphorus-limited but the Baltic has an excess of phosphorus for the reasons explained earlier (fig. 25). However, coastal areas of the sea may behave differently and there are large seasonal variations in nutrient supply. The Redfield ratio is the nutrient balance (N:P) for optimum growth of marine phytoplankton. Deviations from the Redfield ratio may be associated with ecosystem changes; for example, the low N:P ratio of the Baltic encourages harmful blooms of nitrogen-fixing cyanobacteria. A major challenge lies ahead for restoring the status of Europe's semi-enclosed seas by lowering human nutrient fluxes in a way that also brings overall supply close to the Redfield ratio.

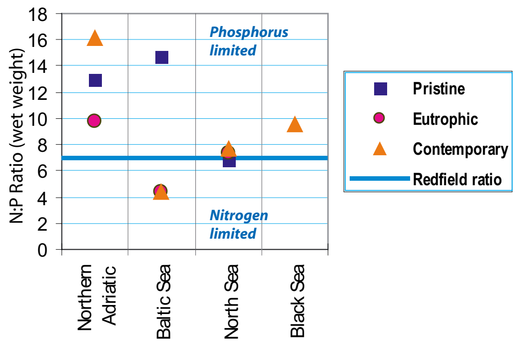


Fig. 25 Estimates of N:P ratios of inputs to all four seas.

Discussion: Joined-up thinking

In Europe's regional seas, damage to marine habitats is directly and indirectly connected to human lifestyles. This damage is most often associated with coastal development, fisheries and eutrophication. However our research has shown that the pathways through which these (and other) drivers result in habitat loss and degradation vary in each sea due to regional socio-economic differences.

Links between habitat loss and human lifestyles

Increased wealth and personal mobility have lead to growth of coastal populations and resource use. Additional infrastructure and commercial development are needed to support these changes. Artificial surfaces in coastal zones are increasing in all regional seas, causing loss of sedimentary shore, transitional water body, and near-shore marine habitats. In addition to their role as habitats, these ecosystems are important tourist attractions and sources of raw materials for coastal development. Therefore, their loss and degradation have severe economic, social and ecological implications.

Transitional water bodies (e.g. estuaries, lagoons) are often surrounded by large urban populations, infrastructure and industry, all of which have heavy resource requirements. Such demands lead to temporary (e.g. due to pollution, water abstraction, temporary structures) and permanent (e.g. due to land claim, coastal defence, permanent structures) habitat loss. The former can be reversed through management of the pressures, whereas permanently lost habitats are difficult to recreate.

The difference between temporary and permanent habitat loss is partially determined by the initial resilience of the system (see Cross-cutting issues). Habitat loss is especially severe where the key structural species is slow growing (see *Lophelia* case study). Demand for cheap fish, declining stocks, and technological advances have resulted in "fishing down the marine food web" and a move to new fishing grounds; these include relatively unexplored deep water habitats. Around 80% of newly discovered deep water coral reefs in the NEA have signs of fishing gear damage. In the Mediterranean, where the movement to new fishing grounds is limited, there is increasing evidence of illegal trawling of inshore areas resulting in degradation of seagrass beds.

Demand for cheap fish, declining stocks and technological advances have resulted in "fishing down the marine food web"

Invasive and opportunistic species

During the last 10 years shipping transport has expanded in many EU countries, a change linked to the rising number of alien species found in Europe's regional seas. Some of these become "invasive", thriving in their new environment and competing with, and sometimes displacing, native species. For example, in the Baltic 37 alien species introduced in the last 30 years have had an ecological impact. Across the regional seas, shipping

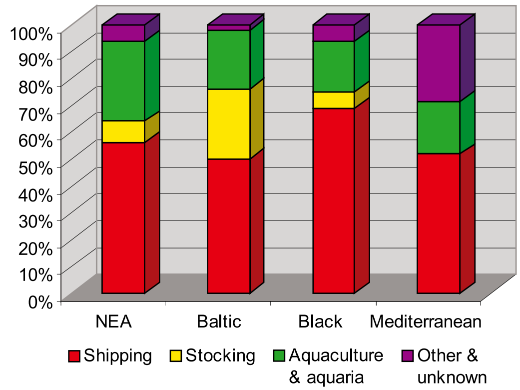


Fig. 26 Proportional mode of introduction of exotic species into Europe's regional seas.

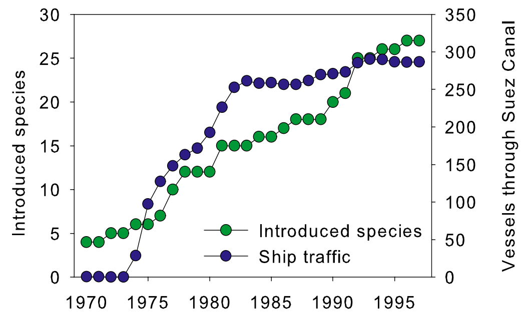


Fig. 27 Cumulative species introductions into the Mediterranean and number of vessels passing through the Suez Canal (after CISEM Atlas, Mostafa, 2004).

is the main method of introduction (fig. 26). In the Mediterranean, the direct impact of shipping is evident, with similar trends between newly recorded alien species and traffic through the Suez Canal (fig. 27). The increase in new species is exacerbated by changes in climate which aid the establishment of warmer-water species in European seas.

Habitat degradation can allow invasive and opportunistic species to colonise, further affecting the health of the ecosystem. Examples illustrated below include alien species which can invade following physical damage (Mediterranean: *Caulerpa*, North-East Atlantic: *Sargassum*, both in seagrass beds) and native opportunistic algae whose growth can be enhanced by nutrient loading (Baltic: filamentous green algae on *Fucus*, Black Sea: *Polysiphonia* (inset) on *Phyllophora*).

New approach for assessing damage of marine habitats

In the absence of large-scale coordinated studies, ELME devised an approach to integrate information on habitat loss and degradation in Europe's

Growth of coastal populations and increased tourism has resulted in loss of suitable habitat for monk seals in the Mediterranean

regional seas. This was critical for understanding the degrees of loss, decline and degradation of key habitats, and their associated causal pressures and human lifestyle drivers. Our method enables the integration of different types of data (quantitative, qualitative, expert judgement and personal communication) across various spatial and temporal scales. By using a ranking scheme ELME integrated scale-related concepts (spatial extent, magnitude and duration). The scheme also considered the recovery potential of the habitat to provide a comprehensive assessment of the importance of the pressure. This enabled prioritisation of pathways through which pressures act upon habitats and is a valuable tool in understanding how multiple pressures interact to cause habitat damage and loss.

Marine Protected Areas

Is it possible to separate human lifestyle pressures from the marine environment? Marine Protected Areas (MPAs) can be effective tools for conserving marine biodiversity by removing the influence of humans. Results from ELME, however, have demonstrated that the successful implementation of MPAs may not be consistent across Europe's regional seas. Success or failure depends upon the major pressures influencing habitat loss. For example, in the Mediterranean, the most important pressures resulting in loss of seagrass habitat are local impacts, such as urban sewage water discharge and trawling damage (fig. 28). In the Baltic, the main pressures are regional in character, involving eutrophication from a range of primarily diffuse sources. Therefore, similar MPAs designated within the two seas to protect seagrass ecosystems may potentially have different results – effective against mitigating local pressures in the Mediterranean, but less successful in the Baltic unless regional problems are resolved.

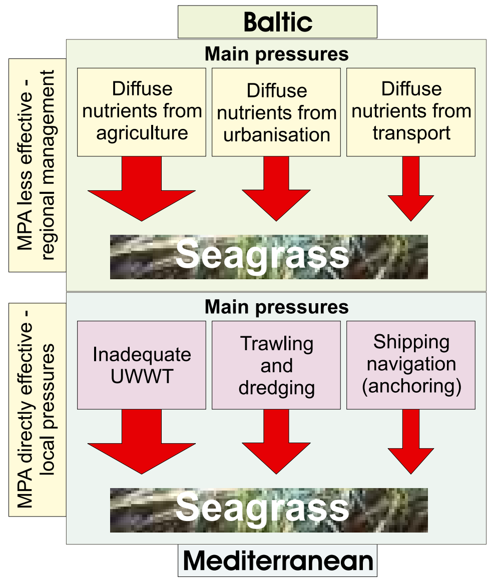


Fig. 28 Effectiveness of MPAs for managing the major causes of seagrass habitat loss and degradation in the Mediterranean and Baltic Seas. Arrows are scaled to represent the importance of pressures.

Discussion: Joined-up thinking

While the Common Fisheries Policy (CFP) may not have achieved the goal of sustainably managing EU fisheries, our study shows that fishery policy is a major driver for shaping fishing effort. The pressure exerted on European marine ecosystems by fishing is more sensitive to regulatory policies than other pressures identified in ELME.

Fishing

Case studies included in this project indicate that the CFP framework results in strong commonalities in driving forces across northern European fisheries. Our findings show that TAC is the most important variable influencing cod catch in the Baltic and is three times more important than any other legislative instrument in the Basque trawl fishery. However, in Turkey and other Black Sea countries, fishing pressure is primarily driven by societal structures and dynamics related to poverty, high unemployment, migration and an under-developed welfare system (see Samsun case study). Thus, fishery policy in Turkey confronts different challenges than in EU fisheries, and the CFP policies, if implemented here, may also have additional effects.

Our case studies also confirm that a second dimension of fishery policy - subsidies and various support schemes - is an important driver in all four regional seas. Although CFP decommissioning schemes may not yet have had much effect in EU-15, our case study of the Baltic cod fishery shows that it has been hugely important in reducing fishing capacity in Poland. Our survey of effects of EU enlargement on fishery policies also indicates that a similar decommissioning scheme can potentially be very effective in Turkey.

Outside of the policy fields, other drivers impact fishing pressure. While 'technological creep' (innovation, improvement) and the cultural importance of fishing are of lesser importance overall, consumption (and hence consumer preference) remains a major driving force. In the case studies where we have been able to model this, there is a strong relationship between demand and landings/stocks (see Basque trawler case study, Cod case study). Although eco-labelling has not emerged as an important issue in our case studies, it is evident that consumer preferences can have considerable impact on fishing pressure. Therefore, policies to stimulate and regulate eco-labelling schemes can potentially have a significant influence on the practice of fishing and its sustainability through consumer preference.

Erratic and unpredictable natural events may also have a huge impact on stocks. This is especially true for the irregular saltwater inflows important for cod spawning in the Baltic. Invasive species - an indirect anthropogenic factor of similar importance - have dramatically impacted fish stocks and overall ecosystem functioning, especially in the Black Sea where the comb jelly, *Mnemiopsis*, contributed to the collapse of anchovy stocks in the early 1990s. Such events are difficult to foresee; for example, we do not know whether or not the recent arrival of *Mnemiopsis* in the Baltic will have damaging impacts on fish stocks. The management challenge related to invasive species is particularly complex when they too become important commercial species (such as the sea snail, *Rapana*, in the Black Sea).

Issues for further analysis

In conducting our studies, we have often been frustrated by the lack of information to populate wider conceptual models that are likely to be needed for implementing ecosystem-based management. An urgent need exists to develop and populate a wider and accessible information base in Europe for this purpose. We outline some issues worthy of further consideration:

Poverty is clearly an important driver in Turkey, but availability of increasingly cheap labour has become important in many European fisheries, especially through labour migration from the east and south. Cheap labour lowers operating costs and there is anecdotal evidence that it can increase safety in cases where vessels have been operating with insufficient crew. On the other hand, such a movement may increase fishing capacity and may also have undesirable social consequences, particularly where the migrants are illegal immigrants, lack training or are operating outside the protection of employment laws.

Another widely recognised factor that we cannot quantify or model is IUU (Illegal, Unregulated, Unregistered) fishing. Narratives and anecdotal evidence of this practice abound and it will shortly be the subject of new EU regulation. The absence of estimates of its extent for individual fisheries impairs the accuracy of simulations. Closely related to this problem is that of bycatch and discarding. Bycatch of non-target species is either landed and reported as catch or unreported and discarded at sea. In some cases, the discards include fish from stocks that are protected by catch quotas which can undermine efforts to conserve stocks.

Similarly, the insufficiency of systematic studies of the ecosystem effect of fisheries (e.g. by 'fishing down the food web' or by the destruction of benthic habitats) has prevented us from fully incorporating this issue into our fisheries case study models.

For future work, we recommend further exploration of a fisheries typology that may enable clear lessons to be drawn from the results of numerous case studies as well as the consolidation of generic models for each type of fishery. This may help to overcome the problems of patchy data that we have highlighted.

Discussion: Emergent issues

Discussion: Emergent issues

ELME focuses on issues where there is sufficient information to model causal relationships. The analysis would be incomplete however, if we did not consider some of the emergent issues, often at time scales beyond the 2-3 decade horizon employed in the present study, that we regard as key to determining the future of Europe's seas:

Climate change

There is little doubt that human-induced climate change is emerging as a consequence of our history of fossil fuel use and the difficulties of decoupling future economic growth from fossil fuel demand. For the sea, there is considerable debate regarding the magnitude of future sea level rise, temperature changes, acidification, wind pattern shifts, increased storm events and changes in runoff. These will have enormous consequences for biological production and diversity, animal behaviour, and resource availability.

The Thames Barrier protects London from increased flooding due to sea level rise and other climate effects

Evidence of the changing behaviour of the NAO is beginning to emerge. Sea level rise is also demonstrating a clear long-term trend and there are legitimate fears that this will accelerate with the melting of polar ice caps. Ocean acidification has recently been demonstrated as a previously unexpected consequence of high atmospheric CO_2 concentrations and this may have serious repercussions for ecosystem integrity in the future. One of the major difficulties is to predict exactly when these climate-related issues will cause major state changes. Our working assumption is that within the 2-3 decade horizon of ELME, climate change will not be a dominant pressure. However, this is no reason for complacency; unless a radical change occurs in current emissions of greenhouse gases, humanity is already locking itself into a situation where massive, and possibly irreversible, changes to marine systems will eventually occur.

Studying and modelling these inevitable changes is extremely difficult. This is because of the insufficiency of historical data – particularly on biological systems - and the difficulty in distinguishing anthropogenically caused changes from natural long-term climatic variations (such as the NAO) that have major impacts on physical drivers and their biological response. This complexity is illustrated in the North Sea study (see Climate box) which shows the regulating effect that changes in the NAO and sea surface temperature have on the phytoplankton community.

Given the large high frequency variations in common indicators (because of weather, plankton blooms, etc.) and their limited availability, attention is being given to 'integrative' indicators such as species shifts in sessile organisms or the cumulative data from the Continuous Plankton Recorder, deployed by Sir Alister Hardy Foundation for Ocean Science (SAHFOS) in the North-East Atlantic since 1931. Tentative predictions have been made in other studies of shifts in fish feeding areas (fig. 29).

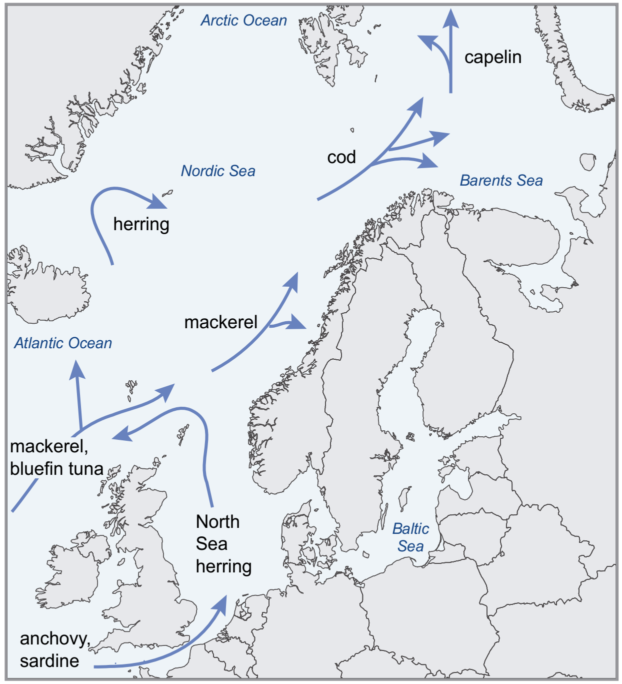


Fig 29 Likely extension of the feeding areas for some fish populations if sea temperature continues to increase (after German Advisory Council on Global Change, 2006).

Research often focuses on the immediate effects of climate change on the environment; however the social consequences of climate change may impose even greater pressure on European ecosystems. For example, water shortages are already affecting the economies and demography of southern Mediterranean

Discussion: Emergent issues

countries while tourism growth is putting higher seasonal demands on the water resources of northern shores. There is likely to be an increasing number of desalination plants built in the future to meet the demand for domestic water consumption, and food supply will rely more heavily on imports. Both solutions will require abundant cheap energy if they are to be viable in the longer term. If temperatures increase above comfort levels for tourism, this economic mainstay may also decline and tourism pressure could move to Europe's other regional seas.

Emerging 'lifestyle' chemicals

Synthetic chemicals are routinely used in manufacturing goods and providing services to the European population. Some of these have well-recognised toxic effects and regulation has been put in place to control their use and disposal (e.g. PCBs, DDT). However, many of these 'lifestyle' chemicals, whilst regulated in the workplace, are released into the environment and have toxic effects including disruption of the endocrine system, carcinogenicity, destruction of DNA (genotoxicity) and damage to cells (oxidative stress). The long-term impacts of these synthetic chemicals on human health and the environment are not fully understood although more evidence is emerging about their detrimental effects. As a result of their pattern of usage, lifestyle chemicals are frequently discharged in waste water and through diffuse mechanisms so that they are routinely present in surface waters and ultimately transported to coastal and marine environments. Their regulation is addressed in several existing EU Directives and initiatives: Water Framework, Nitrates, Groundwater, Pesticides and Sewage Sludge Directives; Registration, Evaluation and Authorisation of Chemicals; Soil Thematic Strategy; Strategy on Sustainable Use of Pesticides; Dioxin Strategy; and the Stockholm Convention on Persistent Organic Pollutants.

As more is discovered about the potential risks these lifestyle chemicals pose, the longer the list of harmful substances becomes. Due to the subtle and chronic nature of the effects, endocrine disruption is of particular concern. Benzotriazoles used in aircraft de-icers, engine coolants, plastic stabilisers and some dishwashing agents are suspected endocrine disrupters. Siloxane, another endocrine disrupter, is found in paints, cosmetics, cleaning agents and fuels and has been observed in marine fish and mammals. Perfluorinated organic compounds (PFCs) are used in fire-fighting foams, electronics, herbicides, paper manufacturing and water resistant coatings on clothing. PFCs have been used for 50 years, but recognition of their potential impact on human and ecosystem health has only emerged recently. PFCs have been found in marine fish, seals and polar bears. Other groups of chemicals of particular concern include pesticides and herbicides, pharmaceuticals (e.g. estrogen in sewage effluent, non-steroidal anti-inflammatories, anti-bacterials), brominated flame retardants, illegal drugs (cocaine), and manufactured nanoparticles (found in clothing, polymers, toothpaste, sunscreen). There is a significant lack of understanding about the pathways, fate and effects of these chemicals, particularly when a number are combined in complex mixtures frequently present in the environment. Consequently, little is known about the impact of these chemicals on natural ecosystems and human health. Despite this, as industrial technology advances, the number of such chemicals in use is expected to increase.

The modelling approach developed and tested within ELME provides a valuable tool for assessing the significance of emerging and known chemicals. However, data on the biological effects of many lifestyle chemicals are scarce, although limited data exist about the effects of tributyltin (TBT), an anti-fouling agent used on ships since the 1960s. TBT has been found to cause imposex (the development of male sexual characteristics) in female dog whelks (*Nucella lapillus*) preventing reproduction and resulting in the death of affected whelks (see photo). TBT was used as a case study: significant drivers and pressures were determined, pathways between pressures and states were addressed, and data gaps were identified. This methodology can be applied to other lifestyle chemicals as data regarding their effects are gathered. The incorporation of socio-economic factors and the application of scenarios will be useful for forecasting likely trends in use and production of lifestyle chemicals. The development of new analytical techniques is challenging and resource-intensive and the ELME approach may be used to focus effort. Where 'hard' data are lacking we can explore the use of proxies to identify the causes of observed state changes and the probable impact on biological systems, making use of previous epidemiological studies.

Example of TBT-induced imposex in a female dog whelk *(Nucella lapillus)*

New uses of the sea

The requirement for natural resources to meet the growing demands for energy and food is already creating a footprint on the marine environment. Some of these uses are innovative and there are few precedents that can be employed as proxies to explore their full consequences. There are a number of other new or potential uses of marine resources such as bio-prospecting for pharmaceuticals that we have been unable to evaluate at this stage. However, we can postulate some potential implications of key emergent issues that could not be modelled in ELME but should be investigated further:

The development of schemes and devices to capture renewable energy is becoming a major priority, particularly with increasing uncertainties for fossil fuel supply and the imperative to reduce carbon emissions. Offshore wind farms have moved from concept to reality (€2 bn already invested) in less than a decade; the first commercial scale trials of wave energy devices are at an advanced planning stage; sea current powered generators have been deployed in trial sites; and new tidal barriers are in planning that could dwarf the Rance Estuary barrier in France. The North-East Atlantic is a prime site for most of these developments but their scale largely depends upon the proportion of 'alternative' energy used in the future, and particularly on the outcome of the nuclear versus renewable energy debate.

Renewable energy installations have local environmental impacts that must be properly evaluated. On a regional scale however, the most significant impact may be the displacement of other users from sites. Operators of wind generator arrays, for example, are keen to exclude fishing activities using towed gear or fixed nets. This offers the attractive potential of creating Marine Protected Areas; albeit somewhat disturbed by cables in trenches and periodic piling operations that can produce mortality of marine animals. The biggest danger is that fishing effort will increase significantly, perhaps unsustainably, in the 'unprotected' areas. The outcome is difficult to predict and future fisheries management will need to adapt to this new reality.

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Aquaculture is becoming increasingly adventurous in the range of species produced, particularly as availability of wild stocks of predator fish decline and prices for these 'luxury' items increase. Pen rearing of sea bream and bass is well established in warm Mediterranean waters and salmon farms abound in coastal seas of Scotland and Scandinavia. There is much discussion of local impacts, the wider implications on the marine food web of exploiting unregulated stocks to supply food for aquaculture, and the long-term consequences of accidental releases of fish with a low genetic diversity (or potentially, of genetically engineered fish). The capture of juvenile wild Mediterranean bluefin tuna and their subsequent pen rearing to adult size has been severely criticised as a factor contributing to the rapid decline of wild stocks. This sea ranching is another activity with outcomes that are difficult to predict. The release of juvenile salmon to the Baltic from hatcheries has been a comparatively successful species conservation activity for many years. In the Black Sea non-native mullet were introduced in Soviet times to boost flagging stocks and have become a popular target species for many fishers. On the other hand, Pacific oysters from farms on the Atlantic seaboard are now replacing wild stocks.

It is important to ensure that future marine policy is not restricted to well established pressures and state changes, but continues to employ horizon scanning as a means of recognising the range of uncertainties that the future may bring.

Discussion: Cross-cutting issues

Beyond the provision of insights into the future status of European seas, ELME has identified a number of cross-cutting issues related to emerging EU marine policy that require further work.

Appropriate scales for management

One of the biggest challenges for managing natural systems is to define appropriate temporal and spatial scales for action. The EU Water Framework Directive (WFD), for example, defines 'River Basin Districts', - largely with watershed boundaries - as the most appropriate scale for assessment and governance. This is a major step forward in integrated management but has resulted in huge issues for data gathering.

The seaward boundary of the WFD is rather arbitrarily set at 1 nautical mile. This arrangement works well for defining targets for controlling inputs of substances into "transitional" waters, but less well when wider sub-regional or regional interests are considered and may result in the transfer of inshore problems to offshore areas by natural forces, climatic variability, or advances in technology. Even within the boundaries used by ELME (based on Europe's Regional Seas Conventions), large spatial inhomogeneities exist. For example, the Baltic and Mediterranean Seas have distinct sub-regions (fig. 30) and the chlorophyll regime is significantly different both between and within the two regional seas. The Gulf of Finland is considerably more productive than the western Baltic, though both are part of a shared marine ecosystem that is clearly distinct from the oligotrophic Mediterranean. The on-going process of development of management boundaries and definitions of 'Good Ecological Status' for Europe's Marine Strategy Directive should consider the characteristics of such sub-regions very carefully.

In the socio-economic sphere, most information is presented within political rather than natural boundaries, leading to spatial mismatch. For example, data on human activities are generally collected at the country level, while data aggregated over geographical scales (such as catchment area or coastal region) would be more relevant to establishing relationships to the marine environment. Additionally, damage to marine ecosystems may result from human activities sited in only part of, or completely outside of, a political region.

While new institutional arrangements may be used to overcome the difficulties associated with differences in geopolitical scales, addressing those that result from the differing timescales between human activities and environmental change constitutes a major challenge for further integrated research. For example, developments in economic activities can be examined over various periods of time but the question arises as to which is most appropriate to assess the environmental effects of those developments and the effectiveness of policy responses. The problem is acutely exacerbated where complex intermediary processes are involved which introduce time lags, such as between inputs of nutrients and the occurrence of eutrophication.

The challenges to integration arise not only from the divide caused by differences in the scales of measurement and management, but also in the divide between social and natural sciences. The DPSIR framework and the lifestyle perspective adopted in our analyses highlight the essential connectedness of human activities and environmental changes. Thus, integration of social and natural sciences is critical to effectively assess sources of damage, environmental effects, and the strength of the linkages between them, and to understand the measures needed to reduce or eliminate these adverse effects.

Our analysis has identified another scale that should not be ignored in future European marine policy. Europe's marine footprint is spreading to other parts of the planet as a consequence of globalisation. Seafood

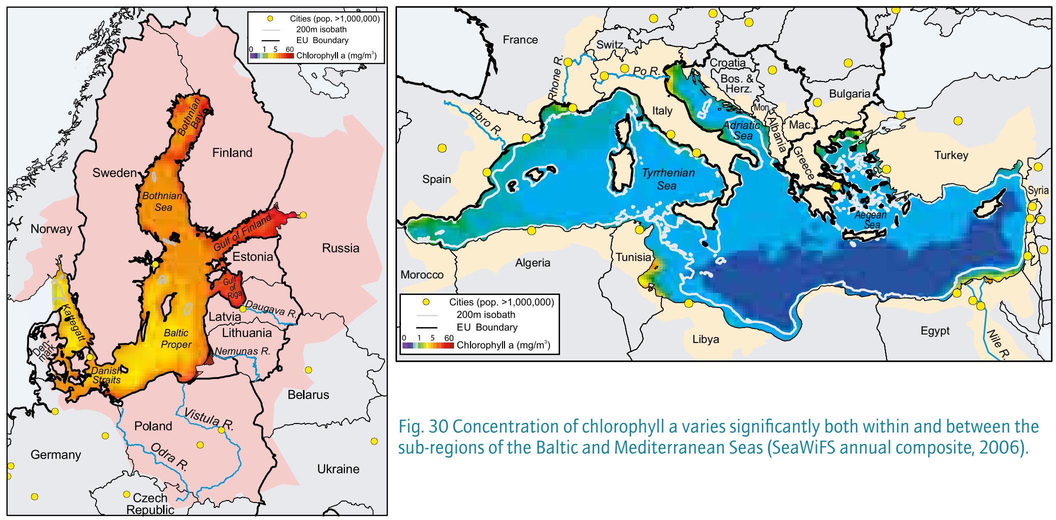

Fig. 30 Concentration of chlorophyll a varies significantly both within and between the sub-regions of the Baltic and Mediterranean Seas (SeaWiFS annual composite, 2006).

and fish products are imported into Europe in massive quantities, partly to substitute for the decrease in production from the region and to supply our growing aquaculture sector (as food for fish) and luxury food markets. Lifestyle chemicals may also be imported and large quantities of our own luxury goods are transported abroad for disposal, potentially contaminating marine environments elsewhere. We have little information on Europe's global marine footprint but this should be assessed carefully and care should be taken not to protect our own seas at the expense of those in other parts of the world. Europe's seas are also affected by burgeoning global trade and the consequent spread of invasive species, an important threat to all of the regions studied (see fig. 26, p. 34).

Non-linearities and regime shifts

A number of our studies encountered situations where certain attributes of the ecosystem suddenly shifted from one relatively stable state to another. In the Black Sea, this probably occurred through a combination of eutrophication and the removal of predatory fish (the former drove the change while the latter weakened ecosystem resilience, fig. 31). Sudden changes are difficult to predict and it is important to manage human pressures so that they are well below thresholds for change. But the thresholds themselves are altered by multiple pressures acting together (e.g. eutrophication *and* overfishing; invasive species *and* habitat disturbance). In the past, the various factors contributing to ecosystem degradation have been managed separately. Ecosystem-based management will need to examine multiple risks and apply precautionary actions to limit them. This may involve new systems of assessment and careful consideration of the complex trade-offs required.

Data and information gaps

Throughout ELME many different types of information have been collated and integrated, from data on major ecological state changes affecting marine ecosystems to pressures on the environment producing these changes

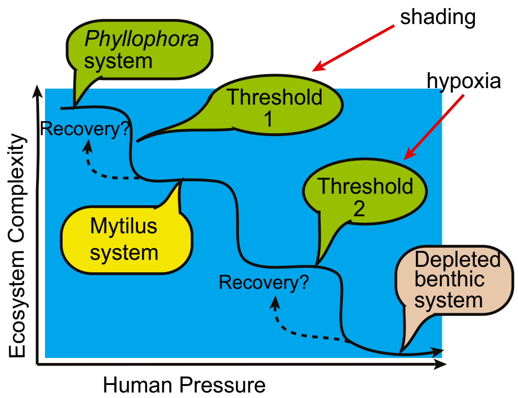

Fig. 31 A combination of eutrophication and overfishing led to stepwise changes in the Black Sea ecosystem.

and the socio-economic drivers leading to these pressures. Some data have been available but large gaps in our knowledge exist and have been highlighted during this process.

Setting baseline conditions has been a challenge for all the regional seas, and in many instances unworkable due to the lack of historic time-series. This has proven

In the Baltic, harmful algal blooms are a symptom of eutrophication

to be a limitation on the simulations, as no amount of model refinement can counter poor/absent data, and this will continue to be a problem in the future. Of the four regional seas analysed within ELME, the Mediterranean and Black Seas clearly had the least reliable ecological data available. For example, the Black and Mediterranean Seas lack a long-term spatially comprehensive plankton monitoring system, a programme which could provide early warning signals of environmental change. Furthermore, fisheries statistics reported for these seas do not consistently include stock estimates.

Information describing pressures on the environment and their socio-economic drivers also varies greatly in quality. In particular, chemical pollution data are almost entirely lacking from the Black Sea and are highly spatially restricted in the Mediterranean. Similarly, key sectoral activities relating to coastal land use and resource exploitation, such as coastal urbanisation, coastal development, coastal defence and aggregate dredging, are extremely difficult to quantify. These activities are predicted to increase in the future, but without a good understanding of past trends and how these have caused degradation and loss of coastal habitats, our ability to forecast is limited. Prioritisation of coherent monitoring programmes is an imperative if we are to sustainably manage Europe's seas.

Abbreviations

ACACIA – A Concerted Action Towards A Comprehensive Climate Impacts and Adaptations Assessment for the European Union

AFMEC – Alternative Future Scenarios for Marine Ecosystems

CFP – Common Fisheries Policy

DDT - Dichloro-Diphenyl-Trichloroethane

DPSIR – Driver – Pressure – State – Impact – Response conceptual framework

FiB – Fishing-in-Balance index

HAB – Harmful Algal Bloom

MPA – Marine Protected Area

MSD – Marine Strategy Directive

NAO – North Atlantic Oscillation

PAHs – Polycyclic Aromatic Hydrocarbons

PCBs – Polychlorinated Biphenols

PFCs – Perfluorinated Organic Compounds

SAHFOS – Sir Alister Hardy Foundation for Ocean Science

SRES – Special Report on Emissions Scenarios developed by the Intergovernmental Panel on Climate Change

SSB – Spawning Stock Biomass

SST – Sea Surface Temperature

TAC – Total Allowable Catch

TBT – Tributyltin

TSS – Total Suspended Solids

TWB – Transitional Water Body

UKCIP – UK Climate Impacts Programme

UWWT – Urban Waste Water Treatment

WFD – Water Framework Directive

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