Alternative future scenarios for marine ecosystems

Technical report

Alternative Future Scenarios for Marine Ecosystems

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Executive Summary

In this report a set of four contrasting AFMEC (Alternative Future Scenarios for Marine Ecosystems) 'futures' are developed, detailing how marine ecosystems might look and how activities in the marine environment might develop over the next 20-30 years given assumptions about climate change and socio-political development.

In elaborating these four 'futures', this report draws on earlier scenario exercises. It aims to complement work carried out by the UK Climate Impacts Programme (UKCIP), the Office of Science and Technology (OST) and the UK Environment Agency.

The scenario framework segments the future 'possibility space' into four quadrants following other work on scenario development. Here scenarios are defined by a 'societal values' axis (ranging from consumerism to community) and a 'governance' axis (ranging from autonomy to interdependence). The four scenarios are: World Markets, Fortress Britain, Local Stewardship and Global Commons.

- The World Markets scenario assumes the prevalence of materialist and libertarian social values operating within interdependent and globalised governance systems.

- The Fortress Britain scenario assumes individualistic and conservative social values, and a reinforcement of a national governance system and identity.

- The Local Stewardship scenario assumes tolerant, community-oriented social values encouraging co-operative self-reliance and regional development.

- The Global Commons scenario attempts to reconcile growth and sustainability, where sustainability is seen from a global perspective, including the maintenance of biodiversity, the protection of global commons (the atmosphere, oceans, wilderness areas) and fair access to environmental resources.

In AFMEC, each of the four 'futures' is elaborated with respect to: climate and hydrography, fisheries and aquaculture, tourism, ports and shipping, nutrients and contaminants, aggregate extraction, oil and gas extraction, offshore renewable energy, flood and coastal defence, biodiversity and conservation.

Extreme, low-probability high-impact geological, astronomical, climatic, ecological and socio-political 'shock' events are also considered and the likelihood of them occurring under each AFMEC scenario.

This report concludes with an exploration of how the AFMEC scenarios might be used in the future, plus a discussion focusing on how they might be further quantified and elaborated upon.

Four Scenarios

World Markets:

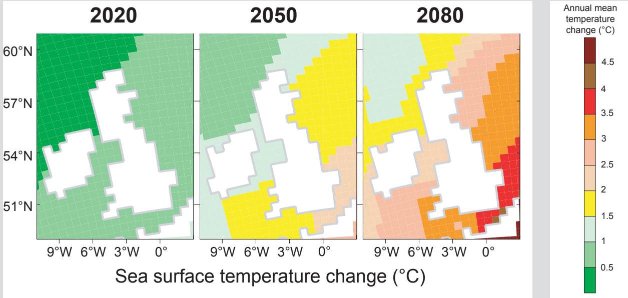
technology and markets fail to deliver sustainable solutions

The 'World Markets' scenario assumes that people aspire to personal independence, material wealth and greater mobility, to the detriment of wider societal and environmental goals.

The role of government in economic management and in the provision of healthcare, education and other social services is greatly reduced by 2020. Pressure grows to reduce taxes, and public services are privatised or privately managed. Social and environmental governance is increasingly achieved through international legal frameworks establishing minimum standards, and implemented using market-based approaches. By 2020, explicit monetary values are ascribed to a wide range of resources and environmental services. Access to these services is limited through charging, or by allocating rights that can be traded.

Under this scenario the structure and function of marine ecoystems are damaged by man's activities. There are increased pressures on marine biological resources, either through resource use or through increasing levels of stressors (eg, habitat loss, eutrophication, changes in water quality). Due to attitudes about the environment under this scenario, little action is taken to mitigate man's effects at the macro-level. Local circumstances result in healthier marine systems in some discrete areas. But marine ecosystem services collapse in other areas, resulting in symptoms such as nearshore algal blooms, increase in invasive species and pests, reduced biodiversity and increasing rarity of top predators such as whales and sharks. Under the World Markets scenario, it is too late to take action that will return ecosystems to previous states - what lies ahead is a permanent altered state for marine ecosystems.

‘World Markets’ Scenario



Ports & Shipping

- Exports from the UK expand to 35% of GDP (£520 billion)
- Growth in international trade and removal of trade barriers/constraints
- Port development largely market-driven
- Deep-water ports in south-east expand, smaller ports close
- Commodities obtained from cheapest suppliers
- Few environmental controls, greater pollution risks
- Arctic ice melting creates new shipping routes

Climate & Hydrography

- Global climate change +0.94°C by 2020
- Channel and North Sea witness 4% increase in wind speed
- West coast experiences 10% drop in summer wind speed
- Sea level rises in southern England, drops in Shetlands

Inputs & Run-off

- River water quality deteriorates.
- Agricultural policy non-interventionist, subsidies reduced
- Technology may allow higher yields with targeted fertiliser inputs, or
- Cheap fertiliser prices may encourage indiscriminate usage
- Inputs of metals and contaminants decline as manufacturing declines
- Low fuel prices will mitigate against expansion of nuclear power
- Radioactive emissions decrease
- Resumption of waste dumping at sea

Fisheries & Aquaculture

- Common Fisheries Policy (CFP) plays only a minor role
- Subsidies (eg for vessel decommissioning) are scaled-back
- The industry becomes more industrialised & global in scale
- Indigenous supplies supplemented with increasing inputs
- High level of fishing effort continues unabated
- Major stocks (cod, plaice, hake) collapse
- Deep sea stocks become heavily impacted
- Rapid expansion in the marine fish-farming industry
- Increased industrial fishing on sandeels (for fish-meal & oil)

Aggregate Extraction

- Increase in number of UK households (to 31 million)
- Substantial quantities of aggregates required for construction
- Aggregates required to maintain coastal defences
- Aggregates obtained from the cheapest sources world-wide
- Extraction carried out by powerful multinational companies
- ‘Aggregates Levy’ abandoned

Tourism & Leisure

- Few constraints on international travel
- Domestic travellers more inclined to go overseas
- Low fuel prices, so jet-skiing, power boating etc. increase
- Cruise ship industry and use of marinas continue to expand
- Warmer climate leads to UK resorts becoming more attractive
- Competition between resorts for investment & development
- Resorts become more homogeneous

Oil & Gas

- Primary energy consumption increases by 1.7% per year
- Continued reliance on fossil fuels, particularly natural gas
- Energy prices remain low because of imports
- Large-scale transportation of oil & gas around the world
- More tankers, terminals and pipelines, greater risk of spillage
- Minimal environmental restrictions
- Installations decommissioned in cheapest way/place

Coastal Defence

- 141-175 m of coastline eroded away over next 100 years
- State withdraws from funding coastal defence
- High value of coastal assets justify high investments
- Coastal defence investment increases to £350 million yr^{-1}
- 240,000 ha of coast protected by defences
- No formerly protected land lost to ‘managed retreat’

Renewable Energy & Construction

- Renewable electricity generation viable, but not widely adopted
- Low priority attached to climate change
- ‘Climate Levy’ abandoned as would constrain economic growth
- Offshore electricity generation at today’s level (16.8 TWh yr^{-1})
- Electricity imported directly from neighbours (using cables)
- European energy generation & trading policy

Fortress Britain:

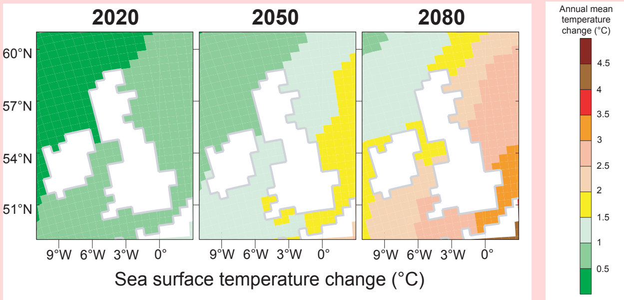
national identity gets in the way of global sustainability

The 'Fortress Britain' scenario assumes that people aspire to personal independence and material wealth within a nationally-rooted cultural identity.

The UK's relationship with the EU remains at arms-length with the balance of opinion favouring entrenchment of independence in economic, foreign and defence policy. The EU is viewed as a trading bloc, market values are dominant, but the scope of markets is limited where they are perceived to be at odds with national interests. Long-term economic growth is somewhat constrained by government policies that restrain international competition and protect key national industries. Conservation and sustainable development are not a main priority.

By 2020, this scenario results in marine ecosystems that are under greater pressures than at present. Collapses of key fish stocks affect local communities and conflicts arise due to conflicting priorities (eg between different spatial users of the marine environment). Marine biodiversity comes under increasing threat as pressure mounts to make the most of indigenous marine resources (fish stocks, minerals, aggregates). Efforts to mitigate against human impacts are abandoned where they conflict with issues of national self sufficiency. Resources are exploited that under any other scenario would prove unprofitable, or their impact unacceptable. Large scale, environmentally damaging projects such as tidal barrages and wide-scale oil exploration develop under the Fortress Britain scenario. Water quality deteriorates and this results in contamination of beaches, sediments and biological resources. Under the Fortress Britain scenario, governments fail to address global problems – what lies ahead are heavily degraded marine ecosystems and fractured relationships with other nation states.

'Fortress Britain' Scenario



Ports & Shipping

- Exports from the UK expand to 28% of GDP (£290 billion)
- Sectors operating in global markets face slow growth rates
- Ports expand slowly as international trade less important
- Less pressure to accommodate larger container ships
- Small ports serving the domestic market are retained and grow
- Fewer international vessels, therefore fewer non-native species introduced
- Royal Navy required to patrol boundaries of EEZ

Climate & Hydrography

- Global climate change +0.88°C by 2020
- Channel and North Sea witness 8% increase in wind speed
- West coast experiences 10% drop in summer wind speed
- Sea level rises in southern England, drops in Shetlands

Inputs & Run-off

- River water quality deteriorates considerably
- Only 50% river water classed as good chemically, 85% 'good' biologically
- High inputs of nitrogen an phosphorous fertilisers
- Environmental protection is weak and pesticide use increases dramatically
- Manufacturing industry declines less, therefore continued inputs
- Metal and organic contamination in the marine environment increases
- Operating life of existing nuclear power stations extended
- Radioactive emissions continue
- Waste dumping resumes at boundaries of EEZ

Fisheries & Aquaculture

- Maintaining UK fishing industry is the key driver
- Government assumes greater control over territorial waters
- National subsidies to ensure capacity remains in place
- Imports still important but less reliance on other countries
- Expansion of domestic aquaculture industry with subsidies
- Expansion of domestic industrial fisheries and their impacts
- Pressure to exploit <u>all</u> of UKs domestic resources
- Cost of enforcement, monitoring, patrolling increases
- Cold water species (eg cod) retreat northwards

Aggregate Extraction

- Moderate increase in number of UK households (to 25.5 million)
- Main priority is maintaining national supplies, exports restricted
- National government plays major role in procurement for large projects
- Large quantities of aggregates required for construction
- Large quantities of aggregates required to maintain coastal defences
- Importance to the nation (e.g housing) takes precedence over environment

Tourism & Leisure

- Focus on national identity and local communities
- Increased visitation by domestic tourists to UK resorts
- Growth of traditional activities, promenades & piers
- Strong emphasis given to the regeneration of seaside resorts
- Role of local authorities & tourist boards are enhanced

Oil & Gas

- Primary energy consumption increases by 1.5% per year
- Emphasis is on maintaining national supplies, control over exports
- Drive to exploit all remaining domestic resources, including oil & gas
- Exploration throughout the continental shelf & into deeper waters
- Many new (short-lived) installations, wide scale decommissioning of rigs
- High energy prices associated with increased difficulty in extracting remaining resources

Coastal Defence

- 113-150 m of coastline eroded away over next 100 years
- By 2080 £87 million per year in damages due to erosion
- Coastal defences protect all housing & commercial assets
- Publicly funded sea defences protect agriculture
- Coastal defence investment increases to £230 million yr^{-1}
- 235,000 ha of coast protected by defences
- 2500 ha of land flooded as a result of 'managed retreat'

Renewable Energy & Construction

- Main driver is maintaining national energy security
- Some small-scale renewable technologies exploited, particularly wind
- Global climate targets viewed as being of only secondary importance
- Offshore electricity generation at today's level (16.8 TWh yr^{-1})
- Tidal barrage built on the R. Severn, energy security takes precedence over environment
- Only finite spatial availability in national waters, other activities take precedence

Local Stewardship:

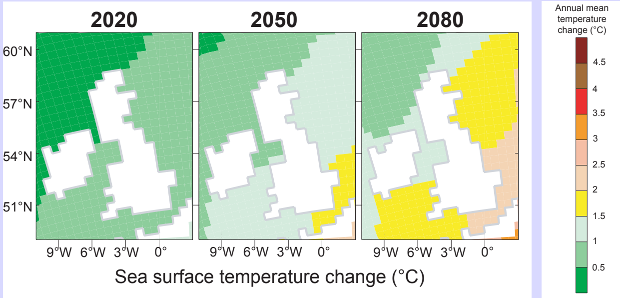
tailored solutions for local problems

The 'Local Stewardship' scenario assumes that people aspire to sustainable levels of welfare in local communities. Active public policy aims to promote economic activities that are small-scale and regional in scope, and acts to constrain large-scale markets and technologies.

Sustainable development is an underlying objective of this scenario. A key focus is on using technology and ingenuity to maximise the utilisation of local and regional resources, while not damaging their long-term use. Global and regional environmental problems receive less attention. There is a strong emphasis on equity, social inclusion and democratic values. There are high levels of public provision for health, education and social services, funded through high levels of taxation. Flows of capital, and trade in goods and services, is constrained, with a greater focus on local resources and development. By 2020 this leads to highly diverse outcomes in different parts of the UK. Economic growth is slow but considerable, social and environmental improvements increase many aspects of the quality of life.

Under this scenario natural marine resources are managed on a more sustainable and long-term basis. Pressure continues to protect but also to exploit indigenous marine resources, and this results in a diverse range of impacts with some marine areas becoming degraded, while others see great improvements. Local communities are involved in the management of the marine environment and in making decisions about local development. With reduced reliance on international trade there are fewer occurrences of introduced species, oil spills and less damage due to port development. Action is taken to mitigate against man's effects at a local level and this results in a healthier marine environment overall. Marine biodiversity benefits under this scenario. With reduced nutrient input to rivers, inshore algal blooms are less frequent. Local action fails to address large-scale global environmental concerns, but on a local scale marine ecosystems revert to what is perceived as a more 'natural' state.

'Local Stewardship' Scenario



Ports & Shipping

- Exports from the UK decline to 20% of GDP (£180 billion)
- Sectors operating in global markets face difficult growth prospects
- Closure of some international ports and supply chains much shorter
- Greater reliance on small-scale local or domestic transport of goods
- Stakeholder input into port development plans
- Fewer international vessels, fewer ballast water problems
- Increased monitoring and legal control of passing ships
- Royal Navy required to resolve local disputes

Climate & Hydrography

- Global climate change +0.88°C by 2020
- Channel and North Sea witness 4% increase in wind speed
- West coast experiences 8% drop in summer wind speed
- Sea level rises in southern England, drops in Shetland

Fisheries & Aquaculture

- The main goal is local self-sufficiency
- The industry is heavily subsidised to protect local resources
- There is strenuous effort to protect wildlife and habitats
- Management responsibility transfers to regional committees
- An effort-based management system is introduced
- The number of small inshore vessels increases
- Reduced dependency on other countries (ie imports)
- A network of closed areas to protect stocks, habitats and species
- Rapid growth in organic and low-input aquaculture

Inputs & Run-off

- River water quality improves dramatically
- 65% river water classed as good chemically, 95% 'good' biologically
- Agricultural subsidies tied to low-intensity farming practices
- Stringent water quality standards, necessitating improved water treatment
- Levels of metals and contaminants decline as manufacturing declines
- High levels of environmental control lead to phasing out of nuclear energy
- Decrease in emissions of radioactivity to marine environments
- Possible resumption of waste dumping at territorial boundaries

Aggregate Extraction

- Moderate decline in number of UK households (to 23 million)
- Much of demand for aggregates met through recycling of materials
- Export of materials restricted, resources owned locally
- National government plays only a small role in procurement and regulation
- Small-scale local suppliers pledged to exploit resource sustainably
- Fallow periods to enable regeneration of biological communities

Tourism & Leisure

- Focus on local identity
- Unique selling points of destinations heavily drawn upon
- Increased visitation by domestic tourists to UK resorts
- Destinations will provide more 'eco-friendly' activities
- Development in-keeping with existing natural landscape
- UK residents support seaside towns of yesteryear
- Co-operatives and joint ventures encourage development

Oil & Gas

- Primary energy consumption increases by less than 0.1% per year
- Some local coal & oil exploited, but with stringent environmental controls
- High energy prices lead to large-scale adoption of energy efficiency measures
- Reduced demand for oil & gas results in lower risk of spillage etc.
- Installations commissioned & decommissioned according to local needs
- Scotland would become owner of UK oil reserves (northern North Sea)
- England would become owner of UK gas reserves (southern North Sea)

Coastal Defence

- 99-138 m of coastline eroded away over next 100 years
- By 2080 £51 million per year in damages due to erosion
- 'Managed retreat' becomes increasingly important
- Coastal defence investment decreases to only £150 million yr^{-1}
- 220,000 ha of coast protected by defences
- 10,000 ha of land flooded as a result of 'managed retreat'
- Substantial loss of coastal grazing marsh

Renewable Energy & Construction

- Wide range of small-scale renewable technologies exploited, particularly wind
- Global climate targets viewed as being of only secondary importance
- Imported energy or electricity less important, local resources become main focus
- Offshore electricity generation expands slowly to 33.6 TWh yr^{-1} in 2020
- Growth in offshore wind sector may be stifled whilst other local resources exist

Global Commons:

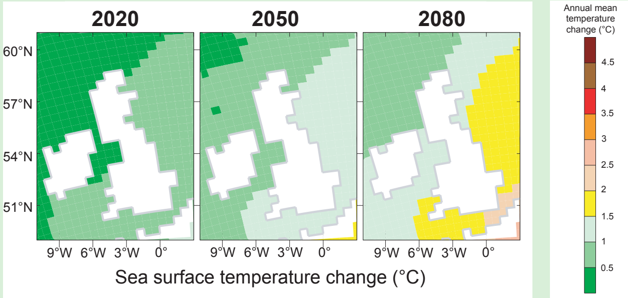
international co-operation towards global sustainability

The 'Global Commons' scenario assumes that people aspire to high levels of welfare and a sound environment. There is a belief that these objectives are best achieved through cooperation at an international level.

Individuals attach high value to balancing economic, social and environmental welfare, and see their personal interests as being connected to a strong and cooperative society. Sustainability is seen from a global perspective, including the maintenance of biodiversity, the protection of global commons (ie, the atmosphere, oceans, wilderness areas) and the fair access to environmental resources. Policy is increasingly coordinated at the EU and international level. This is a relatively high tax scenario.

The Global Commons scenario assumes the slowest rate of climate change. Concerted international efforts lead to a reduction in greenhouse gas emissions. Consequently, marine biodiversity and habitats are less affected by temperature increases and sea level rise. Substantial investment in offshore renewable energy projects does however have a direct impact on seabed communities. International agreements become commonplace and aim to promote the sustainable management of marine resources and to mitigate against damage. Internationally agreed control measures reduce contaminant and pollutant inputs to the marine environment, as well as reducing the risk of spillage and transport of invasive species. Globally the status and health of the oceans improve, although at a local scale it is necessary to sacrifice some areas for development. Fish stocks and populations of top predators (eg whales and sharks) are allowed to recover, many ecosystems revert to what is perceived as a more 'natural' or 'balanced' situation. Under the Global Commons scenario, what lies ahead are healthy marine ecosystems but limited attention to local problems or local stakeholders.

‘Global Commons’ Scenario



Climate & Hydrography

- Global climate change +0.79°C by 2020
- Channel and North Sea witness 0-4% increase in wind speed
- West coast experiences 2-6% drop in summer wind speed
- Sea level rises in southern England, drops in Shetland

Fisheries & Aquaculture

- The main goal is to balance high yields with low impacts
- Resources are obtained from sustainable stocks world-wide
- Management through international authorities
- Greater international integration of science & enforcement
- Effective, unanimous control when stocks heavily depleted
- The number of small inshore vessels increases
- All fish caught must be landed (no discarding allowed)
- Size of European fishing fleet reduced
- Little need for intensive fish-farming, not cost-effective
- Limited growth of industrial fisheries and their impacts

Tourism & Leisure

- Heavy taxes on fuel, discourages overseas travel
- More UK residents visit coastal resorts
- Less powered activities, more focus on ‘ecotourism’
- Increased demand for blue-flag beaches and better standards

Coastal Defence

- 82-123 m of coastline eroded away over next 100 years
- By 2080 £87 million per year in damages due to erosion
- ‘Managed retreat’ where favourable for diverse habitats
- The majority of investments in coastal defence are public
- Coastal defence investment remains at £200 million yr^{-1}
- Only 225,000 ha of coast protected by defences
- 15,000 ha of land flooded as a result of ‘managed retreat’
- Substantial loss of coastal grazing marsh

Ports & Shipping

- Economy is increasingly export-oriented, 25% of GDP (£360 billion)
- Increased international trade therefore expansion of port facilities
- Commodities obtained from sustainable sources world-wide
- International action to control vessel emissions
- International action to encourage safer ships and good practice
- Busier waterways & longer shipping routes
- Europe-wide ports development strategy
- Royal Navy part of an international enforcement body

Inputs & Run-off

- River water quality improves dramatically
- 75% river water classed as good chemically, 95% ‘good’ biologically
- Reduced pesticide inputs & shift to cleaner production in industry
- Stringent water quality standards, necessitating improved water treatment
- Levels of metals and contaminants decline
- High levels of environmental control lead to phasing out of nuclear energy
- Decrease in emissions of radioactivity to marine environments
- International conventions prohibit waste dumping at sea

Aggregate Extraction

- Expansion in the number of UK households (to 27.5 million)
- Much of demand for aggregates met through recycling of materials
- Strong international control over industry and environmental impact
- Strong international legislation to protect habitats & species
- Restrictions such as the ‘aggregates levy’ become more prevalent
- Smaller quantities of aggregates required for beach replenishment

Oil & Gas

- Primary energy consumption increases by less than 0.1% per year
- Natural gas remains dominant energy source up to 2010
- High energy prices result from stringent environmental controls
- International controls over safety and environment (tankers, pipelines etc.)
- Small, short-lived fields not exploited
- Rigs decommissioned where the least environmental damage will be inflicted

Renewable Energy & Construction

- Main emphasis is on international action to protect the environment
- Control of global climate emissions (Kyoto Protocol) seen as important
- After 2010 renewable energy sources gain large market share (30% of UK needs)
- Offshore electricity generation expands quickly to 100.8 TWh yr^{-1} in 2020
- As offshore industry expands, causes wide-spread disruption of the seabed
- Installations lead to the creation of areas closed to fishing and new ‘artificial reefs’

Key messages

- Under all four scenarios sea temperatures are expected to increase. Differences in predicted climate and sea-level are relatively small up to 2020 but become more apparent thereafter.

- Climate change will not only cause changes in average temperatures, but will also trigger more so-called 'extreme weather events' under all four scenarios. Hot summers, intense precipitation and coastal flooding will all become more prevalent.

- Energy policy will be a key factor in determining the status and health of future marine ecosystems. It will determine whether offshore windfarms or inshore tidal barrages are constructed. It will determine whether wide-scale oil exploration is required on the continental shelf and whether large amounts of oil or gas need to be transported by ships around the world's oceans. It will determine the need for nuclear power stations and thus the release of radioactive materials into the marine environment. It will determine the release of greenhouse gasses and hence influence global climate.

- World-trade and globalization might have a big impact on marine ecosystems, determining the need for port facilities and cargo vessels, influencing the ability of non-native species to be transported around the world, determining whether local resources are exploited or imported from elsewhere.

- Spatial planning issues are likely to become more important under all four scenarios, whether the balancing of development versus food production or national/local self-sufficiency, against the setting aside of areas for the protection of biodiversity/habitats and/or recreational use.

- Policy objectives and initiatives on land can never be fully divorced from impacts in the marine environment. Changes in agriculture or manufacturing lead to different levels of inputs (contaminants or nutrients) to marine ecosystems, housing policy influences the demand for marine aggregates, food prices determine the demand for fish and shellfish.

- However well we might hope to plan for the future of the marine environment, such plans can always be disrupted by sudden and inexplicable 'shock events', whether in the human environment (eg wars, famines or new discoveries) or in the natural environment (eg sudden climate change, tsunamis, disease/pest outbreaks).

1. Devising the scenarios

1.1 Introduction to the report and to the project

AFMEC is a strategic project funded under Defra's 'Horizon Scanning' initiative. The Horizon Scanning Programme was established by Defra's Chief Scientific Adviser in 2002, in order to anticipate and prepare for new science risks and/or opportunities. Horizon scanning research aims to encourage crosscutting thinking in both the natural and social sciences.

The goal of the AFMEC project has been to encourage debate about alternative futures for marine ecosystems, and to develop a series of future scenarios that can be used by Defra and other stakeholders for strategic planning.

Whilst marine ecosystems around the UK provide the main focus for the AFMEC project, the study is framed within a wider EU and global perspective. In terms of future time-frames, the AFMEC scenarios were developed for the next 20-30 years and they are designed to be compatible with similar 'futures' work carried out by the UK Office of Science and Technology (OST)[1] and the UK Climate Impacts Programme (UKCIP)[2,3].

AFMEC has made extensive use of recent modelling work carried out by the Prime Minister's Strategy Unit, ie, *Net Benefits: A sustainable and profitable future for UK fishing*[33]. This important project itself made use of scenario planning and some of the imagined futures are virtually identical to those independently developed here.

The AFMEC scenarios are also designed to complement the recently published, *'Charting Progress: An Integrated Assessment of the State of UK Seas'*[154] and to provide discussion material for deliberations surrounding the development of a UK Marine Bill in 2006 and potentially a Marine Strategy at the EU level.

1.2 What is this report for and what does it contain?

This report describes and presents four possible 'marine futures' for the United Kingdom. The differences between these four visions are a result of alternative paths of world development or governance, different climate change scenarios and contrasting societal values. The scenarios illustrate the possible impact on the marine environment and marine-related activities, of choices being made about technology and about lifestyles; each of which has consequences for emissions and exploitation of natural resources.

This report contains the following information:

- it <u>summarises</u> the changes that are already occurring in the marine environment of western Europe;
- it <u>presents</u> four contrasting visions, including information about fisheries, aquaculture, offshore wind energy, oil and gas exploitation, shipping, aggregate extraction, pollutant inputs, marine tourism and climate change;
- it <u>highlights</u> the main areas of uncertainty within the scenarios and explores those considered of greatest importance;
- it <u>warns</u> about sudden discontinuities and extreme-events which might divert future policy away from a particular course;
- it <u>directs</u> users to further sources of information, both quantitative and qualitative, that will assist in using AFMEC scenarios for scoping impacts or policy analysis in the UK.

1.3 What are scenarios?

One of the most effective ways to communicate complex issues is in the form of a relatively small number of contrasting "scenarios", which lay bare the conflicts and inconsistencies buried in the often very daunting technical information[4].

Scenarios are imagined 'futures'. They do not come singly, as a forecast would, but in sets of alternatives. Scenarios are not necessarily "visions" or "plans", but they can help to guide strategy. They describe both optimistic and problematic futures. Each may concentrate on a different driver of change (eg sustainable development) or a different area of influence (eg fisheries or port development). Scenarios work well when they explore different ramifications and extensions of one central driving force. There is no temptation then to choose between them and they are all equally relevant (see Chapter 3)[4].

Good scenarios help us to understand how key drivers might interact and affect the future. Scenarios create representations of alternative worlds and can offer an inclusive and systematic way of thinking about what the future might look like. Scenarios go beyond a single best estimate, or a 'high' and 'low' projection either side of this, and encourage us to explore a number of different, logically-consistent pathways.

Scenarios describe the relevant world as it might be, far enough ahead to be beyond the scope of trend extrapolation, and after radical shifts in the social and cultural conditions which we unconsciously assume to be fixed. The wealth of recent experience suggests is that there is no single strategically best way to work with scenarios. However, well-designed scenarios do seem to share some common features[4]:

- DIY: scenarios are best created by a panel - or at least commissioned and then explored and focused by a panel.
- 10 years distant, or longer: scenarios are for the future that we cannot see, yet must still plan for. Their horizon is typically around ten years, though it may be as little as five when change is fast or chaotic, and as much as fifty when strong and unambiguous drivers are operating.
- Credible: scenarios are not forecasts. They can usefully examine fairly extreme sets of consequences of the driving forces. However, it is important that those involved feel comfortable with each scenario - however surprising, they should be able to imagine living in such a world.
- Internally consistent: it follows that the social, political, economic, environmental, technical and cultural features of a scenario should hang together, as they would if a piece of consistent history had been written leading up to that state of affairs.
- Focused: the best scenarios dramatise a few key features or events which are of prime concern.
- Plural: some groups have experimented with a unique scenario. This is usually a mistake, because a single view of the future is too easy to confuse with a forecast. The practitioners' consensus is that two is a minimum and, in the time usually available, four is a maximum.
- Striking and sometimes uncomfortable: one of the prime objectives of scenario work is to startle managers, fire their interest and get them thoroughly involved and excited. Scenarios should never be boring.
- Dramatised: scenarios work best when they are dramatised in various ways - brought to life by scene-setting, stories, case-studies metaphors or encapsulated in memorable and vivid catch-phrases (see Section 1.6).
- Altering plans and recommendations: the acid test of good scenarios is that working with them changes the vision or plan that was proposed before the exercise. If one goes out by the same door that one went in, then the scenarios were probably too remote to have been useful.

1.4 Scenario exercises in the UK

In 1997, the Intergovernmental Panel on Climate Change (IPCC) established an expert group to prepare global socio-economic scenarios (SRES)[5]. Four main 'storylines' (with 40 variant scenarios) were developed, each describing possible future worlds and taking into account factors such as global population trends, land-use changes, economic growth and per capita income. These contrasting 'storylines' have subsequently proven to be of great utility, and they have formed the basis of many regional or national-scale evaluations[5].

In April 2002, the UK Climate Impacts Programme (UKCIP) developed and published four possible climate futures for the United Kingdom, based on the SRES framework[2]. The UK Office of Science and Technology (OST) also used the SRES system when formulating much broader-scope UK-orientated scenarios under their 'Foresight' programme[6]. The recently released 'Foresight Future Flooding' report (22 April 2004)[22], outlined the possible risks for the UK from flooding and coastal erosion (see Section 2.9), and highlighted the decisions that need to be made under each of the four scenarios, to protect people, homes, businesses and the environment in the future. The Environment Agency adopted a similar generic scenario framework for their work on forecasting water demand, although they used different nomenclature (alpha, beta, delta, gamma)[7].

'The Tomorrow Project' is an initiative which aims to examine peoples' lives upto 2020. It is funded by a range of public and private organisations in the UK, and it was set up in order to allow society to learn about the choices which will influence the future. For example, in 2002 it prepared a report for the Countryside Agency[8] in which four scenarios were described (Go-for-green, The-country-means business, All-on-board, The-triple-whammy) based on social cohesion/inclusiveness and environmental sustainability. They identify the main drivers of change, and the potential impact on rural areas and communities over the next 20 years.

In 2001, the UK Defence Evaluation and Research Agency (DERA) conducted a meta-analysis of the published body of 'strategic futures' work in the UK. The aim of this analysis was to come up with a consensus view describing the key drivers for change that might be expected to affect UK policy over the next decades, and also to contrast the different approaches used in 'Futures' thinking[9].

In 2004 the Prime Minister's Strategy Unit published it's *Net Benefits* report[33], providing a long-term strategy for management of the UK fishing industry. This document included three scenarios developed and refined by stakeholders: **Market-World**, **Green-World** and **Fortress Europe**.

1.5 Marine scenarios world-wide

There have been a number of earlier attempts to construct sectorially-based scenarios, but it is clear that there have been few over-arching scenarios for the marine environment generally. The lack of any previous integrated assessment makes AFMEC particularly worthwhile.

The nearest attempt at crosscutting, non sector-based scenarios were those constructed by the New Zealand government. In a report titled 'Setting course for a sustainable future: the management of New Zealand's Marine Environment', the parliamentary commissioner for the environment outlined future visions for New Zealand up to the year 2043[10]. Imagined futures for the fishing industry, aquaculture and coastal zone management were included. These scenarios were not mutually exclusive and significant climate change (a 3.5ºC rise in global temperatures) was implicit in each of them.

Even among marine sectors, the prevalence of scenario work can be patchy. The fisheries and oil sectors have received much attention whilst others (eg shipping) have benefited relatively little from scenario planning (see Section 2.4). A recent paper by Canadian Scientists[11] proposed four scenarios (see Figure 1.1) to investigate the future of marine fisheries world-wide, based on earlier work by the UN Environment Programme (UNEP)[12]. The four scenarios were: (1) **Markets First**, where environmental policy is subject to un-regulated market forces; (2) **Security First**, where national interests take precidence; (3) **Policy First**, where regulatory reforms result in tighter environmental controls; and (4) **Sustainability First**, where global and long-term sustainability of resources is the key driving force.

The Netherlands National Council for Agricultural Research presented a similar set of scenarios and future priorities for the year 2015, focusing mainly on North Sea ecology and the impacts of fisheries[13]. Three scenarios were proposed:

- **Commercial sustainability** – in this scenario the role of the government is very limited, with strong steering through market forces.
- **Nature Reserve North Sea** – the management of environmental issues and nature becomes a core task for governments. This leads to more effective European policies but also conflicts between member states.
- **The Drifting Fleet** – characterized by a shift of political power to Brussels, a withdrawing national government and declining support for fisheries as an economic sector. Diminishing subsidies and a 'Euro levy' on diesel fuel, increase the pressure on the profitability of the fisheries sector.

A study conducted by the World Fish Centre (Malaysia) in 2003[14] used a global economics model (IMPACT) to provide regional predictions (up to the year 2020) of fish prices, fish production, per capita fish consumption, and the contribution of aquaculture given six contrasting scenarios. The scenarios included: (a) a 'best-guess', judged to be the most plausible; (b) a scenario assuming faster aquaculture expansion world-wide; (c) a scenario whereby feed conversion efficiency for fishmeal and fish-oil improved markedly; (d) a scenario assuming slower aquaculture expansion; (e) a scenario which attempted to modify the 'baseline' to account for the over-estimation of Chinese fishery landings; and (f) a scenario assuming complete ecological collapse.

Pope (1989)[15] proposed scenarios for fisheries research and management in the North Sea. Four contrasting visions were elaborated; North Sea as a 'playground', North Sea as a 'foreign exchange earner', North Sea as a 'fish farm', North Sea as a 'larder', each taking into account changing climate, economy and leisure activities.

ACTIS, a geoscience consulting company produced 'big-oil', 'little-oil' and doomsday' scenarios for the North Sea oil industry in the form of newspaper articles[16]. 'Big-oil' is a world characterised by large multinational oil companies, rationalisation and unrestrained market forces. 'Little-Oil' is a world in which small independent oil companies dominate and the government is pro-active in encouraging new developments. 'Doomsday' is a world whereby the oil industry in North Sea is in a state of perilous decline, largely as a result of high taxation and restrictive environmental legislation.

The Millennium Ecosystem Assessment (MA) is an international program, launched by U.N. Secretary-General Kofi Annan in June 2000[17]. It is aimed at investigating the consequences of ecosystem change for human well-being and at evaluating options for responding to these changes. In March 2004 four scenarios were published (see Figure 1.1), focusing on development paths for ecosystems and their services over the next 50 years[17]. The four ideological scenarios were named: (a) **Global Orchestration**, (b) **TechnoGarden**, (c) **Order from Strength**, and (d) **Adapting Mosaic**, each of which has different implications for the marine environment.

The **Global Orchestration** scenario is characterised by a strong belief that social and economic well-being will, in the long run, improve ecological condition. The central tenet is that a combination of markets coupled with policies aimed at fostering good governance and equity, will ultimately provide appropriate solutions to society's problems. Under the **TechnoGarden** scenario, technology and market-oriented institutional reform are used to achieve solutions to environmental problems. Technological improvements that reduce the environmental impact on goods and services are combined with improvements in ecological engineering that optimise production of ecosystem services. In the **Order from Strength** scenario the World becomes progressively compartmentalised as governments and then businesses and citizens turn their focus inwardly in response to threats from global terrorism and breakdown of processes involving global co-operation. They see looking after their own interests as the best defence against economic insecurity. Underlying the **Adapting Mosaic** scenario a rich mosaic of local strategies to manage ecosystems and ecosystem services emerges, but eventually the focus on local governance leads to failures in managing the global commons. Problems such as climate change, marine fisheries and pollution grow worse and global environmental surprises (see Section 4) become common.

1.6 The importance of memorable phrases

As stated in Section 1.3 (above), experience has shown that scenarios work best when they are dramatised in various ways - brought to life by scene-setting, stories, case-studies, metaphors or encapsulated in memorable and vivid catch-phrases.

This is the approach taken by Constanza (2000)[18] who in essence, developed scenarios which were very similar to those subsequently developed under the Millennium Ecosystem Assessment (see Section 1.5, above). Constanza chose to breathe extra life into his scenarios by giving them imaginative and thought-provoking names (although see criticism of this approach by Vanclay 2000[19]).

Constanza's four scenarios[18] were based around the distinction between 'technological optimism' and 'technological scepticism' (see Figure 1.1). The 'technological-optimist' World-view is one in which technological progress is assumed to be able to solve all current and future social problems. It is a vision of continued expansion by humans and their dominion over nature. However, there are two versions of this vision: (a) the positive version (the optimists were right), whereby technology solves all future energy and food demands and reduces the need for fossil-fuels; and (b) the negative version (the sceptics were right), whereby technological solutions do not materialise and there is widespread ecological collapse, flooding and famine. Constanza chose to label the former possibility as **Star-Trek** after the popular TV series that is its most articulate and vividly fleshed-out manifestation; he called the catastrophic vision **Mad-Max** after the popular movie which embodies many aspects of this vision gone-bad.

The 'technological sceptic' or precautionary worldview depends much less on technological change and more on social and community development. It assumes that some technologies may create as many problems as they solve, and that the key is to view technology as the servant of social policies rather than the driving force. Constanza labelled the vision that corresponds with the sceptics being right, as **Ecotopia** after the popular book of the 1970s. He called the situation whereby the optimists turn out to be right about the real state of the world, **Big Government** or alternately **Ronald Reagan's worst nightmare** of overly protective government policies getting in the way of the free market.

When 418 members of the public (316 Americans and 102 Swedes) were asked to rank the visions in terms of overall desirability, the majority found the 'Ecotopia' vision as most desirable and the 'Mad-Max' vision as wholly undesirable. Most also ranked the 'Star-Trek' vision highly, and this Constanza suggests, reflects a general ambivalence about the direction in which society currently seems to be heading. While many found 'Big-Government' acceptable, some found it completely abhorrent (probably because of the limits on individual freedom implied), and interestingly Swedes were more favourably disposed to 'Big-Government' than were Americans.

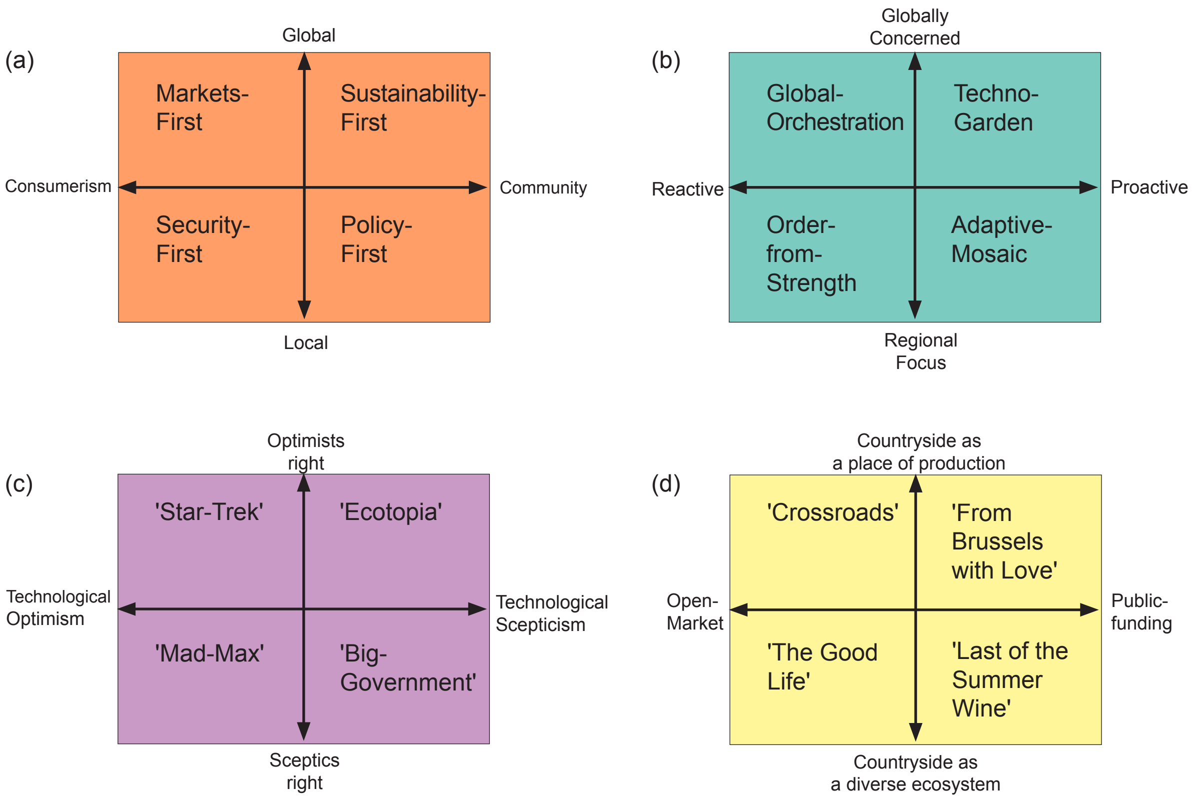


Figure 1.1. Existing four-quadrant scenario frameworks: (a) UNEP, (b) Millennium Ecosystem Assessment, (c) Constanza 2000, (d) DEFRA 2001.

In the early months of 2001 following the inception of Defra, the government department made use of memorable and vivid scenarios to help promote discussion about strategic policy objectives (as part of the government-wide 'Strategic Futures' project)[20]. The four scenarios it created were centred on two alternative views of the countryside, - as a place of production or as a diverse and sustainable ecosystem; and two means of supporting rural economies/activities, public-funding or free-markets. The four scenarios were labelled: (a) **Last of the Summer Wine**, whereby subsidies play a role in preserving the environment and landscapes; (b) **Crossroads**, where global trade liberalisation continues apace; (c) **From Brussels with Love**, characterised by a 'Fortress-Europe' mentality and heavy subsidies; and (d) **The Good Life**, whereby land is taken out of farming and given over to nature and leisure activities (see Figure 1.1).

In preparing scenarios for AFMEC, and following consultation with stakeholders, it became clear that names with sufficient resonance and immediate impact would be desirable here too. We henceforth refer to the AFMEC scenarios as: World Markets, Global Commons, Fortress Britain and Local Stewardship. Section 1.7 describes how these scenarios were derived, and how they map onto earlier initiatives. For the sake of clarity this report uses colour coding at each mention.

1.7 How were the AFMEC scenarios derived?

At two stakeholder workshops participants from a wide variety of marine-related disciplines (see Annex 1) were asked: (a) to outline what key issues should be elaborated under each scenario, and (b) to refine and amend scenarios once draft versions had been prepared.

At the first workshop in London (March 2004) participants were tasked with defining key 'attributes' within six activity domains: (1) offshore energy & construction, (2) fisheries, aquaculture & conservation, (3) marine inputs and water quality, (4) extractive industries in the marine environment), (5) ports & shipping, (6) tourism & leisure. The first workshop was attended mainly by representatives from government agencies (eg English Nature, Environment Agency etc.) and academic institutions, it aimed to provide much of the narrative for the four scenarios.

'Attributes' are considerations or factors which are likely to differ under each imagined future, and which would hence require further elaboration. Participants suggested, for example, that scenarios should be elaborated with respect to 'seabed disturbance, 'spatial planning issues' and 'navigation risks' under the 'offshore energy & construction' activity domain. The outputs from this task provided much of the material now included in Chapter 2 of this document.

In addition participants at the first workshop were issued with a broad description of the socio-political conditions (see Section 1.10) assumed within each of the AFMEC scenarios, and they were asked to derive a list of two key questions for three out of four scenarios and for each of the six activity domains. This exercise provided vital contributions for developing the 'character' of each future vision. Gaps were filled (the remaining one scenario out of four) by 'triangulation', ie, considerable effort was dedicated to ensure that the same broad issues were addressed under each scenario (see Section 1.3 with regard to 'symmetry').

Between the first and second workshops a draft version of Chapter 2 (sector by sector storylines) was prepared, summarised and circulated. The second workshop (in June 2004) was attended by a much broader range of stakeholders including representatives from companies and industry associations. The agenda for the day comprised of two main tasks in small breakout and brainstorming groups lead by a nominated chairperson: firstly to comment on the proposed draft scenarios, and to discuss how these might be improved; secondly to discuss possible low-probability 'extreme events' and also how the scenarios might be used or developed in the future. As such the second workshop provided much of the material now comprising Chapters 4 and 5 of this document.

As recognised by the United Nations Environment Programme (UNEP), in their handbook on methods for climate change impact assessment[21], it is "impossible to make a scenario of everything" and to encompass all possibilities. UNEP also state that 'scenarios do not have to be developed from scratch;' they can be borrowed or adopted from the literature. Futurists are 'strongly advised to rely on existing scenarios to save time and to be comparable and consistent'.

This is the approach we have taken to develop the AFMEC scenarios, ie, to build on the wealth of existing scenarios work (as outlined in Sections 1.4, 1.5 and 1.6), but to meld and amend such scenarios to meet our own purposes.

The four-quadrant approach, whereby the future 'possibility-space' is divided, based on two axes or dimensions has become commonplace (see Figure 1.1) following its earlier adoption by the Intergovernmental Panel on Climate Change (IPCC)[5]. The basis of the 4-quadrant model involves the identification of the two driving forces with the greatest importance and the highest uncertainty. Many existing scenario exercises, whether coincidentally or not, seem to have chosen similar criteria to define their 'possibility-space', with an axis representing 'local to global' and an axis representing societal/economic intervention (from community to consumerism). Conveniently, in broad terms, this means that many existing scenarios, can be mapped onto one another (eg Table 1.1).

The most widely used scenarios in the UK are those produced by the Office for Science & Technology (OST)[1] and also those produced by the UK Climate Impacts Programme (UKCIP)[2,3], both of which possess the same basic architecture inherited from SRES and IPCC[5].

The four 'Futures' are represented on a two-dimensional grid (Figure 1.2). At one end of the horizontal axis ('Individual'), values are dominated by the drive towards private consumption and personal freedom. The rights of the individual and the present are privileged over those of the collective and the future. Resources are distributed predominantly through free and competitive markets, with

Table 1.1. Broad correspondence between scenarios developed under various earlier exercises and those developed for the marine environment under AFMEC.

SRES Story-line[5]	Millennium Ecosystem Assessment[17]	OST 'Foresight Futures'[1]	UKCIP Socio-economic Scenario[3]	Environment Agency water demand Scenario[7]	UKCIP02 Climate change Scenario[2]	AFMEC Marine Scenario	Net benefits[33]
B1	Techno-Garden	Global Commons	Global Commons	Gamma	Low Emissions	Global Commons	Green World
B2	Adaptive-Mosaic	Local Stewardship	Local Stewardship	Delta	Medium-Low Emissions	Local Stewardship	–
A2	Order-from-Strength	Provincial Enterprise	Fortress Britain	Alpha	Medium-High Emissions	Fortress Britain	Fortress-Europe
A1FI	Global-Orchestration	World Markets	World Markets	Beta	High Emissions	World Markets	Market-World

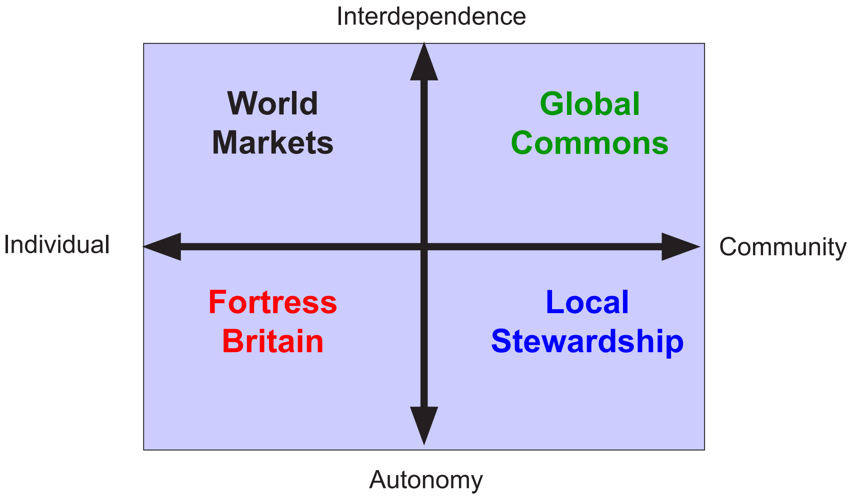


Figure 1.2. The four-quadrant scenario framework used by AFMEC (based on OST[1] and UKCIP[2,3] – see Table 1.1).

the function of governance limited to regulating markets and securing law and order. At the other end ('Community'), values are shaped by concern for the common good. The individual is seen as part of a collective, with rights and responsibilities determined by social goals. There is greater concern about the future, equity and participation. Civil society is strong and highly valued, and resources are allocated through more heavily regulated markets.

At one end of the vertical spectrum ('Interdependence'), the power to govern is distributed upwards, downwards and outwards away from the national state level. International economic, political and cultural relationships strengthen, and regional and national boundaries become more permeable. At the other end of the spectrum ('Autonomy') economic and political power is retained at national (Fortress Britain) and regional (Local Stewardship) levels. Sovereignty is retained over key areas of policy, and the processes characterised as 'globalisation' are weakened. Governments have greater autonomy in decision-making, and economic, political and cultural boundaries are maintained or strengthened. National and regional development is linked more closely to local capabilities and resources.

Apart from the adoption of slightly more evocative names (Fortress Britain instead of National Enterprise, Global Commons instead of Global Sustainability), the AFMEC scenarios follow the same basic format, and have been designed to complement those of OST[1] and UKCIP[2,3]. Indeed, in developing the AFMEC scenarios many parameters which had been quantified in the earlier studies were taken 'as read' here. In particular UKCIP (2001) provided useful estimates for GDP, exports, household numbers, agricultural production, water quality and investment in coastal defence. Such values proved invaluable when attempting to elaborate consequences for the marine environment. In addition, UKCIP[2] provided useful narrative for each scenario concerning environmental policy, energy policy and the attitude towards biodiversity and nature conservation. Recent outputs from the OST Foresight-Flood & Coastal Defence programme[22] were also utilised, in Section 2.9 of this report.

1.8 Additional variants?

In reality there are an infinite number of possible 'futures' (a multidimensional 'possibility-space') and in some scenario exercises separate variants of the four main visions have been proposed. The IPCC SRES[5] scenarios for example, consist of 4 main storylines, but the A1 storyline (equivalent to 'World Markets') is divided into three variants, labelled A1FI (intensive fossil fuel use), A1T (non-fossil energy sources), and A1B (a balance of energy fuels). Pope's (1989)[15] three scenarios for fisheries in the North Sea can be divided into 8 variants on the basis of climate change and assumptions about the state of the economy. Several authors have proposed reliance on new technologies as a possible further dimension (notably the Millennium Ecosystem Assessment[17] and Constanza 2000[18]), whilst others have created variants with or without a particular (sudden) event occurring and subsequent feedbacks.

In constructing the AFMEC scenarios we have deliberately tried to keep the structure simple. We ask the reader to take 'as read' certain assumptions about climate, economic growth and technology. Each AFMEC scenario assumes a specified level of climate change (as prescribed for the equivalent scenario by UKCIP[2,3]). We also assume a specified set of economic conditions (see Section 1.9, Table 1.2), and population growth – as outlined in the UKCIP socio-economic scenarios. Major shocks or extreme events are not part of the storylines presented here, although they are discussed at length in Chapter 4.

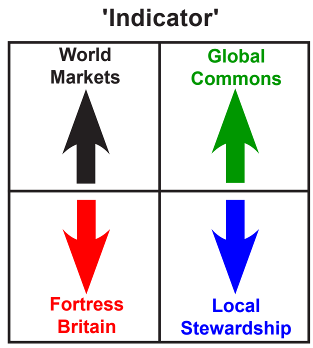
Participants at the two scenario elaboration workshops expressed concern that several of the scenarios (notably World Markets and Global Commons) could have an 'alternative reality' depending on the role of China as an emerging superpower in the global economy. Here we have chosen to remain consistent with the assumptions of UKCIP (2000[3]) which do make some allowances for developments in Asia, and competition from newly industrialising nations.

A review of the global 'futures' literature[23] identified five main dimensions of choice: demography and settlement patterns; the composition and rate of economic growth; the rate and direction of technological change; the nature of governance (global or local); and social and political values (individualistic or community).

For a number of reasons the last two have been considered the most relevant dimensions in the majority of studies (including AFMEC). Human demography in developed societies is relatively well-characterised in current population models and does not need to be contested within the scenario elaboration process. Economic growth can be regarded as the outcome of a set of institutional factors (economic and monetary policy, trade, the liberalisation and regulation of markets and so on), not as an autonomous factor of change. Likewise, technology is regarded as being shaped by market, regulatory, political and cultural factors and should not be seen as an autonomous factor of change. This corresponds with theories in evolutionary economics that see the rate and direction of innovation as the product of economic and institutional contexts within which innovation occurs[23]. We therefore sought to include technology as endogenous to the processes of social and technological change – an outcome, rather than an exogenous input.

1.9 A four-quadrant 'traffic light system'

Whilst drafting the AFMEC scenarios it became apparent that some simple method was needed to easily convey the differences between the four futures, with regard to each particular issue or theme. A number of different qualitative and semi-quantitative approaches were suggested (traffic lights ● ● ● or arrows → ↗ ↘ ↑ ↓), but henceforth we have adopted a simple quadrant scheme, whereby a particular indicator is assessed as being likely to increase (↑), decrease (↓) or remain at about the same level (=) over the next 20-30 years. For the sake of clarity we use the same colour coding system throughout, ie, World Markets, Global Commons, Fortress Britain and Local Stewardship, and the layout of the quadrant figure always follows the same basic format (also used in Figure 1.2 and 3.1):



To express the relative magnitude of anticipated increases or decreases, three sizes of arrow (7pt, 4pt and 2pt) are used; ie, large, moderate and small.

1.10 Socio-political storylines

In Section 2 of this document different sectors of human activity are considered; past changes and future prospects are examined. Cross-cutting summaries of each scenario are provided at the front of this report but also in an accompanying 'summary document' (Viner *et al.*, 2006). In Section 1.10 a short précis is provided, detailing the socio-political conditions assumed under each scenario. A list of key indicators and assumptions is also provided (Table 1.2). These are mostly taken from OST and UKCIP scenarios and should be taken 'as read' for the present-day and for 2020.

World Markets:

"technology & markets fail to deliver sustainable solutions"

*The '**World Markets**' scenario assumes that people aspire to personal independence, material wealth and greater mobility, to the detriment of wider societal and environmental goals.*

The role of government in economic management and in the provision of healthcare, education and other social services is greatly reduced by 2020. Pressure grows to reduce taxes, and more public services are privatised or privately managed. There is light regulation of markets, concerned primarily with ensuring fair and open competition. Social and environmental governance is increasingly achieved through international legal frameworks establishing minimum standards, and implemented using market-based approaches. By 2020, explicit monetary values are ascribed to a wide range of resources and environmental services. Access to these services is limited through charging, or by allocating rights that can be traded.

Fortress-Britain:

"national identity gets in the way of global sustainability".

The 'Fortress Britain' scenario assumes that people aspire to personal independence and material wealth within a nationally-rooted cultural identity.

The UK's relationship with the EU remains at arms-length, with the balance of opinion favouring entrenchment of independence in economic, foreign and defence policy. The EU is viewed as a trading bloc, market values are dominant, but the scope of markets is limited where they are perceived to be at odds with national interests. Long-term economic growth is somewhat constrained by government policies that restrain international competition and protect key national industries. Economic and political power is consolidated in closed policy networks dominated by business interest groups (industrial organisations, professional bodies, and trade associations). Conservation and sustainable development are not a main priority.

Global Commons:

"international co-operation towards global sustainability"

The 'Global Commons' scenario assumes that people aspire to high levels of welfare and a sound environment. There is a belief that these objectives are best achieved through cooperation at an international level.

Individuals attach high value to balancing economic, social and environmental welfare, and see their personal interests as being connected to a strong and cooperative society. Sustainability is seen from a global perspective including the maintenance of biodiversity, the protection of global commons (ie, the atmosphere, oceans, wilderness areas) and the fair access to environmental resources. Policy is increasingly coordinated at the EU and international level. The scope for exercising national powers becomes limited with greater international cooperation resulting in legally binding standards and commitments. This is a relatively high tax scenario. The Global Commons scenario assumes the slowest rate of global climate change.

Local Stewardship:

"tailored solutions for local problems"

The 'Local Stewardship' scenario assumes that people aspire to sustainable levels of welfare in local communities. Active public policy aims to promote economic activities that are small-scale and regional in scope, and acts to constrain large-scale markets and technologies.

Sustainable development is an underlying objective of this scenario. A key focus is on using technology and ingenuity to maximise the use of local and regional resources, while not damaging their long-term use. Global and regional environmental problems receive less attention. There is a strong emphasis on equity, social inclusion and democratic values. There are high levels of public provision for health, education and social services, funded through high levels of taxation. Flows of capital, and trade in goods and services, is constrained, with a greater focus on local resources and development. By 2020 this leads to highly diverse outcomes in different parts of the UK. Economic growth is slow but considerable social and environmental improvements increase many aspects of the quality of life.

Table 1.2. Key indicators and assumptions taken 'as read' from OST[1] and UKCIP[3] scenarios, now and for the 2020s.

	Now	'World Markets'	'Local Stewardship'	'Fortress Britain'	'Global Commons'
Economic Development (UK)					
GDP (average growth 1995-2025)	+2% p.a.	+3% p.a.	+1.25% p.a.	+1.75% p.a.	+2.25% p.a.
GDP (at factor cost, current prices)	£600 billion	£1500 billion	£900 billion	£1000 billion	£1200 billion
GDP/capita (at factor cost, current prices)	£10,500	£20,000	£15,000	£17,000	£20,000
Export of goods (from UK)					
Export (value)	£154 billion	£360 billion	£180 billion	£290 billion	£360 billion
Export (% GDP)	25%	30%	20%	28%	30%
Planning and Built Environment					
UK Population	58.5 million	62 million	60 million	61 million	61 million
Average household size (UK)	2.4 persons	2.0 persons	2.6 persons	2.4 persons	2.2 persons
Household numbers (UK)	24.5 million	31 million	23 million	25.5 million	27.5 million
UK land use %					
Agricultural	75%	71%	76%	73%	71%
Forest, woodland and other	10%	11%	9%	10%	13%
Urban and non-specified	15%	18%	15%	17%	16%
Water					
UK water demand (% change)	+0.2% p.a.	+1% p.a.	-0.2% p.a.	+0.5% p.a.	+/-0% p.a.
UK public water supply (volume)	20,000 Ml day^{-1}	27,000 Ml day^{-1}	17,000 Ml day^{-1}	23,000 Ml day^{-1}	20,000 Ml day^{-1}
UK river quality (% classified good)					
Biologically	93%	90%	95%	85%	95%
Chemically	63%	60%	65%	50%	75%
Coastal Zones					
Zones protected by coastal defences (UK)	240,000 ha	240,000 ha	220,000 ha	235,000 ha	225,000 ha
Formerly protected areas flooded or eroded as a result of managed retreat (UK)	-	0 ha	10,500 ha	2,500 ha	15,000 ha
Climate Change					
Global climate change (increase in °C with respect to 1961-90 average)	-	+0.94	+0.88	+0.88	+0.79
Global sea-level change (cm) [with respect to 1961-90 average]	-	7	7	6	6
Energy					
Primary energy consumption UK (tonnes of oil equivalent)	230 million	280 million	230 million	270 million	230 million

2. Drivers, trends and scenarios by marine sector

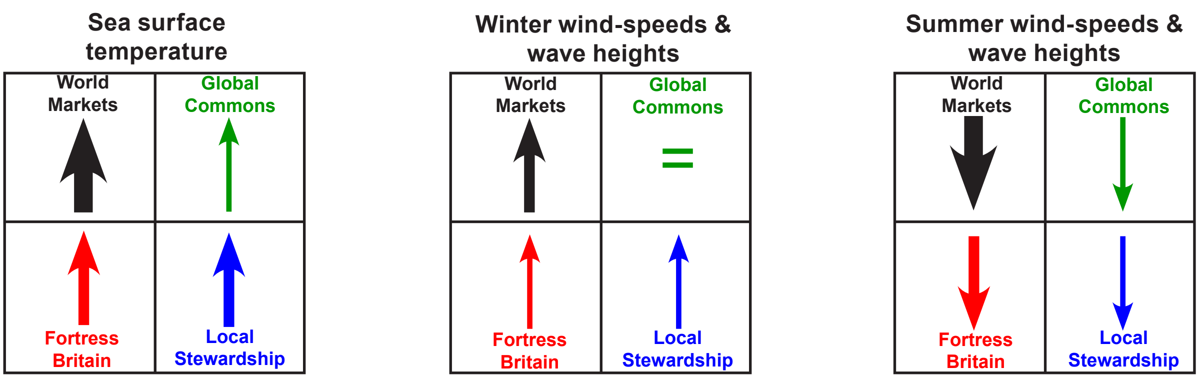
2.1. Climate and hydrography

Climate variability can have an enormous impact on marine ecosystems, as well as those industries which strive to operate in this challenging environment. Long-term climate change may well affect the physical, biological, and biogeochemical characteristics of oceans and coasts, modifying ecosystems and the way that they function. In this section we discuss long-term climatological and hyrographical changes (we discuss sudden climatic events in Section 4.2), most of which can be considered as 'locked-in' changes that will occur to some extent, whatever the scenario.

Sea Temperature

The UKCIP-02 climate change scenarios provide a common starting point for assessing climate impacts and adaptation in the UK[2]. They were developed by the Hadley Centre (part of the UK Meteorological Office) using complex ocean-atmosphere models and they are based on global emissions scenarios published in 2000 by the Intergovernmental Panel on Climate Change (IPCC)[5].

Global temperature has risen by about 0.6°C over the last 100 years, and the UK climate has also experienced marked changes over the same period. Central England air temperature rose by almost 1°C during the twentieth Century (Figure 2.1), and 2003 was the hottest year since records began in 1659. Warming over land has been accompanied by an equally dramatic warming of UK coastal waters (Figure 2.2)[2]. The longest continuous time-series of sea-surface temperature in the UK (for Dover, Eastbourne and the Isle of Man) show an increase in annually-averaged temperature of about 0.6°C over the last 70 to 100 years.



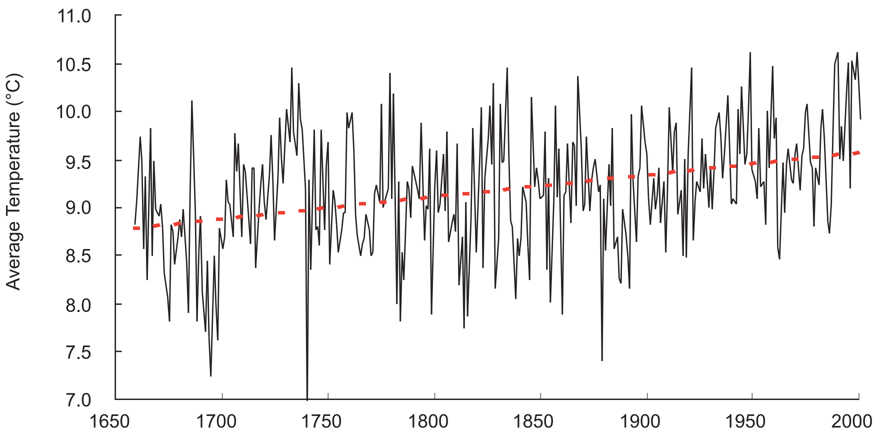
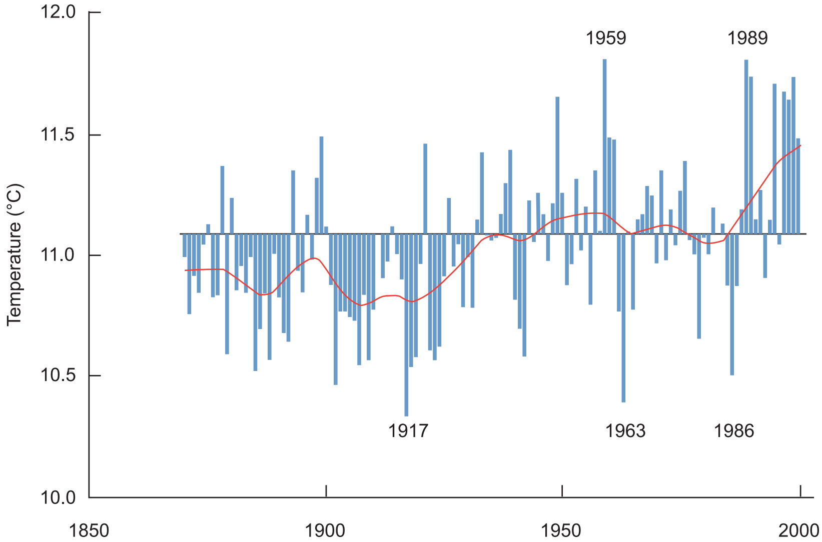


Figure 2.1. The monthly mean air temperatures, for the English Midlands, expressed in °C for the period from 1650 to the present (Source: CRU).

Figure 2.2. Annual sea-surface temperature averaged around the UK coastline for the period 1871-2000. Annual deviations are from the 1961-1990 average (Source: UKCIP)[2].



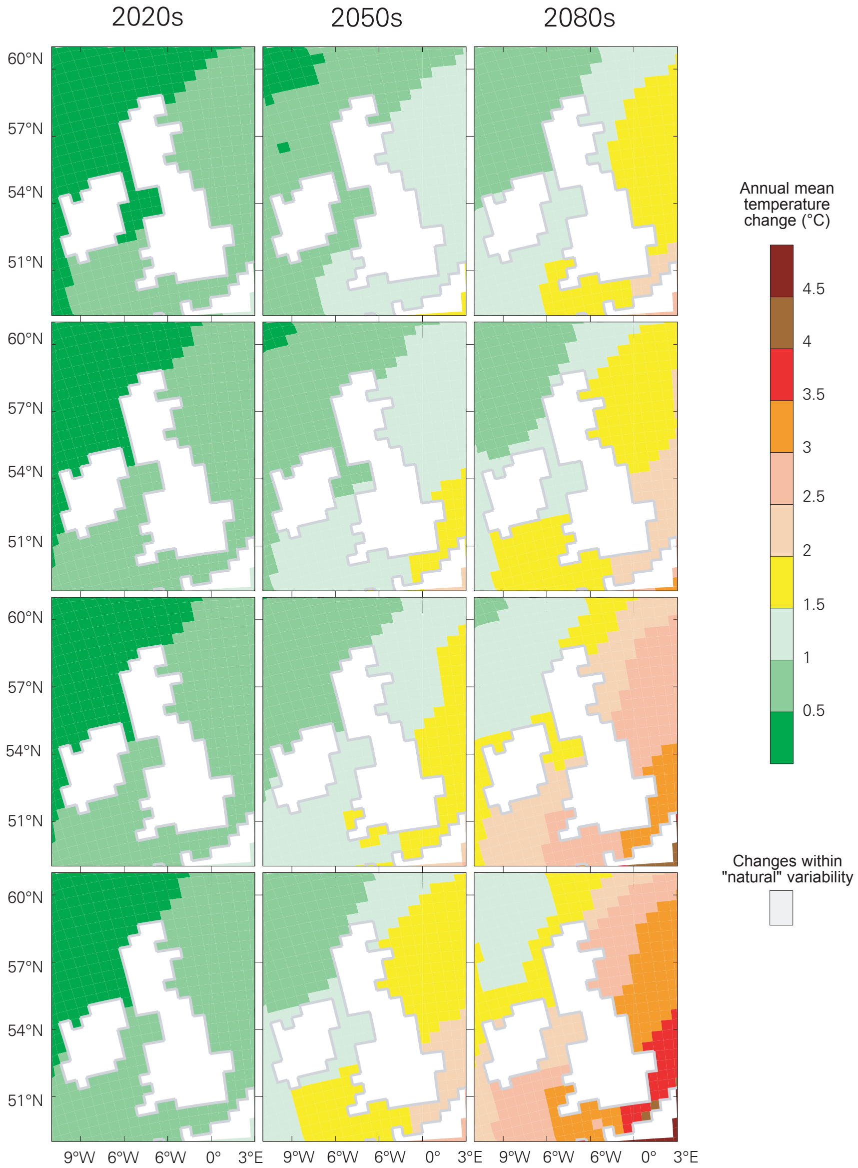


Figure 2.3. Potential changes in annual sea-surface temperature in the 2020s, 2050s and 2080s (Source: UKCIP)[2].

UKCIP2 provided detailed spatial predictions for sea surface temperature up to the year 2080 (Figure 2.3). All scenarios anticipated a continued rise in the temperature of coastal waters, with the shallowest seas such as in the southern North Sea and English Channel warming the most whilst those off northwest Scotland are expected to warm the least. Under the Fortress Britain (Medium-High Emissions) and **World Markets** (High Emissions) scenarios, North Sea surface waters are expected to warm by as much as 3-4ºC up to the year 2080. Even under the Global Commons scenario, waters in the eastern English Channel are expected to warm by 2-2.5ºC. Temperature rises up to the year 2020, are expected to be relatively modest ranging between 0 and 0.5ºC.

Case Study:

Predicting the impact of climate change at fine spatial resolution and in deeper waters around the UK coast can be very difficult and requires complex models. A recent study (S. Dye, unpublished) has attempted to predict fine-scale patterns of sea temperature throughout the whole water column, using a three dimensional ocean-circulation model incorporating detailed knowledge about currents and vertical mixing. This model suggests that waters off southwest England will experience much stronger thermal stratification in the future, with a 7-9ºC difference in temperature between bottom and surface waters anticipated in 2070-2089, compared to a difference of only 5-7ºC in 1970-89 (Figure 2.4). Thermal stratification and the existence of temperature 'fronts' can greatly influence the survival of juvenile fish.

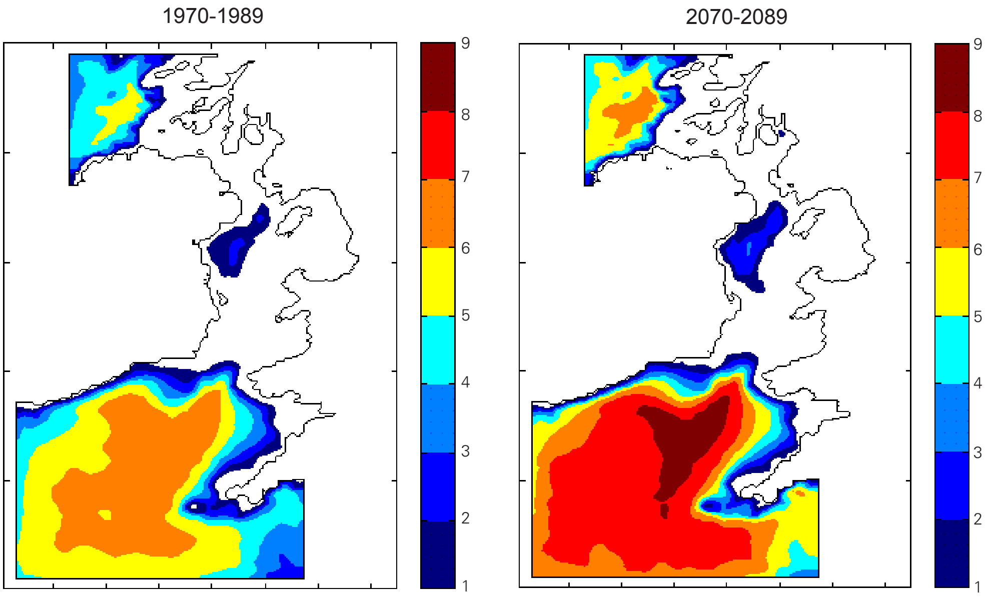


Figure 2.4. Predicted change in the thermal stratification (difference between surface and bottom temperatures in ºC) of Celtic and Irish Sea waters under the Fortress Britain scenario. The left panel indicates the modelled average pattern of stratification in September 1970-1989, the right-hand panel shows the predicted stratification pattern for September 2070-2089.

Wind speed, wave heights and the NAO

The North Atlantic Oscillation (NAO) is a phenomenon associated with winter fluctuations in temperatures, rainfall and storminess over much of Europe. When the NAO is 'positive', westerly winds are stronger or more persistent, northern Europe tends to be warmer and wetter than average and southern Europe colder and drier. When the NAO is 'negative', westerly winds are weaker or less persistent, northern Europe is colder and drier and southern Europe warmer and wetter than average.

In recent decades the winter NAO index has increased markedly, with surface pressure falling over Iceland by around 7hpa over the past 30 years. Most climate models, including that used by UKCIP[2], assume that the winter NAO index will continue to rise in response to increasing concentrations of greenhouse gases. Hence, for all UKCIP (and thus AFMEC) scenarios it is suggested that UK winters will become more "westerly" in nature - milder, windier and wetter[2].

Changes in wind speeds over ocean areas will be an important factor driving changes in extreme sea levels and hence possible risks of coastal erosion and floods (see Section 2.9). The heights of waves are dependent on wind strengths and, as with gale frequencies, wave heights around the UK are also related to the behaviour of the North Atlantic Oscillation (NAO). Direct measurements of wave heights in UK waters (1960s to present) together with inferences drawn from pressure and tide gauge data, (1880 to present) have indicated substantial variability in wave height, depending on season and location. Although there have been no clear trends over the twentieth Century, the wave climate roughened appreciably between the 1960s and the 1990s. In the northern North Sea, for the period January-March, there has been an upward trend in average significant wave height over the last 30 years[2]. As indicated in the 1999 report of the JERCHIO project (supported by the UK Environment Agency), the roughening wave climate is likely to be a consequence of a change in the strength of the North Atlantic Oscillation[24].

Figure 2.5 shows changes in wind speed, as predicted by UKCIP for seas around the British Isles. Under all four scenarios, the areas off the south and east coasts will see the greatest wind speed increases. Speeds in winter and spring, may increase by up to 8 per cent by the 2080s, depending on the scenario. In summer and autumn, the wind speed decreases as climate warms, especially off the west coast of the British Isles where reductions are up to 10 per cent. These patterns are consistent with drier, more settled summers[2].

Sea-level and tides

Global-average sea level rose by about 1.5 mm per year during the twentieth Century, believed to be due to a number of factors including thermal expansion of warming ocean waters and the melting of land (alpine) glaciers. After adjustment for natural land movements, the average rate of sea-level rise around the UK during the last Century was approximately 1 mm per year (Figure 2.6).

The predicted change in future sea-level will not be the same everywhere. Regional differences can be quite substantial (see Table 2.3)[2]. Sea level is expected to drop in Orkney, Shetland and Northern Ireland, largely due to rising land-masses. The most dramatic increases in sea level are anticipated in London and eastern England (where the land is subsiding), the extent of the rise depends on the UKCIP (or AFMEC) scenario chosen.

Storm surges are temporary increases in sea level, caused by low atmospheric pressure and strong winds. They occur in shallow water regions, such as on the continental shelf around the UK and, in some places, their height may be increased by the funnelling effect of the coastline. Regional climate models cannot yet produce detailed simulations of storm surge height directly. Instead, the atmospheric winds and pressure from the HadRM3 model have been used to drive a separate high-resolution (30 km) model produced by the Proudman Oceanographic Laboratory (POL)[25]. Using the POL tidal surge and HadRM3 climate model, it has been suggested that increases in surge height might be greatest off the southeast coast. In contrast, a decrease in the storm surge height is simulated for the Bristol Channel (Figure 2.7)[2].

Figure 2.5. Per cent change for the 2080s in the daily-average wind speed. Expressed as the change in the threshold wind-speed which is expected to be exceeded only once in every two year period (Source: UKCIP)[2].

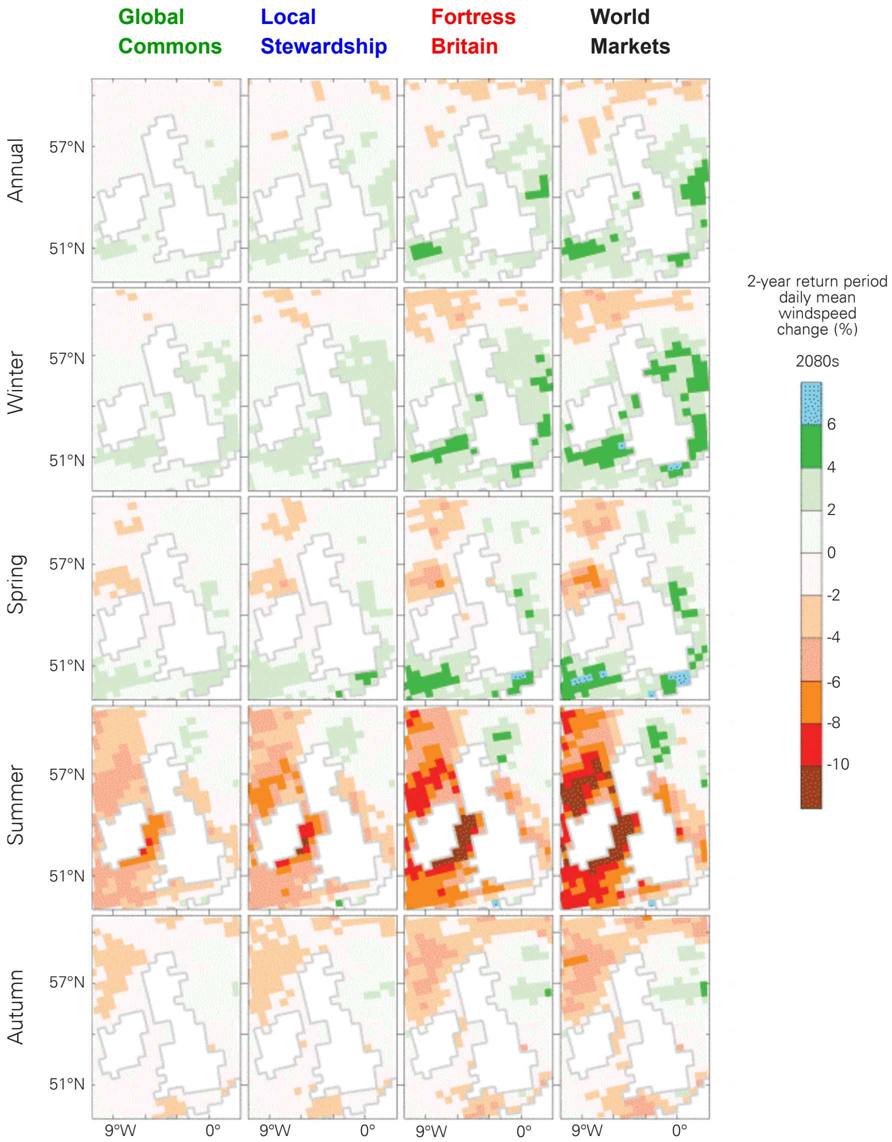


Figure 2.6. Changes in annual relative sea level (mm scale) recorded by tide gauges at five locations around the UK coastline. Data are unadjusted for natural land movements. (Source: UKCIP)[2].

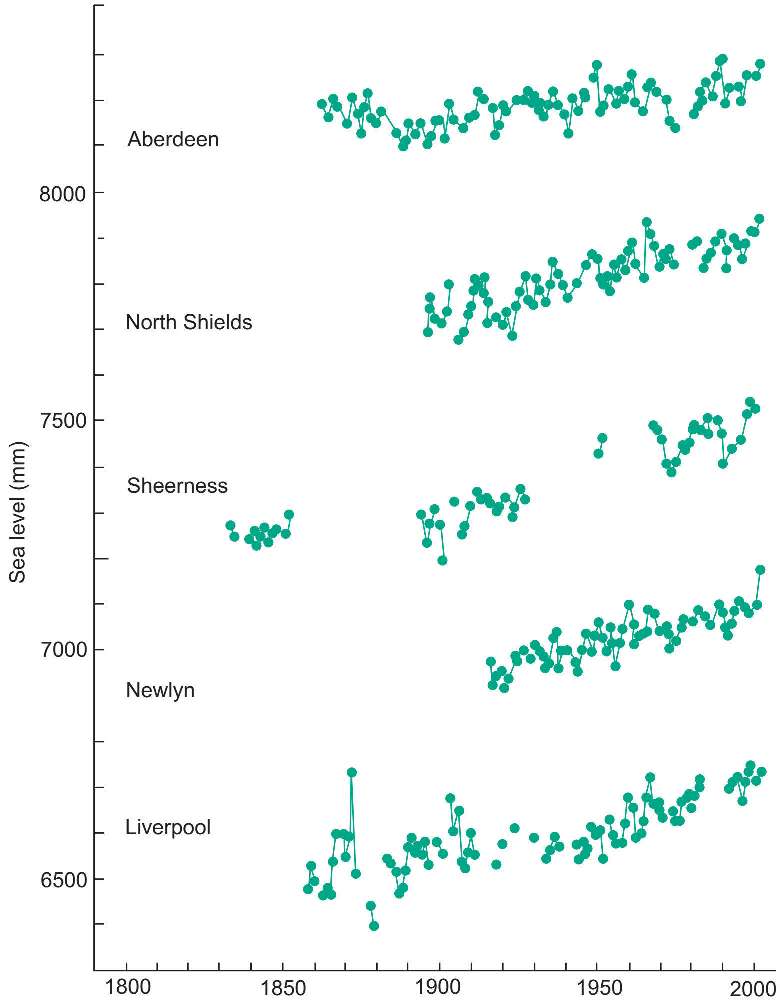


Table 2.3. Relative sea-level change for the 2080s with respect to the 1961-1990 period (Source: UKCIP)[2].

	Regional isostatic uplift (+ve) or subsidence –ve) (mm yr^{-1})	Net sea-level change 2080s (cm) relative to 1961-90	
		Global Commons scenario	World Markets scenario
NE Scotland	+0.7	1	61
SE Scotland	+0.8	0	60
NE England	+0.3	6	66
Yorkshire	-0.5	15	75
East Midlands	-1.0	20	80
Eastern England	-1.2	22	82
London	-1.5	26	86
SE England	-0.9	19	79
SW England	-0.6	16	76
Wales	-0.2	11	71
Northern Ireland	n/a	-9	-69
NW England	+0.2	7	67
SW Scotland	+1.0	-2	58
NW Scotland	+0.9	-1	59
Orkney & Shetland	n/a	-9	-69
Global Average	n/a	9	69

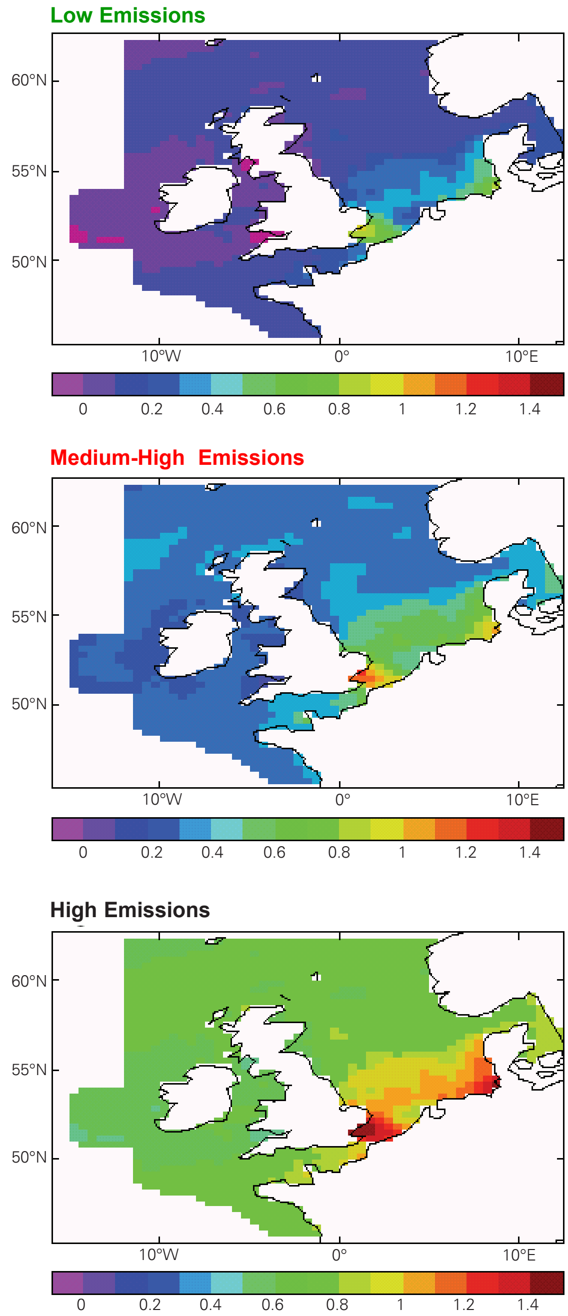


Figure 2.7. Predicted change in the sea-surge height (metres) expected only once in each 50-year period, for the 2080s. The combined effect of sea-level rise, changes in storminess and vertical land movements are considered. (Top) Global Commons scenario (low sea-level rise estimate; 9 cm); (Middle) Fortress Britain scenario (central estimate; 30 cm); (Bottom) World Markets scenario (high estimate; 69 cm). (Source: UKCIP)[2].

Precipitation, run-off and changes in ocean circulation

No long-term trend has been observed in the amount of annual precipitation (snow and rain) received by the UK over the past 250 years. However there has been a significant shift in *seasonality*. Of the total amount of rain and snow falling in the UK, the proportion that falls in winter relative to summer has changed over time. Winters have been getting wetter and summers have been getting drier[2].

Winter precipitation is predicted to increase for all periods and all UKCIP/AFMEC scenarios, although these increases range from 5 to 15 per cent for the Global Commons scenario, to more than 30 per cent in some regions for the Fortress Britain and World Markets scenarios by the 2080s. In summer, the pattern is reversed and almost the whole country is set to become drier. Under the Global Commons scenario rainfall may decrease over England by more than 20 per cent, or as much as 40 per cent for the World Markets scenario. The largest changes in precipitation in both winter and summer are expected in eastern and southern parts of the country–changes in northwest Scotland are relatively modest[2].

Arnell and Reynard (1996)[26] attempted to extrapolate from climate change scenarios, to predict future river-flows throughout the UK. Their PE2-'best' scenario is broadly similar to the Global Commons scenario, and for nearly all catchments, annual river runoff was predicted to decline markedly by 2050. The percentage change in annual runoff was predicted to be greatest for catchments in the south and east of Britain, relative to those in the humid north west.

The climate of the UK is greatly influenced by its proximity to the ocean and, in particular, by the characteristics of the circulation in the Atlantic Ocean. The relative mildness of UK winters is, in part, due to warm water transported to northwest European coasts by the Gulf Stream, and its northeastward extension, the North Atlantic Drift. The Gulf Stream is driven partly by surface wind patterns and partly by differences in water density caused by spatial variations in temperature and salinity. The density-driven component is part of a larger ocean system, known as the "thermohaline circulation" (THC). Surface water is cooled by cold winds from the Arctic, becomes denser and sinks. This cold water then moves equatorward deep in the ocean. To replace the water removed from the north Atlantic, warmer surface water is drawn up from the Gulf of Mexico (the Gulf Stream)[2].

The formation of deepwater could theoretically be reduced by a decrease in the density of north Atlantic surface waters, for example through a large input of fresh water at the surface. If this occurs, we might experience a reduction, or even a shutdown of the THC, including the Gulf Stream. It is believed that a modification, or even a shutdown, of the THC occurred around 11,200 years ago at the end of the last Ice Age, when temperatures in northwest Europe are thought to have cooled by 5°C within only a few decades. This was caused by a sudden discharge of fresh water from the melting of a large ice sheet over North America. The Greenland ice sheet is more stable and a repeat performance is unlikely to recur in the short-to-medium term, however evidence has started to emerge, suggesting that the thermohaline circulation may be weakening[2].

The main source of cold dense water for the THC is from the Greenland-Norwegian seas from where water flows over an under-water ridge that lies between Scotland and Greenland. The Faroe Bank channel is the deepest pass through this ridge and a third of the total overflow into the North Atlantic passes through this channel. Not only has this overflow become warmer and less saline over time, but the volume passing through is estimated to have decreased by at least 20 per cent (about 0.5 Sv, where 1 Sv = 1 million cubic metres of water per second) since 1950. If this diminishing source of North Atlantic deepwater has not been compensated by an increased flow through the Denmark Strait - between Iceland and Greenland - or from sources in the Labrador Sea, the consequence must be a weakening of the global thermohaline circulation[27].

A recent paper by Dickson *et al.* (2002)[28] used long-term hydrographic records to demonstrate sustained and widespread freshening of the deep ocean throughout the North Atlantic (Figure 2.8). This is in line with predictions based on the UKCIP climate scenarios[2]. When the Hadley Centre model was run with no human influences on climate, the THC exhibited no long-term trend. When greenhouse gas concentrations were increased, the strength of the THC steadily decreased under all the four UKCIP scenarios, declining by about 25 per cent by 2100 (Figure 2.9). A full shut-down of the THC is not predicted by the model over the next Century (see Section 4.2), although further analysis shows that one of the two deepwater formation areas – ie, that near Labrador - does appear to cease operating[2].

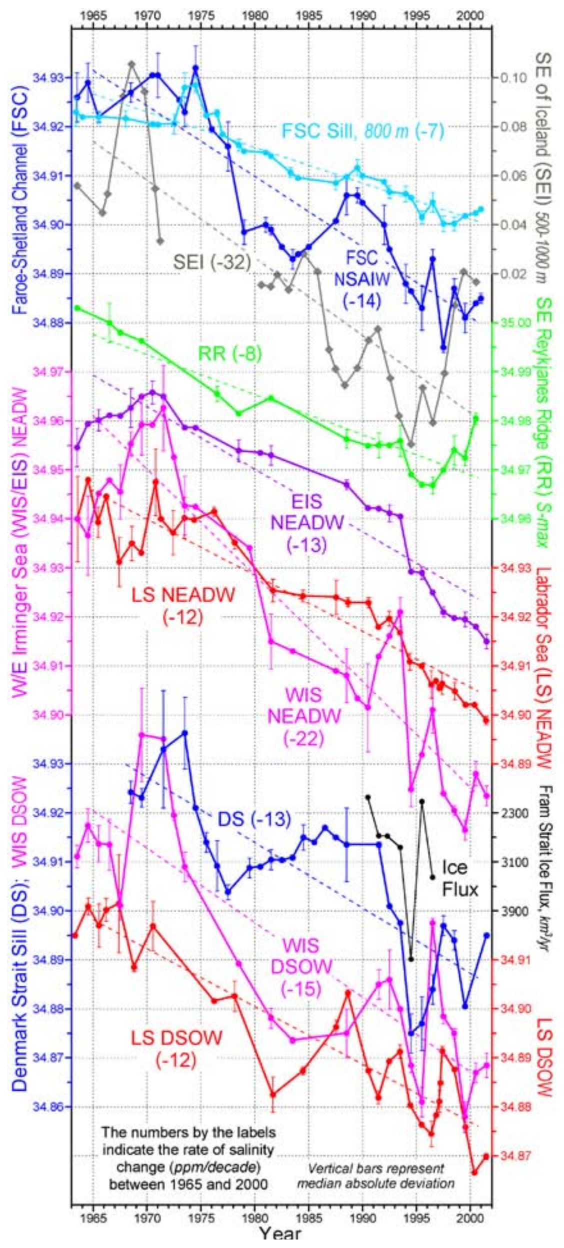
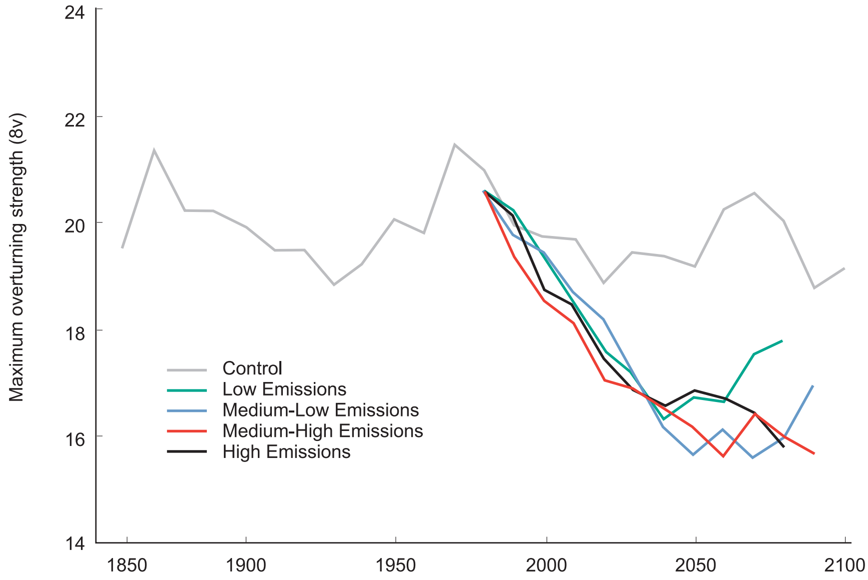


Figure 2.8. Evidence of sustained and rapid freshening throughout the system of overflows that ventilate the deep Atlantic (from Dickson *et al.*, 2002)[28]. The salinity time series shown are each plotted to a common scale.

Figure 2.9. The strength of the North Atlantic thermohaline circulation (in Sverdrups, where 1 Sv = 1 million cubic metres of water per second): grey = no change in greenhouse gases; colours = with observed changes in greenhouse gases to 1990, and thereafter for the four SRES emissions scenarios as shown. Source: UKCIP[2].



Theoretical modelling exercises have suggested that a change of 0.1 Sv in the freshwater flux to the North Atlantic ocean, would greatly impact the THC. Predictions for arctic river outflows (expected to increase by 0.01-0.04 Sv by 2100), anticipated Arctic sea ice loss (some 8500 km^2 or 0.0027 Sv equivalent by 2100), and freshwater melting from Greenland ice shelf (0.015 Sv over the period 1970-2080), amount to around 0.04 Sv. This is a worryingly high figure given our current limited knowledge of how the thermohaline circulation functions[29] and the uncertainty in some of these estimates.

Anthropogenic carbon and ocean pH

Most carbon dioxide released into the atmosphere as a result of burning fossil fuels will eventually be absorbed into the ocean. As the amount of CO_2 in the atmosphere rises, more of the gas reacts with seawater to produce bicarbonate and hydrogen ions thereby increasing the acidity of the surface layer. Ocean pH was around 8.3 after the last ice age and 8.2 before CO_2 emissions took-off in the industrial era (CO_2 in the atmosphere amounted to around 280 parts-per-million). Ocean pH is now 8.1, with an atmospheric CO_2 concentration of around 380 parts-per-million (ppm).

Caldeira and Wickett (2003)[30] used an ocean circulation model, together with observed atmospheric CO_2 data (1975–2000), and projected CO_2 emissions from the Intergovernmental Panel on Climate Change, to predict future changes in ocean acidity. These authors concluded that atmospheric CO_2 will exceed 1900 ppm by the year 2300, and this could result in a pH reduction at the ocean surface to 7.4.

Atmospheric CO_2 has risen well above 2000 ppm several times in the past 300 million years, but this has never pushed ocean pH below 7.5 before. Under normal circumstances carbonate rocks on the seafloor act as a natural buffer, limiting ocean acidity. However, that process takes 10,000 years or more to function, enough time to neutralise acid deposited by geological processes, but not to deal with the more rapid changes caused by human activity or natural catastrophes such as asteroid impacts (discussed in Section 3.1)[30].

We have limited understanding of the effect increased acidity might have on marine biota, but coral reefs, calcareous plankton and other organisms whose skeletons or shells contain calcium carbonate, may be particularly affected. Experiments with double the present CO_2 level in the giant, self-contained greenhouse 'Biosphere 2' showed that the rate of calcium carbonate formation in such organisms fell by 40%[31]. Most biota reside near the ocean surface, where the greatest pH change would be expected to occur.

A report published by the Royal Society in June 2005[155] has suggested that higher concentrations of carbon dioxide may also make it harder for some larger animals to obtain oxygen from seawater. For example squid are particularly sensitive because of their highly muscular and energy-demanding method of locomotion (jet propulsion). This high energy use requires a good supply of oxygen from the blood, however this can be seriously compromised by increases in CO_2 concentration, as this lowers the pH of the blood, thereby reducing its ability to carry oxygen.

2.2 Fisheries and aquaculture

Introduction

Global demand for fish protein continues to rise. Humanity consumes around 86 million tonnes of fish per year, which is nearly 15.7 kg per person, (having risen from less than 7 kg per person in 1950). Recent predictions suggest that world fish consumption will rise to around 17.1 kg per person by 2020, consumption rates in the European Union will however most likely remain stable at around 23.7 kg (compared to 23.6 kg in 1997)[14].

The proportion of total fish production obtained through aquaculture is predicted to increase markedly over the next two decades, reaching 41% by 2020. In contrast, capture fisheries are predicted to grow by less than 0.7% per year as many stocks are already over-exploited[14]. Indeed, there is evidence that global capture-fishery landings may have declined since the late 1980s, by an estimated 0.36 million tonnes per year[32].

The UK fish catching sector is composed of many different sub-fleets which together generated approximately £546m in 2002[33]. Fleet segments differ from one another in terms of their vessel numbers, physical capacity and value to the UK economy. Fluctuations in total value mask trends in financial performance across the sectors. Here we consider the four main fleet sectors: whitefish, pelagic fish, shellfish and deep-sea fish.

The UK whitefish sector

The whitefish sector generated approximately £260 million in 2002 and lands the bulk of those species desired by UK consumers (i.e cod, haddock, sole and plaice). These species are currently under considerable pressure and stock sizes have fallen significantly in recent years (eg Figure 2.11)[33,34]. Capacity in the sector far outstrips the current level of resources, in large part due to over-investment during the 'gadoid outburst' of the 1970/80s. The fleet is ageing and many skippers are finding it hard to attract skilled young people into the industry. The mixed nature of the whitefish fishery does not allow for the same scale economies as the pelagic sector, and so there is a limit to the level of economic consolidation that can occur. Only a small proportion of the whitefish we currently consume originates from the UK fishing industry, most comes from Iceland and Norway. The UK is increasingly reliant upon imports. Import volumes have increased by 31% between 1991 to 2002. In 2002, the UK imported 560,700 tonnes of seafood worth £1.28 billion[33].

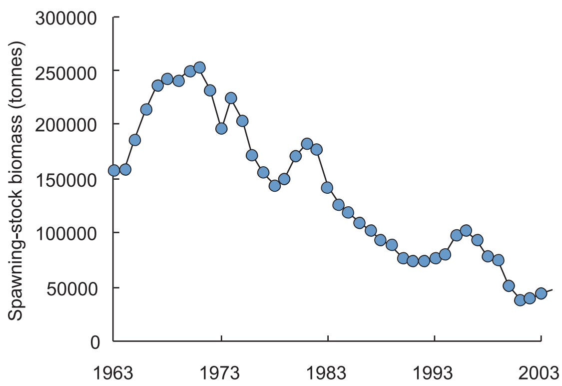


Figure 2.10. Biomass of adult cod in the North Sea (Source: ICES)[34].

The UK pelagic fish sector

The pelagic fishery (mainly targeting herring and mackerel) is a highly consolidated and capitalised sector making good profits and returns on capital. The sector generated approximately £110 million in 2002, with operating profit margins in excess of 40%[33]. The sector is comprised of just over 40 boats and operates largely out of Fraserburgh and the Shetlands. The sector is export-led with a high demand for products in Eastern Europe and Asia. The fleet is modern and crews are highly professional.

Based on the most recent estimates, ICES classifies the North Sea herring stock as being within safe biological limits[35]. Stock biomass in 2002 was estimated at 1.6 million tonnes. Biomass has increased gradually since low stock sizes in the mid-1990s. This is in response to reduced catches, strong recruitment, and management measures that reduced exploitation both on juveniles and adults. During the mid twentieth Century, the North Sea herring stock experienced a complete collapse having been over-fished since the end of the second world war (Figure 2.11). A complete moratorium on herring fishing was in place between 1978 and 1982.

The UK shellfish sector

The UK shellfish sector generated approximately £60 million in 2002-3. The major species caught are *Nephrops* (scampi), scallops, crabs and other high-value invertebrates. Profitability appears strong. There is intrinsically low biological volatility and there is greater economic flexibility to manage fluctuations due to lower levels of invested

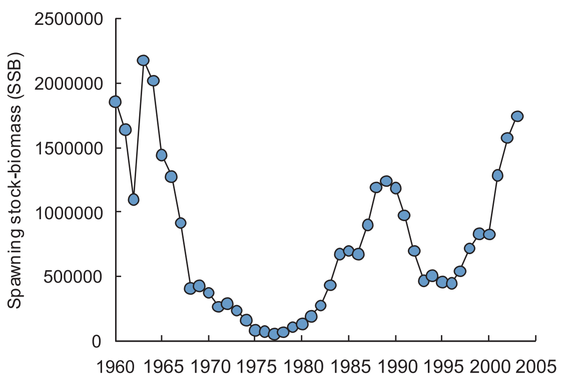


Figure 2.11. Biomass of adult herring in the North Sea (Source: ICES)[35].

capital and smaller fixed costs. The sector has grown significantly over the last ten years, in large part driven by the growth in the *Nephrops* fishery. The export market for the higher value species within the sector has also been important in driving profitability[33].

The deep-water sector

In recent years, fishing in deep waters (greater than 400 m) has increased as traditional shallow-water stocks such as cod have declined[36]. The target fish are often long-lived, late-maturing, slow-breeding (and hence vulnerable) species such as roundnose grenadier and orange roughy. Orange roughy can live to 125 years of age and may not mature until 20 years[15]. Fishing by factory trawlers and modern long-line fleets started in the late 1960s. Analyses of several of the most important deep-sea fishes, using catch per unit fishing effort (cpue) data, have indicated a clear declining trend in abundance[36]. For orange roughy, the cpue in 1994 was 25% of initial catch rates when the fishery commenced in 1991[36].

Aquaculture and industrial fisheries

The European Union's aquaculture production amounts to around 1.3 million tonnes in volume and 2.5 billion € in value. The EC's Aquaculture Strategy under the Common Fisheries Policy (CFP) reform sets an ambitious target, to increase production and employment in aquaculture, creating up to 10,000 new jobs in the sector by 2008 - an increase of over 15%[37].

The UK is one of the top aquaculture nations in Europe. During the 1999 season, the UK produced 126,686 mt of Atlantic salmon, 17,113 mt of rainbow trout, and 9535 mt of blue mussels. There are over 1000 fish and shellfish farming businesses operating on 1400 sites and employing more than 3000 people[38,39].

Cod, halibut and turbot have long been considered among of the most promising candidates for future aquaculture. Up to now, farmers were unable to compete with the relatively cheap catches from the fishery. However, *Fish Farming International* reported in April 2002 that Norway would be producing 30,000 tonnes of farmed cod before the end of this decade, a quantity which is equal to the yield from a good fishing year on the highly productive Lofoten Island fishing grounds. Expectations for 2010 range from 30,000 to 120,000 t. Some experts believe that by 2020 Norway will be producing as much as 400,000 t of cultured marine fish each year; this would be twice as much as Norway's current cod quota from the wild (2002: 195,000 t)[40]. Fish farms in the UK also plan to begin rearing cod on a large scale.

Most farmed fin-fish (salmon, cod, seabass, seabream, halibut, turbot) are carnivores and they largely feed on fishmeal, prepared from wild fish such as sandeels and anchovy. It takes 2-3 kg of fishmeal to produce 1 kg of farmed fish protein, and thus these industries can increase the pressure on some wild fish stocks[41,42]. According to one estimate, aquaculture will consume the entire world production of industrially-derived fish oil by 2006[41].

The main targeted industrial fisheries in the north-east Atlantic are those for Norway pout, sandeel and sprat in the North Sea, capelin in the Barents Sea and blue whiting to the west of Scotland. After rapid expansion in the 1970s, the sandeel fishery has become by far the largest single-species fishery in the North Sea. The vast majority of the catch is landed and processed by Denmark and in 1997 combined Danish and Norwegian sandeel landings exceeded 1 million tonnes[34].

Sandeels are important prey species for many marine predators such as seabirds, seals and fish. The magnitude of the fishery has led to concern over the potential impact of sandeel harvesting. Furness (2003)[43] has stated that the current level of sandeel fishing effort is almost certainly incompatible with long term recovery of cod stocks. 2004 was reported as the worst ever year for breeding success in UK seabirds and industrial fishing has been widely implicated in this failure. Sandeel spawning stock biomass (SSB) in 2004 was 325,000 t, the lowest ever recorded[34].

In addition to possible food-web effects, the small-meshed fishing gears used by the industrial sector, are thought to catch a substantial quantity of juvenile whitefish (cod, haddock, whiting etc.). In 2001 this was estimated at 13,192 tonnes, or 5.6% of total whitefish catches in the North Sea[41]. Offshore fish farms (in floating cages) can also affect wild fisheries by disrupting the balance of nutrients and chemicals in the surrounding water, or may spread pathogens from one fish population to another (see Section 4.3).

Fish and climate

Fishermen and scientists have known for over 50 years that the status of fish stocks can be greatly influenced by prevailing climatic conditions[44]. Some species at the southern-most extent of their range, contract northwards during warm years, whilst other 'warm-water' species (often those also present in the Mediterranean), become more abundant in British waters when warmer conditions prevail[156].

In recent years scientists have focused their attention on the potential impact of climate change on North Sea cod populations. Cod is a cold-water species with a northerly distribution. A series of recent research papers have demonstrated that the number of juvenile fish entering the stock (termed 'recruitment') has declined markedly, and there is a strong negative correlation[45] between cod 'recruitment' and ocean temperatures, which have generally been increasing - (see Section 2.1).

Furthermore, it has been demonstrated that rising temperatures have coincided with marked changes in the plankton[46], with a decline in the abundance of the copepod *Calanus finmarchicus* and its replacement by the closely related but smaller species *Calanus helgolandicus*. It has been suggested that *C. finmarchicus* is a prey item for cod larvae, and the loss of this species may be linked with recent failures in cod 'recruitment'[47].

The optimal temperature for cod growth appears to be at around 8.5°C. As waters around Europe continue to warm, cold-water species such as cod may retreat northwards. This effect would be most notable under the World Markets scenario, with an annual increase in sea surface temperature of 0.026°C yr^{-1} and least dramatic under the Global Commons scenario, with an annual increase in sea surface temperature of only 0.005°C yr^{-1}. Localised patterns of extreme warming in the southern North Sea may make this region particularly inhospitable to cod.

Some fish species may well benefit from warmer ocean conditions. European seabass and red mullet populations around British coasts have been growing in recent years. Similarly sightings of blue-fin tuna, triggerfish, thresher and blue sharks, sting-rays, turtles and seahorses are becoming more commonplace. A recent study by Perry *et al.*[156] shows that distributions of both exploited and non-exploited North Sea fishes have responded markedly to recent increases in temperature, with nearly two thirds of species shifting in mean latitude or depth over 25 years. These authors suggest that further temperature rises are likely to have a profound impact on commercial fisheries through continued shifts in distribution and alterations in community interactions.

Fisheries for warm-water species such as sea bass and red-mullet can be very profitable, and these might replace (in terms of value and total landings) the catches of traditional target species such as cod. Seabass are also important target species for marine anglers. Under the Global Commons scenario, with the lowest expected temperature rise, fewer warm-water stocks would become exploitable.

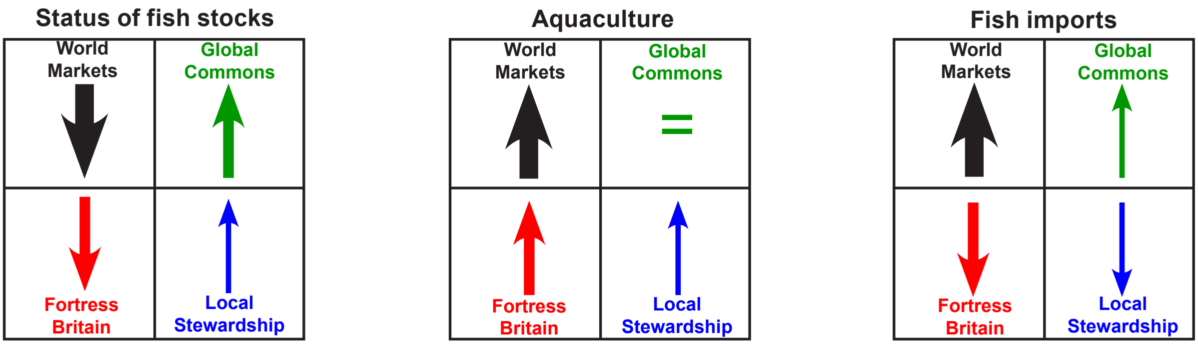
Future fish supplies

In describing their socio-economic scenarios, neither UKCIP[3] or OST[1] specifically addressed fisheries and/or aquaculture. However, they did provide useful narrative with regard to protection of the environment, conservation, as well as trends in the food industry. Through brainstorming exercises AFMEC has elaborated on implications with respect to fishing and food production in the marine environment.

Under the World Markets scenario, fisheries policy becomes much less interventionist and subsidies (eg for vessel decommissioning) are reduced to a comparably low level. Fisheries continue to be managed at a European scale although with greater emphasis on market forces, and fewer legal and technical restrictions. The Common Fisheries Policy (CFP)[37] plays only a minor role, with relatively open access throughout the continental shelf area and supplies obtained from the cheapest or most cost-effective source.

Economic yield and the demand for low food prices are important drivers, prompting fishermen to seek increasingly efficient methods. The industry becomes ever-more industrialised, global in scope and dominated by a fewer high-tech vessels. Indigenous supplies are increasingly supplemented with imports. Iceland and Norway continue to be major suppliers but, in addition, fish products would be obtained from around the world, with distant-water EU fleets operating off western Africa and in the south Atlantic. Large vessels and multinational companies predominate and many small scale inshore operations prove not to be cost-effective. This inadvertently offers some protection for inshore habitats (ie, an 'economic refuge').

Under the World Markets scenario government proposed 'stock recovery plans' meet with much resistance from the industry and are unlikely to be agreed upon or implemented. High 'discount rates' mean that it pays to catch every last animal and consequently high levels of



Case Study:

Clark *et al.* (2003)[48] used projections of future North Sea surface temperatures (see Section 2.1) and estimated the likely effect on the reproductive capacity of North Sea cod, assuming that the current high level of mortality inflicted by the fishing industry continues. Output from the model suggested that the cod population will decline (if fished at the current level), even without a significant temperature increase. However, even a relatively low level of climate change (+0.005°C yr^{-1}) under the Global Commons scenario, resulted in a more rapid decline in adult biomass and juvenile 'recruitment' (Table 2.4). Scenarios with higher rates of temperature increase resulted in greater predicted rates of decline in the cod population.

In the analyses of Clark *et al.* (2003)[48], fishing mortality was assumed to continue at the 1998-2000 average (F = 0.96). This is a relatively high value and does not take into account current efforts to cut fishing pressure. In a recent re-analysis by Kell *et al.*[49], the authors modelled the implemention of a 'cod recovery plan' (as currently mandated by the European Commission), under which catches were set each year so that stock biomass increased by 30% annually until the cod stock had recovered to around 150,000 tonnes. The length of time taken for the cod stock to recover was not greatly affected by the choice of climate scenario (generally around 5-6 years). However, overall productivity was impacted, and even under the Global Commons scenario, stock biomass (SSB) was predicted to be considerably less than would have been the case assuming no temperature increase (251,035 tonnes compared to 286,689 tonnes in 2015).

Table 2.4. The implications of predicted climate change for cod reproduction (recruitment) and stock biomass (Source: Clark *et al.* (2003)[48]).

Scenario	Trend in annual mean SST 2000-2050 (°C yr^{-1})	Mean cod recruitment year class strength) in 2050	Spawning Stock Biomass (quantity of adult fish) in 2050
Today (2003)	-	107,720,000	53,000
No temperature change	-	15,270	5,952
Global Commons (2050)	0.005	10,662	4,246
World Markets (2050)	0.026	586	325
Local Stewardship (2050)	0.021	1,256	675
Fortress Britain (2050)	0.014	1,758	907

fishing effort continue unabated. Management is somewhat reactionary, with a focus on the short-term. Major stocks (cod, plaice, hake) collapse and show very little sign of recovery. Deep sea stocks become heavily impacted as alternative target-fish are sought. Some non-target species benefit from the exclusion of cod eg, dogfishes, and crustaceans (competitors and prey respectively). New and highly profitable (but employing fewer people) industries develop around these species.

To make up for the shortfall in cod supplies, there is the rapid expansion of the fish-farming industry with many large-scale facilities run by multinational companies. The Norwegian and Scottish cod-farming industries exceed 400,000 t by 2010, creating increased need for fish-meal and fish oil in order to produce feed. The use of genetically modified stock becomes more common, raising productivity and demand for feed further. Increased industrial fishing has wide-spread impacts on seabird breeding success and other marine predators. Fears about the environmental impact of fishing and aquaculture on biodiversity are demonstrated, but are primarily of concern to environmentalists who have little influence in this scenario.

Most costs (excluding costs associated with environmental damage) are internalised, with the industry contributing a levy in order to fund monitoring, research and management activities. Fuel prices are important in determining whether it is profitable to target a species or not, and the needs and views of recreational sea fishermen are little regarded. Two alternative and disparate realities are possible under the **World Markets** scenario: (a) 'slash and burn' future, obtaining fish from the cheapest sources around the world as outlined above, but also (b) market-led conservation future, involving the trading of Individual Transferable Quotas (ITQs)[157]. Such a system currently exists in the Falkland Islands and in New Zealand but also among the UK mackerel fleet. If controlled by relatively few individuals ITQs might not lead to stock-collapse or environmental degradation. Furthermore, it is possible that sport fishermen, and/or conservation bodies which have substantial economic resources behind them, might buy-up ITQs, thus resulting in an improvement in some stocks.

Under the Fortress Britain scenario, maintaining the UK industry and making the most of the UK's indigenous resources are key drivers. National governments assume greater responsibility and control over their territorial waters, and the CFP focuses mainly on resolving conflicts over straddling stocks. Greater emphasis is placed on Exclusive Economic Zones (EEZs) and the national fleet remains relatively large, with fishermen receiving subsidies from central or regional government to ensure that capability remains in place. Under the Fortress Britain scenario imports would continue, but there would be a greater drive towards self-sufficiency, and less reliance on other countries. This would in-turn, result in pressure to make the most out of all UK resources rather than cheaper imports, and could lead to the exploitation of stocks in environmentally sensitive areas, greatly impacting habitats and wildlife. Sport fisheries would be 'squeezed out' under this scenario, both in terms of space and resources. Charter boats are likely to be otherwise occupied and limited by higher fuel costs. The focus would be on food production and not on recreation.

Under this scenario, the national fleet would struggle to supply sufficient fish to meet the extensive consumer demand and as a consequence fish prices would rise. A domestic cod-farming industry might emerge (aided by government subsidies) as a result of such price rises. The expansion of aquaculture would necessitate development of domestic industrial fisheries, exploiting indigenous sandeel, norway pout and blue-whiting resources. This would result in conflicts between different fleet sectors (since industrial vessels catch juvenile cod and haddock etc.) and environmentalists (since closed-areas aimed at protecting seabirds would have to be abandoned). Nature conservation policy would not be sufficiently strong to restrict development pressures under this scenario, but there is also little public concern about biodiversity. Disputes might erupt over the allocation of the seabed to different marine industries, with decisions based on social and economic costs and benefits to the nation as a whole. Run-off issues and water quality might become an issue under this scenario, with a deterioration of water quality (see Section 2.5) at the coasts conflicting with the need to obtain fish protein from a limited spatial area.

Under this scenario, national governments are able to respond more quickly and decisively to low stock numbers, and there is pressure to manage local resources sustainably. By contrast, ineffective management of straddling stocks, different interests in different countries and misreporting of catches at national boundaries may result in increased pressure on key stocks. Costs of enforcement and patrolling boundaries would increase. Mini 'cod-wars' over the allocation of resources might occur, consequently it would be important to maintain UK seafaring skills.

Under the Local Stewardship scenario the UK adopts a system of local governance and effectively withdraws from the EU Common Fisheries Policy (CFP). The main goal of is to support local self-sufficiency and what are seen as traditional fishing practices and communities. The industry is heavily subsidized to protect food security, local landscapes and habitats. Management responsibility is transferred to regional committees involving fishermen, government, environmentalists and scientists. Effort-based control measures are implemented (with local agreement) and the number of fishing vessels in the national fleet is reduced to a smaller but sustainable level, with small operators benefiting most. The large number of small vessels provide increased employment opportunities but low incomes.

With greater community involvement, and the sustainable management of resources, some fish survive to reach larger sizes. This is of benefit to sport-fishermen, who also enjoy greater catches of seabass and sharks, as sea temperatures warm. The conservation of resources and the natural environment are strong political objectives, and there are strenuous efforts to preserve wildlife and sensitive habitats at the local level. Large scale industrial and distant-water fishing is discouraged, however the high demand for fish protein and the difficulty in maintaining supply will mean that there is continued pressure to exploit stocks. All fish caught are landed and used, ie, no fish are discarded, this results in a reduction in some scavenging species including fulmars and kittiwakes.

Fish imports would most likely remain important, however the Local Stewardship scenario implies reduced dependency on other countries. Retailers and consumers place considerable emphasis on procurement of local supplies with campaigns reinforcing the message "British is Best". There is a rapid growth in small-scale organic and low input fish-farming. Genetically modified fish are prohibited and the use of antibiotics and pesticides in the aquaculture industry decreases.

Under this scenario 'straddling-stocks' (ie, those straddling local or national boundaries) and pollutants become a major problem (see Section 2.5). Different management objectives and priorities emerge in different regions, and there are many local disagreements within and among committees. International problems are not tackled effectively and there is increased uncertainty over things outside of local control. A network of closed areas, and gear-restrictions is established primarily to protect sensitive species and habitats (not stocks). Closed areas are easier and quicker to implement as fewer people need to be consulted, and decisions are taken at a local level. A system of temporary rotational closures allows the main commercial fish stocks to recover. Marine-mammal bycatch limits are agreed, and mitigation measures put in place where necessary.

Under the Global Commons scenario, the key concern is about the amount of global resources we can consume before causing ecosystem harm. The aim of fisheries policy is to balance high yields with low environmental impacts. Resources are obtained from sustainable stocks around the world, allowing recovery in locally depleted fish populations. Larger ideas such as the maintenance of biodiversity, the protection of the 'global commons' (the atmosphere, the oceans, wilderness areas, shared fish stocks) and resource efficiency drive environmental policy and result in binding international agreements and obligations. Fisheries in Europe continue to be managed through the CFP, however national allocation keys are abandoned and an effective effort-based control system is implemented, along with multi-annual quotas. The CFP becomes a cross-cutting 'EU Marine Strategy'. Support payments for fishermen are tied to less damaging practices and retailers transmit consumer concerns to the fishing industry through ethical purchasing policies.

There is greater understanding of 'safe-biological-limits' and where stocks are approaching precautionary reference points, ministers from all countries unanimously agree to close fisheries until stocks recover. All fish caught must be landed, ie, no discarding is allowed, but this has a subsequent impact on scavenging seabird populations. The overall size of the European fishing fleet is reduced and there are strong international restrictions/mitigation measures to prevent bycatch of marine mammals. Although there is limited involvement of local stakeholders in management, regional committees including members from all relevant member states are established (eg for the North Sea or the Irish Sea etc.). Greater integration occurs in the procurement of scientific advice and in enforcement; a pan-European research and enforcement agency is established.

Indirect effects on all species in the ecosystem are considered under the Global Commons scenario (ie, an 'ecosystems approach'). More of the prey-fish resource is allocated to natural predators (other fish, birds, mammals etc.), and less to the fishery. The ecosystem reverts back to a more balanced and 'natural' state. Big fish are available for sport-fishermen and it is agreed that a certain proportion of the total stock can be taken by anglers. The recreational sector expands as a result of increased leisure time, but sport-fishermen (and recreational divers) are subject to the same spatial fishing restrictions as other sectors. Fuel prices limit the utilization of charter boats.

A designated proportion of the seabed is set aside to promote nature conservation as a result of international agreements. Some closed areas are established to protect sensitive habitats or species (an international network of permanent MPAs), whilst others (some temporary) are established to recover commercial stocks. Exploitation of deep sea fish stocks is tightly regulated. Sustainable management of traditional target stocks would mean that there would be little need for fish-farming (priced out of the market), and therefore there is also limited growth of industrial fisheries. Large-scale and environmentally damaging fish-farming practices become much less apparent.

2.3. Tourism and leisure

Britain is made up of 6100 islands of which 291 are inhabited. England and Wales, including their islands, have a coastline of 3240 miles (5214 km) of which 40% has protected status because of its natural or scenic beauty[50]. International and domestic tourism in the UK contributes approximately £75 billion to the national economy. Over 2 million jobs exist in the UK as a result of tourism, more than in construction or transport. By the year 2020 foreign visitor numbers to the UK are expected to rise to around 56 million per year.

Each year, seaside resorts such as Blackpool (which remains Britain's number one tourist destination), generate around £4.5 billion in spending. In 2002 Britons took 79.8 million holidays in England, and 8.8 million holidays in Wales, accruing a total spend of around £14.5 billion[51]. In addition there are in excess of 240 million day-visits made by domestic travellers to the coast each year, amounting to an additional spend of £2 billion[52]. Ocean, marine and coastal activities are among the fastest growing areas of the tourism and leisure industry[53,54,55] and include a multitude of attractions including; fishing, surfing, heritage visits, swimming, scuba diving, windsurfing, yachting and coastal hiking.

The impacts of climate change on coastal and marine tourism

The UK Climate Impacts Programme (UKCIP), has consistently identified the tourism sector as being under-researched in relation to the potential impacts of climate change. The implications for tourism and attractions in England and Wales, as a result of climate change are both direct and indirect. There will inevitably be some 'winners' and some 'losers' [2,56,57,58]. Potential impacts include:

- increases in temperature and changes in precipitation and humidity - affecting visitor numbers, season length and type of activities;
- potential pressure on utilities, services and infrastructure such as water supply, waste management, emergency services, health care and transportation;
- sea level rise and coastal erosion - threatening destinations, beaches, historic buildings etc;
- sea temperature increase - increasing emphasis on water-related activities;
- changes in soil moisture - affecting historic gardens and parks;
- increase in infectious and vector borne diseases - affecting tourists' health and choice of destination;
- increase in frequency and magnitude of extreme events eg flooding, storm surges and subsidence (see Section 4.2) - affecting tourism infrastructure, tourist safety etc.

Case Study:

Mieczkowski (1985)[59] was among the first to apply general findings about 'human 'comfort' to activities associated with recreation and tourism. He devised a unique 'tourism comfort index', drawing on knowledge about the influence of climatic conditions on the physical and physiological well being of humans.

Amelung and Viner[60] have recently applied this index, using future climate change scenarios (see Section 2.1), in order to anticipate possible future changes in tourism within Mediterranean and northern Europe. Currently (1960-1990), most of the Mediterranean region is considered 'good' or 'very good' for tourist comfort, with scores in excess of 60. Scores for Northern and Western Europe are rated 'acceptable' (40 – 60) during summer months.

The dominant seasonal regime in the Mediterranean region and the whole of Europe is the summer peak regime: the mean score in the summer of June, July and August, is higher than in any other season (Figure 2.13). By contrast, in North Africa, a bimodal regime is most common, characterised by higher scores in both spring and autumn but a lower 'tourism comfort index' in the summer when it is too hot.

Looking to the future, the study predicted that the bimodal distribution will slowly 'invade' most of the northern Mediterranean, whilst a winter peak (the only season when conditions are bearably cool) will become the norm in northern Africa. In Europe, changes will be relatively small until the 2020s. By the 2050s, changes will become much more dramatic, and by the 2080s, almost all of Portugal, Spain, Italy, Greece, Turkey, and the Balkans will experience a bimodal regime. In short - the Mediterranean changes from being a region with very good or excellent summer conditions into a region with marginal or acceptable conditions in the 2050s and 2080s[60].

By contrast, Northern Europe, is predicted to change into a region characterised by excellent summer conditions. Changes for the United Kingdom are particularly remarkable. While this region currently scores low on tourist comfort in summer, it will be one of the best places by the 2080s. As an indication of how the 'tourism comfort index' might change over the next Century, Figure 2.13 illustrates the seasonal pattern for Marbella (southern Spain) and Blackpool (west coast of UK). If we assume that a favourable comfort score exceeds 60, then it is apparent that Marbella is predicted to change from being a 'good' tourist destination in the summer to a good tourist destination only in the spring and autumn (when temperatures are cooler). By contrast, Blackpool will change from being an 'acceptable' tourist destination (score 40-60) in the summer to a good or excellent tourist destination by 2099[60].

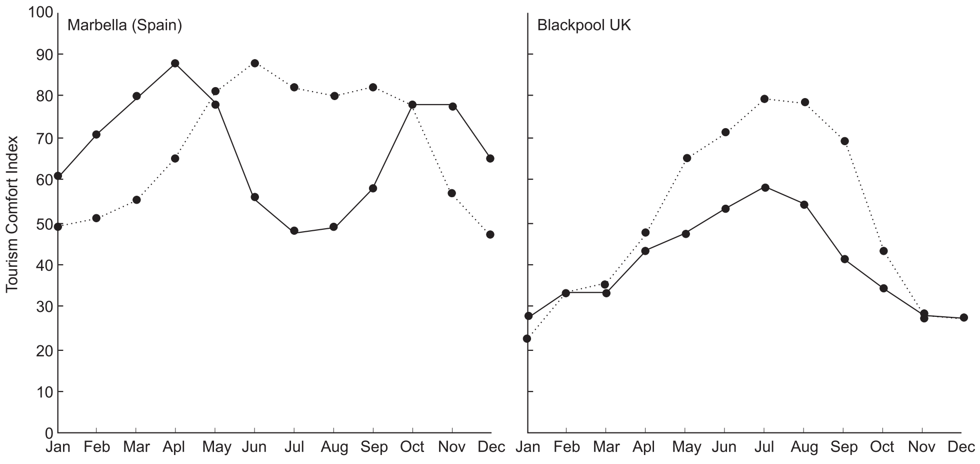


Figure 2.13. An indication of how the 'tourism comfort index' might change over the next Century, for Marbella (southern Spain) and Blackpool (west coast of UK) (from Amelung and Viner)[60]. A value in excess of 60 is considered a 'good' score for tourist comfort.

Trends in visitor flows and tourist numbers[61,62]

Under the **World Markets** scenario, due to greater mobility and personal freedoms, and a general lack of constraints on international air travel, visitation to virtually all global destinations, including the UK would increase. Domestic travelers will increase their mobility and be more inclined to travel overseas, thus the current trend for cheap overseas flights and holidays would continue to escalate. The purchase of holiday homes overseas by UK residents would also increase, contributing further to international travel and detracting from the visitation by UK residents to the coastal areas of the UK.

By contrast, should the **World Markets** scenario also serve to perpetuate or increase current threats to international security (see Section 2.4), then concerns might lead to less international travel and therefore less foreign visitation (ie, the opposite effect).

Similarities exist when considering the impact on visitor flow and visitor numbers under the scenarios of Fortress Britain and Local Stewardship. Focus on both national identity and local communities will result in increased visitation by domestic tourists to destinations in England and Wales and the trend towards overseas travel would slow or be reversed. Destinations with higher visitor numbers would be predominantly coastal, short breaks and day visits to these destinations would increase. UK residents will tend to support both the seaside resorts of yesteryear and smaller towns providing a typically English, Welsh or Scottish regional experience. In the case of a Global Commons scenario taxes on fuel used for air travel would result in the reduction or disappearance of cheaper airlines and consequently less overseas travel. International visitation to all destinations would reduce dramatically. Cheaper and closer alternatives for holidays would become more popular hence visitation to coastal resorts in England and Wales by domestic visitors would increase.

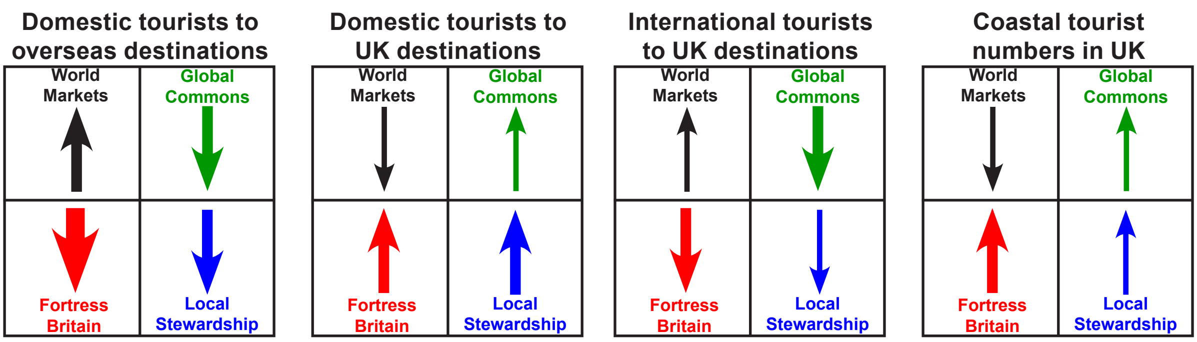
Future tourist activities

Under all four scenarios there will be more emphasis on outdoor and water-related activities. In a **World Markets** scenario, because of low fuel costs, engine powered activities such as water-skiing, power boating and cabin-cruising might become more popular. The cruise ship industry will continue its current trend of expansion and the use of marinas will increase. Ownership of the tourism 'product' will transfer to multi-national companies and international conglomerates, perhaps with less focus on the local community or uniqueness of the specific destination.

A Global Commons scenario will result in less emphasis on powered activities and more focus on nature-based 'ecotourism' activities such as shore/coastal walking, whale-watching, hiking and cycling. Health and spa tourism will also experience considerable growth. Ownership of resorts is likely to be multi-stakeholder based and public/private partnerships will become more common.

The Fortress Britain scenario by contrast, will provide a fertile environment for the growth of more traditional activities such as sailing, yachting, angling and the use of promenades and piers. Tourists will seek 'product' that is nationally owned and nationally focused. English, Welsh and Scottish coastal destinations will strengthen their cultural identity and there will be renewed interest in coastal heritage sites such as castles, holy places etc.

Under a Local Stewardship scenario there would be growth in many local, small and medium sized enterprises (SMEs); overall livelihood benefits to the local community will be more pronounced. 'Products' throughout England and Wales will be very heterogeneous and resorts will be characterised by their uniqueness and local flavour. Local produce will be an attraction in its own right and the availability of new crops and seafoods in certain regions (particularly the south) will lead to an increase in local distinctness and greater popularity of local produce.



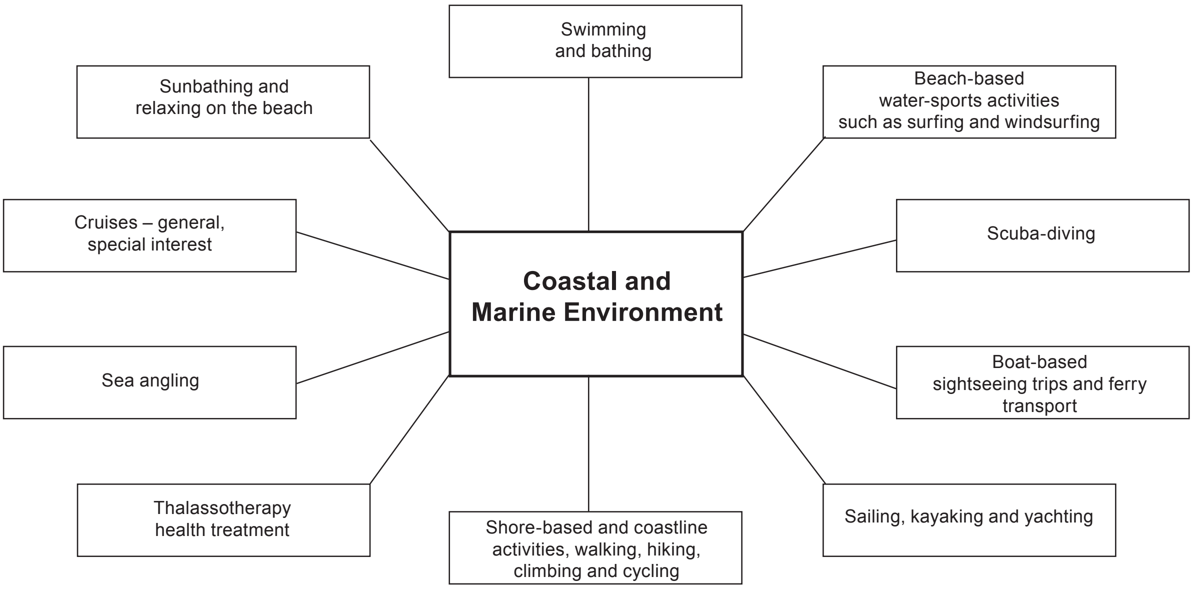


Figure 2.14: The different uses of UK coastal and marine environment by tourists.

Destinations and development

In three of the four scenarios, increased visitation to coastal areas will be experienced. With increased visitation comes increased pressure on infrastructure, transport, utilities, services and the natural environment.

The Fortress Britain scenario assumes that a strong emphasis is given to the regeneration of seaside resorts in England and Wales. The profile of seaside resorts within government policy and the role of local authorities and regional tourist boards will be enhanced. The development of essential transport links, quality assurance programs and best practice schemes, will all play a vital part in the regeneration of the resorts of yesteryear[63].

Unique Selling Points (USPs) and the idiosyncrasies of individual destinations will be drawn upon heavily under a Local Stewardship scenario. Cooperatives and joint ventures will emerge and development will be kept 'low rise' and in-keeping with the existing natural and built environment. The character, history and heritage of each destination will be essential to its individual development and destinations will provide a more 'eco-friendly' experience with sustainable values reflecting the local environment. Under a World Markets scenario, many destinations will become increasingly homogenised with similar hotels, marinas, beach facilities and coastal attractions. Competition between destinations for development, investment and visitation will become progressively fiercer with divisions being created between 'successful' destinations and 'failed' destinations. Under this scenario there is increased likelihood of losing natural coastal assets such as wetlands and beaches, with a reduction in the number of attractive destinations.

Under a Global Commons scenario public concern over water pollution levels will increase, this will lead to an increase in demand for blue flag beaches and other quality assurance and best practice schemes. Integrated land management will aid nature conservation and attract more 'eco-tourists' to well managed coastal destinations.

Socio-economic costs and benefits of change in tourism and leisure

Most seaside towns in England and Wales began to develop in the eighteenth and nineteenth centuries and they continued to flourish well into the twentieth. However, with the development of package holidays in the 1970s and increasingly cheap air travel, many coastal towns have since found themselves falling into a state of dereliction. In a recent study, 'The Seaside Economy'[64], Beatty and Fothergill focused on 43 key seaside resorts in England and Wales (see Figure 2.15). The study found that in-migration to many coastal resorts is greatly outstripping local employment growth. Successful adaptation of seaside towns has depended on location, with resorts in the South West and South East of England generally faring better than those in Wales, the North West and the East[64].

According to a recent report by the insurers Direct Line and the Centre for Future Studies[158]. The UK's second home market will grow by £53bn over the next decade. The number of people buying UK second homes will rise by 24% to 405,000, 156,000 more than abroad. The study forecasts that popular destinations for holiday homes will include Beckhurst in Sussex, Mull on the west coast of Scotland and the Northumberland coast.

Moderate growth is anticipated in the coastal tourism and leisure sector under the Fortress Britain, Global Commons and Local Stewardship scenarios; this will create jobs, provide opportunities for diversification of the

Figure 2.15. Location of Britain's 43 Principal Seaside Towns in England and Wales. Source: Beatty and Fothergill (2003)[64].

industry, and have a knock on effect for secondary and linked industries and the regional economy as a whole. However, some coastal towns and regions of England and Wales may become progressively more vulnerable as a result of climate change, particularly under the World Markets and Fortress Britain scenarios. Beach erosion and the degradation of cultural heritage sites located in coastal or low-lying areas could occur causing irreversible damage. The destruction of tourist attractions might lead to lower regional revenues, increased unemployment and ensuing social problems.

A longer and more reliable summer season is likely to increase both visitor numbers and £ spend per head, resulting in a boost for coastal economies. However an increase in visitor numbers will put greater pressure on transport, utilities and infrastructure. Health services will experience additional pressure, visitors will be vulnerable to increased risk of sunburn, heat-stroke, infection, heat exhaustion, dehydration and skin cancer. This increased stress on resources and facilities will not prove beneficial to local economies.

The environmental impacts of tourism

The quality of the environment, both natural and man-made, is essential to tourism. However, tourism's relationship with the environment is complex - many activities can have adverse environmental effects. Many of these impacts are linked with the construction of general infrastructure such as roads and airports, and of tourism facilities, including resorts, hotels, restaurants, shops, golf courses and marinas. The negative impacts of tourism development can gradually destroy the environmental resource on which it depends.

Negative impacts from tourism occur when the level of visitor use is greater than the environment's ability to cope with this use, within the acceptable limits of change. Tourism can place enormous pressure on an area and lead to impacts such as: soil erosion, increased pollution, discharges into the sea, natural habitat loss and increased pressure on endangered species. It often puts a strain on water resources, and tourism can force local populations to compete for the use of critical resources.

The tourism industry generally overuses water resources for hotels, swimming pools, golf courses etc. This can result in water shortages and degradation of water supplies, as well as generating a greater volume of waste water. In drier regions like the Mediterranean, the issue of water scarcity is of particular concern. Because of the hot climate and the tendency of tourists to consume more water when on holiday than they do at home, the amount used can run to 440 litres a day. This is almost double what the inhabitants of an average Spanish city use. Golf course maintenance can also deplete fresh water resources. Golf resorts are more and more often situated in or near protected areas or areas where resources are limited, exacerbating their impacts.

Increased construction of tourism facilities has increased the pressure on land resources such as forests, wetlands and wildlife and on scenic landscapes. Tourism can cause the same forms of pollution as any other industry:

- Air emissions
- Noise
- Solid waste and littering
- Releases of sewage
- Oil and chemicals
- Visual intrusion

The development of tourism facilities can involve sand mining, beach and sand dune erosion and loss of wildlife habitats. Development of marinas and breakwaters can cause changes in currents and coastlines. Habitat can be degraded by tourism leisure activities. For example, wildlife viewing can bring stress for the animals and alter their natural behaviour.

2.4. Ports and shipping

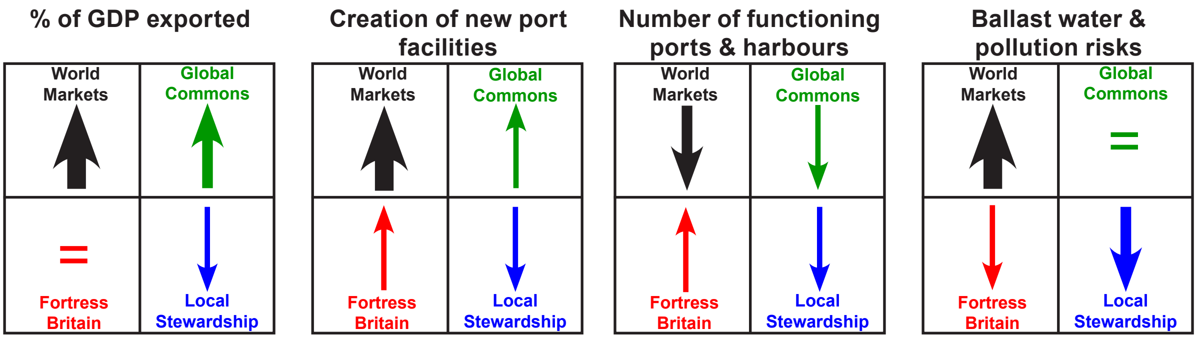
As an island nation, the importance of ports cannot be underestimated, 566 million tonnes of cargo passed through British ports in 2001, 95% (by volume) of imports and exports. Port traffic has increased by two thirds since 1965 and to keep pace with economic demand, new ports may need to be built and existing facilities expanded[65].

About 100 ports are currently commercially active in the UK. Of these, 36 handle over two million tonnes per year. The four biggest ports (London, Tees/Hartlepool, Grimsby/Immingham, and Forth) handle over 200 million tonnes between them. Oil and oil products account for nearly half the tonnage processed. Sullom Voe was built in the 1970s and now handles over 30 million tonnes of North Sea and North Atlantic oil per year. Felixstowe has grown in just over 30 years from a small fishing haven to a major port, handling in excess of 1.8 million containers per year, 40 per cent of the UK total. Dover has grown over a similar period to handle 17 million tonnes of freight in 1.5 million lorries. Dover also handles 24 million passengers[65], 75% of the 32 million passengers passing through British ports each year[65]. The UK ports industry is the largest of all those in Europe.

The past forty years has seen considerable change in the way that goods are transported with approximately 50% of goods now being moved in containers as opposed to only 4% in 1965. Rapid growth in this sector is linked to the globalisation of trade. Many companies now treat the whole world as their market and their production line. Recently the container and trailer sectors have been growing at 8 per cent a year. Long-term forecasts suggest that unconstrained container port demand will continue to rise at a rate of 4-6% per annum for the foreseeable future[65].

Some ports have lost trade because bigger ships cannot use them. The growth of supertankers is a familiar story, but it is matched in other sectors where bigger and more sophisticated vessels make ever-more exacting demands on port services. Facilities are now needed to handle bulk carriers in excess of 300,000 gross registered tonnes (grt). Container vessels have breached the limits imposed by the Panama Canal. Post-panamax vessels carry containers 19-abreast; and the industry anticipates new giants with more than 8000 containers in 22 rows[65].

Imports, exports, supply and demand



Despite their major economic importance and environmental impacts, the provision of port capacity in the UK is currently largely market-driven. There is little long-term planning at the national level to assess and/or put resources into place to meet future demand. Consequently, port expansion proposals tend to emerge from the private sector and are judged on their individual merits. Furthermore, there is currently no overall framework to determine how best to manage the environmental impact of new or expanded port facilities. The Government published its White Paper, *Modern Ports: a UK Policy in November 2000*[65], which makes it quite clear that Government does not think it should *interfere* in the ports industry. *Modern Ports* made no attempt to identify where increasing port capacity might be preferable and how much capacity should be provided in the future. Such a strategic approach is currently the norm for other major infrastructure planning including the development of airports.

The World Markets scenario is characterised by rapid economic growth, growing international trade in goods and services, and the removal of international trade barriers. Global markets, including China and Latin America are expected to become important for a growing number of firms. Exports from the UK are predicted to amount to £520 billion or 35% of GDP in 2020[3]. Port development would continue to be largely market-driven, with very little government intervention. Overall, there would be major expansion of port facilities and infrastructure to handle increased international trade. Deep-water ports in the south-east which can handle larger vessels would expand, whilst other ports such as Hartlepool, Grimsby, Folkestone, Ipswich and Dartford which can not handle such large vessels might contract as determined by world markets. Commodities would be obtained from the cheapest supplier, wherever they are in the world, and hence shipping routes between Europe and the far-east might become particularly important. Waterways would become markedly busier and ships generally larger, hence collision risks and navigation impacts might increase.

The Global Commons scenario also assumes high economic growth (GDP +2.75%, compared to +2.5% today) and increased international trade. Under this scenario, the economy is increasingly export-oriented (30% of GDP in comparison with 25% today)[3], with the highest growth experienced in sectors providing eco-efficient goods and services. There is growth in the role of services generally, at the expense of production and agriculture. Commodities would be obtained from sustainable or less environmentally damaging sources wherever they are in the world, and international action to control emissions from vessels (currently exempt from Kyoto targets) might impact on the industry. There might be a move towards specialist ports at a European scale, and action to protect internationally important wildlife sites.

Under the Fortress Britain scenario export-oriented sectors would grow relatively slowly, whilst businesses focused on domestic consumer demand would fare better. In general there is little state intervention in the economy, except in relation to key industries (eg utilities and defence) where national industries are supported against foreign competition. The current decline in overall manufacturing activity ceases and there is more intensive exploitation of agricultural resources, with greater diversification of output to meet local demands. Sectors operating in global markets (banking and finance, chemicals, pharmaceuticals, metals, automobiles, electronics) face slower growth prospects. Exports from the UK are expected to amount to only £290 billion (28% of GDP)[3]. Ports would expand less markedly under the Fortress Britain scenario. There would be less pressure to accommodate large container ships, and therefore to develop deep-water harbours. There would be more emphasis on the national rather than international transport infrastructure, and small ports around the UK servicing the domestic market are likely to be developed, creating greater employment opportunities for UK sea-farers and dock-workers. The UK would need to import raw materials, and hence ports (eg at Immingham) which can process bulk-materials might expand, however there would be fewer imports of finished goods, eg through Felixstowe. With fewer passenger numbers and less freight to carry, ferry companies and operators of the channel tunnel are likely to come under increasing financial pressure.

The Local Stewardship scenario assumes the slowest economic growth (GDP +1.25% per year), and also the least reliance on international trade. Sectors heavily dependent on international trade face difficult growth prospects. The transportation sector is affected by a major slowdown. Transport costs rise sharply due to high energy prices and policies which internalise environmental costs. Exports represent only 20% of GDP and are expected to amount to only £180 billion under this scenario[3]. Under this scenario we might anticipate the closure of some international ports and much greater reliance on small-scale local or domestic transport of goods. Currently only 6.3% of all load-on load-off goods passing though UK ports originate from domestic sources, and only 15% of all roll-on roll-off traffic[65]. Research has indicated that there may be potential to divert up to 3.5% of the UK's road freight traffic to water: this represents considerable further opportunities for UK-based shipping[66]. Stakeholder input into port development plans would increase, and supply chains (ie, the distance over which foods or goods have travelled before reaching the consumer) would be much shorter under this scenario.

Table 2.5. Exports and GDP under each AFMEC scenario (Source: UKCIP[3]).

Scenario (& UKCIP)	Export of goods in 2020s Export (value) Export (% GDP)	Value added in sectors (% of GDP) 2020s: • Services • Industry • Agriculture
World Markets (High emissions)	£520 billion 35%	80% 19% 1%
Fortress Britain	£290 billion 28%	74.5% 23.25% 1.25%
Local Stewardship	£180 billion 20%	73% 25% 2%
Global Commons	£360 billion 30%	78% 20.75% 1.25%
Today	£154 billion 25%	71% 27% 2%

Climate change and shipping-routes

Observations over the past 50 years have indicated a marked decline in the extent of Arctic sea ice. Recent studies estimate an Arctic-wide reduction in annual average sea-ice extent of about 5-10% and a reduction in average thickness of about 10-15% over the past few decades. Meanwhile, measurements taken by submarine sonar in the central Arctic Ocean have revealed a 40% reduction in ice thickness and climate models project an acceleration of this trend[67].

A recent survey published by the Arctic Climate Impact Assessment (ACIA)[67] has predicted that the navigation season for the Northern Sea Route (NSR) from Eurasia to the Bering Sea, will increase from the current 20-30 days per year to 90-100 days by 2080. Opening of shipping routes and extending the navigation season could have major implications for transportation as well as for access to natural resources. Using the NSR represents up to 40% savings in distance from northern Europe to north-eastern Asia and the northwest coast of North America compared to southerly routes via the Suez or Panama Canals[67]. The Association of British Ports (ABP) is currently considering the implications of new trade routes opening up for the UK, and whether there will be a case for new port facilities in north-west Scotland[68].

Under the World Markets scenario we would expect extensive melting in the Arctic, since this scenario assumes rapid warming of northern latitudes. Because of financial savings associated with shorter journey times to Asia, we would expect high seasonal use of northern shipping routes and exploitation of Arctic resources. The Russian Arctic for example, holds significant reserves of oil, natural gas, timber, copper, nickel and other resources that may best be exported by sea. By contrast, under the Global Commons scenario, we would expect the least melting of Arctic sea ice and great concern for degradation of Arctic habitats and ecosystems.

Along with increasing access to shipping routes and resources comes an increasing risk of environmental degradation caused by these activities. One obvious concern involves oil spills and other industrial accidents. ACIA suggests that the effects of oil spills in high-latitude ocean environments, last longer and are far worse than those in lower latitudes, as became apparent after the *Exon Valdez* disaster in 1989. Under the Global Commons scenario we would expect preventative measures and regulations designed to reduce the risk of spills through enhanced construction standards and international operating procedures.

Not all exerts agree that reduced sea ice, at least in the early part of the 21st Century, will necessarily be a boon to shipping. Recent sea ice changes north of Canada could, in fact, make the Northwest passage more hazardous and less predictable for shipping. Studies by the Canadian Ice Service (CIS)[67] has demonstrated an increase in year-on-year variability in sea ice. As the ice melts there may be more icebergs and also more fog. Consequently, even in the summer, vessels would need thickened hulls and icebreaker support[67].

Case Study:

In 2000, RSPB teamed up with English Nature to carry out a modelling exercise focusing on the question of future port supply and demand[69]. The results (based on an expected trade growth of 4-5% per annum) suggested that an additional 6.5 kms length of new quay will be required for 'load-on load-off' operations (including containers) by 2020, with the greatest need for expansion in the south-east of England (Felixstowe, Tilbury and Thamesport). The study also indicated that an additional 402 hectares of roll-on roll-off port facilities would be required by by 2020, even after taking Channel Tunnel traffic into account. Load-on load-off cargo traffic between the far-east/Australia and the UK are expected to increase most markedly, increasing from 9.9 million tonnes to 35.6 million tonnes (Table 2.6)[69].

Overall the RSPB study predicted that existing load-on load-off (mainly container port) infrastructure of 11.9 km of quays will have to be expanded to 18.4 km by 2020, and this will be concentrated at the deep water end of the market to accommodate larger ships. The existing roll-on roll-off infrastructure of 720 hectares will have to be expanded to 1122 hectares by 2020. The RSPB-English Nature model also anticipates an increase in Channel Tunnel traffic of 37.8million tonnes by 2020, from 17.3 million tonnes in 2000 to 55.1 million tonnes in 2020[69].

Table 2.6. Port capacity in 2000 and the anticipated port capacity in 2020 (source: MDS Transmodal 2002)[69].

	2000	2020
Load-on load-off cargo (Lo-Lo)	35,360 ('000t)	95,221 ('000t)
Accompanied & unaccompanied trailers	69,727 ('000t)	160,809 ('000t)
Trade cars	3,104,000	8,142,000
Tourist cars	10,792,000	20,010,000
Total roll-on roll-off (Ro-Ro)	357,925 ('000t)	836,042 ('000t)
Load-on load-off quay length	11.9 km	18.4 km
Roll-on roll-off port facilities	720 hectares	1,122 hectares

Ports, shipping and the environment

The development of land for commercial purposes such as ports can have many detrimental effects. The coastline of the UK is of global importance for wildlife. There are 163 estuaries covering over 580,000 ha. This represents about 28% of the total estuarine area of the NW Europe[70]. Historically, UK estuaries have proven a cheap source of land for both agriculture and development; ports have contributed to significant losses in habitats. In the last ten years, new facilities built in the Medway, Stour/Orwell, Humber and Dee estuaries, have destroyed or damaged important wildlife habitats. The Suffolk Stour has lost almost half of its salt marsh since 1973, largely because of the expansion of major port facilities at Felixstowe and Harwich[70].

Pollution impacts may include:

- air pollution from ships engines and from lorries, trains and cars used in the transport of containers and port workers
- water pollution from cleaning operations, accidental spillage, flushing of ballast tanks and the import of rubbish and non native organisms on ship hulls
- noise pollution from the loading, unloading and storage of containers and noise from transport to, from and within the port
- light pollution as cranes, fencing, storage areas and buildings are lit to a high level for operations, safety and security.

Under the **World Markets** scenario, the environmental impacts of port development and shipping, are expected to be substantial. Port development would continue to be largely market-driven, with environmental damage being considered an unfortunate but acceptable inevitability. Unhindered access by foreign vessels, with varying safety and environmental standards, would result in greater pollution risks and accidents. There would be fewer international agreements imposing penalties on vessels with low safety standards (eg single-hulled tankers) and with busier waterways and little control of ballast water emissions, non-native and invasive species would be more likely to be spread around the world (see Section 4.3). Ships would be scrapped in the cheapest place and using the cheapest methods, therefore resulting in increased environmental impact at these locations.

The Global Commons scenario also assumes expansion in the shipping industry and port facilities, however greater legal protection (at an EU or global level) would be given to internationally important wildlife and habitats. With busier waterways and longer shipping routes, ballast water problems and pollution risks would remain high, but international agreements would encourage safer ships and good practice. Under both the Global Commons and **World Markets** scenarios environmental and biological consequences are likely to arise from the need to deep-dredge harbours, in order to accommodate larger vessels.

Under the Fortress Britain scenario, environmental effects related to shipping activities are likely to be less marked, simply by virtue of there being fewer international vessels and less demand to expand port facilities into sensitive habitats or to deep-dredge harbours. Government intervention would again be minimal and, as with the **World Markets** scenario, there would be few international agreements imposing penalties on vessels with lower safety standards (ie, still relatively unhindered access). As fewer vessels would be entering UK waters from far-afield, non-native and invasive species would be less of a problem.

Under the Local Stewardship scenario monitoring and legal control of passing ships might increase (ie, tightly regulated access), including binding safety and environmental standards. Again there would be fewer international vessels and less need to expand port facilities into sensitive habitats or to deep-dredge harbours. Shorter supply chains would result in fewer ballast water problems, and there would be better facilities for dealing with waste in ports. We anticipate greater legal protection for nationally rare or threatened species and the development of environment-friendly forms of marine transport (eg high-tech sailing craft).

Port waste reception facilities can enhance the protection of the marine environment by removing any incentive – practical or financial – for ships to dump their waste at sea. The UK strongly supports the MARPOL requirement for the provision of adequate waste reception facilities in all ports. In January 1998 the UK introduced domestic legislation covering all places that provide ships with berths (including fishing and pleasure vessels). Under the **World Markets** scenario, we might anticipate that such measures might be scaled back because charging arrangements could act as a constraint on free-markets and profits. World trade takes precedence over environmental protection in this scenario. By contrast, under the Global Commons scenario, we might expect to see greater emphasis on international agreements and conventions, which would commit nations to the provision of waste reception facilities in ports all around the World.

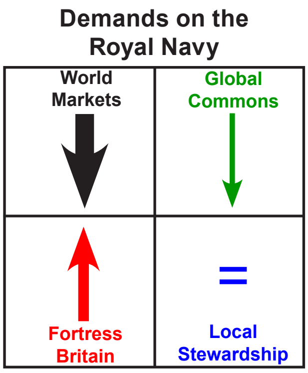
An accelerated timetable for introducing double hull tankers is now in place as a result of the IMO (International Maritime Organization) reacting quickly and positively to an

EU proposal following the sinking of the oil tanker *ERIKA* off the coast of France in December 1999[71]. This means that by 2015 (rather than by 2025) tankers with partial hull protection will not be allowed into EU ports, UK Overseas Territories, Russia and the Baltic States unless they are double hulled. Unprotected single hull tankers will not be allowed to operate anywhere in the world after 2007[71].

Defence

In 1998 the UK Ministry of Defence (MoD) published its 'Strategic Defence review' (SDR)[72], in which it attempted to assess the world as it was then and to look forward to defence needs up to the year 2015. In 2002 this document was revised, updated and predictions extended 30 years hence, responding to recent events and recognizing that decisions made today, particularly regarding equipment procurement, will still be felt in 30 years and beyond[72]. This review predicted that rises in sea level and extensive flooding of coastal areas could have serious consequences for some key UK Defence facilities. In addition, pressure on freshwater as well as agricultural land were anticipated to grow, especially in Africa and the Middle East and this might exacerbate existing tensions and instability in such regions, leading to more calls for military and humanitarian assistance. Increased incidence of natural disasters and extreme weather events (see Section 4.2) will also mean more frequent calls for western powers to contribute to disaster relief efforts[72].

The implications of the SDR for the UK Royal Navy were outlined in a subsequent document labeled '*Future Navy*'[73]. Building on this, it has been possible to speculate about the composition of the naval fleet and the duties the Royal Navy will be required to perform under each AFMEC scenario.



Under the Fortress Britain scenario we might expect a more introvert foreign policy, with little regard for conflicts or humanitarian crises overseas, and greater emphasis on national interests and protecting UK shipping. Consequently the distant water surface fleet might decline in size, but more (possibly smaller) naval vessels would be required to patrol oil extraction areas, the boundaries of the EEZ and ensure compliance with fisheries restrictions, also to protect UK fishing vessels in disputes over 'straddling stocks'. A naval force would be required to ensure safety and security of the UK, as countries around the world become more partisan in nature. This could probably create a need for a substantial submarine fleet, including a significant nuclear deterrent.

Under the Local Stewardship scenario we would expect even greater policy emphasis on local issues, rather than national well-being or international commerce. Consequently we might anticipate a reduction in the naval fleet size, although some vessels would be required not only to patrol the boundaries of the EEZ and prevent illegal entry by foreign fishing vessels (this scenario assumes complete withdrawal from the CFP), but also to help resolve local disputes between regions over straddling stocks, oil reserves and spatial allocation of resources to different activities.

Under the Global Commons scenario we might expect greater co-operation between nations, especially with regard to providing humanitarian assistance and disaster relief. There are likely to be many international agreements with regard to resource exploitation, environmental impacts and shipping. Under this scenario the Royal Navy would assume a role, within an international enforcement body. Thus we might expect some reduction in the size and breadth of the UK naval fleet, with further reductions in military vessels negotiated through weapon anti-proliferation treaties.

Under the **World Markets** scenario the high cost of maintaining a large navy is likely to be an important factor, resulting in a substantial down-sizing of the fleet. Naval ships would be required to protect shipping and commerce but, with few legal restrictions and international agreements, less effort would be dedicated to enforcement and patrolling. Naval alliances might help compensate for the reduction in capability of national fleets, however, this scenario assumes the greatest underlying level of climate change and consequently more extreme weather, more humanitarian disasters and more civil unrest. All of these necessitate a strong naval capability.

2.5. Inputs and runoff

Some 80 percent of substances that find their way into the world's oceans and seas come from land-based activities via riverine or atmospheric inputs[71]. Land-based activities such as farming, together with industry and human settlement, can have a significant impact on the marine environment. In the following section we consider emissions of potentially hazardous substances (metals, organic contaminants, radionucleotides, pesticides) and nutrients to the marine environment. We build on the socioeconomic scenarios developed for UKCIP[3] and OST[6] to elucidate what might happen under each AFMEC scenario.

The current policy landscape

In Section 3.5 we acknowledge that marine 'futures' may not freely evolve unconstrained, since future development depends upon existing or forthcoming legislation and conventions. Nowhere is this more apparent than in the field of marine inputs[71].

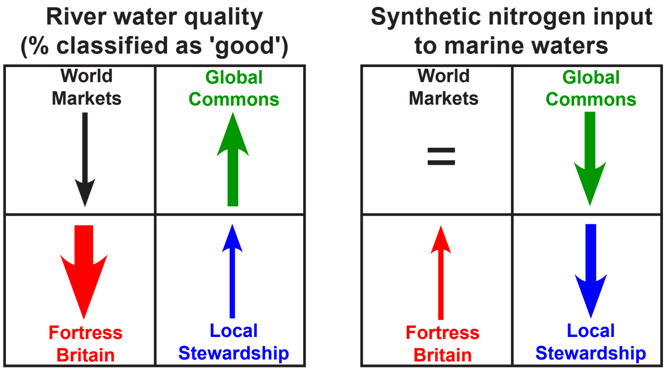
The EU *Water Framework Directive*, implemented in December 2000, commits nations to achieving stringent water quality targets by 2015. The EU *Shellfish Waters Directive* aims to protect and improve the quality of waters in which shellfish grow. The EU Bathing Water Directive sets mandatory water quality standards for coastal bathing waters and the *Urban Waste Water Treatment Directive* (UWWTD) sets standards and deadlines for the treatment of sewage and storm water. The forthcoming *Nitrates Directive* will result in action plans to control agricultural sources of nitrates. In developing scenarios however, we recognize that any of these legal instruments could scaled-back (or strengthened), given sudden upheavals in the prevailing political climate.

River water quality

Under the World Markets scenario, legal controls on emissions are weak and hence we might expect that agricultural and road run-off will remain a problem for the foreseeable future. River water quality is expected to improve slightly in some recreational areas but overall river water quality will decline. It is predicted that only 60% of river water will be classed as 'good' chemically in the mid 2020s (compared to 63% today) and only 90% will be classified as 'good' in terms of biology (compared to 93% today)[3].

Under the Fortress Britain scenario the quality of river and groundwater is expected to deteriorate considerably, as a result of the intensification of agriculture, low investment in sewage treatment and the weak control of industrial pollution. International obligations are abandoned in favour of national self-sufficiency. Only 50% of rivers are anticipated to be classed as 'good' chemically in the mid 2020s and only 85% classified as 'good' in terms of biology[3].

Under the Local Stewardship scenario river water quality is predicted to improve somewhat as a result of acute concerns about the quality of the local environment, reduced pesticide and fertiliser use and changes in industrial practices. 65% of river water is anticipated to be classed as 'good' chemically and 95% classified as 'good' in terms of biology by the mid 2020s[3]. Similarly, the Global Commons scenario is characterised by an improvement in river water quality due to reduced pesticide use and a shift to cleaner production in industry. UKCIP predicts that 75% of river water will be classed as 'good' chemically in the mid 2020s and 95% classified as 'good' in terms of biology[3].



Nutrients

Eutrophication is the undesirable effect of nutrient enrichment in our seas as a result of human activities. The effects of eutrophication can include changes in phytoplankton species composition and increased oxygen consumption in water and sediments. This can have detrimental effects on benthic fauna and the water column (see Section 4.3 on harmful blooms)[71].

The main source of nitrogen is run-off from agricultural land brought to the sea via rivers. Atmospheric deposition of nitrogen may also contribute significantly and this nitrogen originates partly from ammonia evaporation from animal husbandry and partly from combustion of fossil fuels in traffic, industry and households. Most of the anthropogenic phosphorus (P) entering the world's oceans comes from households and industry discharging treated or untreated wastewater to rivers or directly to the sea. Locally, fish farming may also cause eutrophication problems[74]. Rivers account for 65-80% of the inputs of total N, and 80-85% of the total P to the European seas[74].

The Baltic and North Sea regions have experienced a doubling in nitrogen loads between the 1950s to the 1980s, and a four-fold increase in the phosphorus load[74,75]. Since the middle of the 1980s however, the phosphorus load has generally reduced (Figure 2.16) due to improved sewage treatment and wider use of phosphate-free detergents. The nitrogen load from point sources has also reduced, but there has been no perceivable reduction from agriculture as the main source of diffuse nitrogen (Figure 2.16)[75,77].

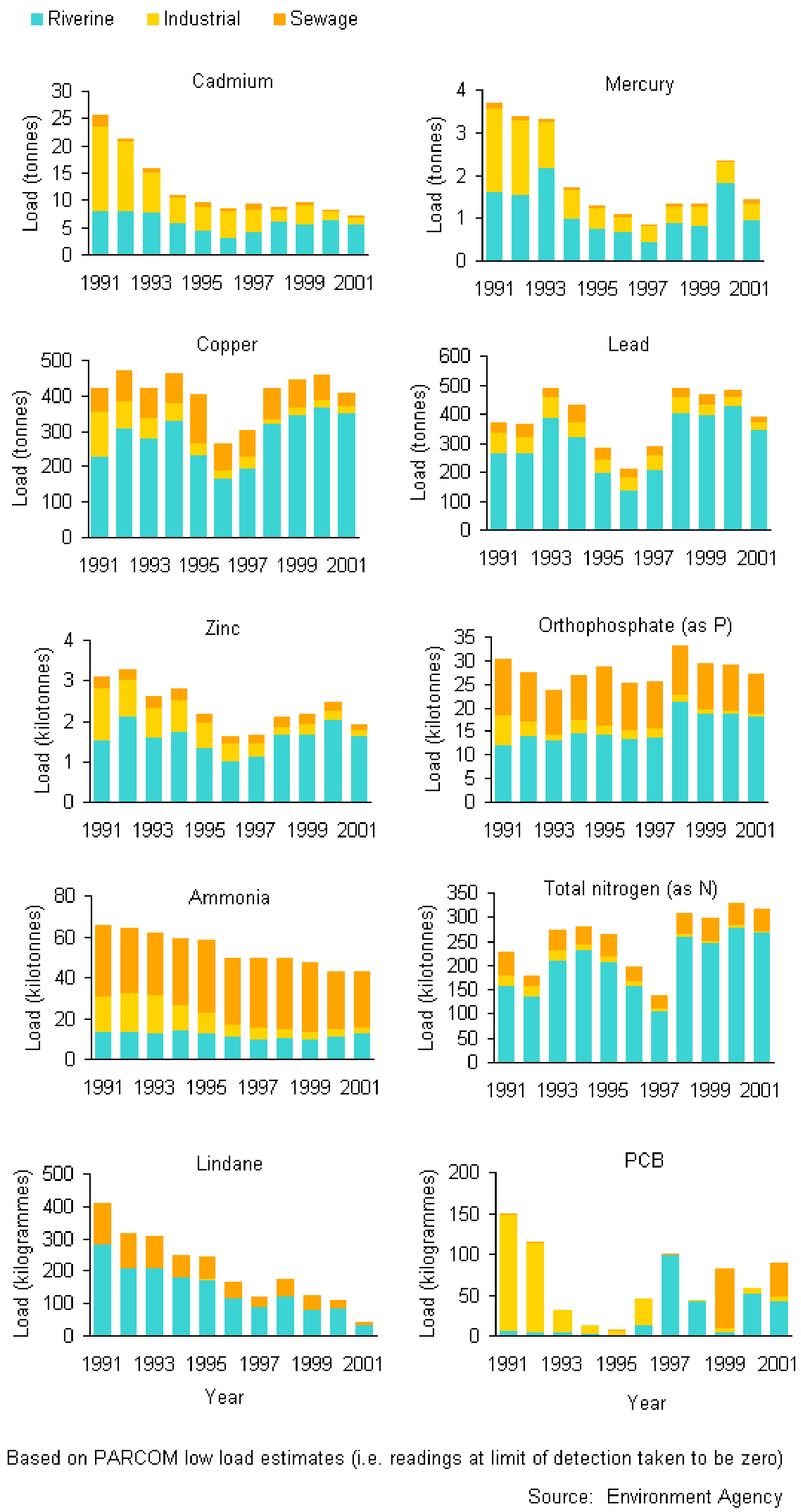
Emissions of nutrients under each of the AFMEC scenarios are considered for the most part, to be dependant upon the types of agricultural production that will predominate.

Within the **World Markets** scenario agricultural policy will be non-interventionist and subsidies, if present at all, will be low. Farms will need to be large to survive and they will use technology (eg precision farming techniques and GM crops) to increase competitiveness. Overall the land area under agricultural production will decline (as increasing areas of the countryside are given over to recreational activities), but yields will be higher. Prospects for nutrient emissions are mixed. On the one hand technological innovations, such as precision farming techniques, may allow higher yields to be achieved with carefully timed and targeted fertiliser inputs, however weak environmental control and relatively cheap fertiliser prices may encourage more than optimum use resulting in greater run-off of nutrients to the sea.

For the Local Stewardship and Global Commons scenarios, nutrient inputs to marine environments will be substantially reduced (relative to other scenarios). Agricultural policies in both scenarios will tie subsidies to use of traditional, low-intensity farming practices, and to the sustainable management of rural landscapes. Under the Global Commons scenario large areas of land will be taken out of agricultural production, while, conversely, a greater land area may be utilised for agriculture under the Local Stewardship scenario. Water quality standards under both these scenarios will be more stringent, necessitating substantial investment in upgraded sewage treatment works.

Under the Fortress Britain scenario, agricultural policy is primarily designed to protect national food supply and keep food prices at relatively low levels. Concern for the environment is not a priority. Agricultural production relies on high levels of fertiliser and pesticide inputs with weak control over application rates and timing of application. Consequently there are high levels of run-off to river systems and eventually to the marine environment. In addition there is only moderate investment in sewage treatment, and only weak control of industrial discharges.

Figure 2.16. Total inputs of metals, nutrients and agrichemicals into the North Sea for the period 1991-2001, distinguishing riverine, direct industrial and sewage components. (Source: UK Environment Agency)[77].



Case Study:

Cost-effectiveness of options to reduce nutrient concentrations in the Humber Estuary[76].

The Humber estuary is an important source of nutrients into the North Sea. Prior to 1993, the Humber was responsible for 30% of the input of nitrogen and phosphorus to UK coastal waters. Total dissolved inorganic nitrogen input was estimated to be about 57,400 tonnes in 2000, of which more than 95% reached the open sea. The total dissolved inorganic phosphorus input was estimated to be 5700 tonnes, of which 15% was exported to the North Sea. The dominant sources of nutrients within the Humber catchment are agriculture (through run-off of fertilisers and from livestock production) and from domestic and industrial sewage.

A recent study[76] explored the cost-effectiveness of measures designed to reduce nutrient concentrations within the estuary. Three measures were studied: controls on agricultural production to limit nutrient run-off (which have been implemented within nitrate vulnerable zones (NVZs) that cover almost 75% of the Humber catchment); upgrading of sewage treatment works to remove nitrogen and phosphorus, and; a policy of 'managed realignment' with respect to flood defences within the estuary.

'Managed realignment' involves the deliberate breaching of engineered defences to allow the coastline to recede to a new line of defence further inland (see Section 2.9). The process has a number of environmental benefits. It creates more habitat with potential biodiversity, amenity and recreational values; it also results in extensive nutrient attenuation capabilities and an increased contaminants storage capacity.

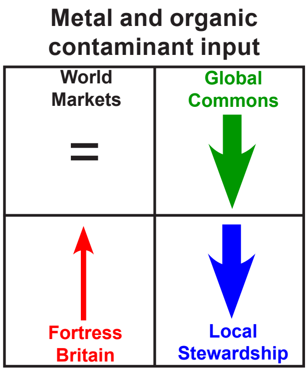
Managed realignment in the Humber Estuary – Photo Rachel Cave 2003

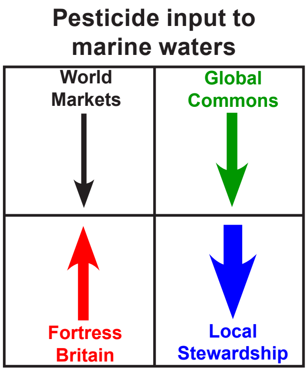
The effect of the three mitigation measures on concentrations of nitrogen and phosphorus were simulated under three differing scenarios using a computer model of the Humber Estuary. The three scenarios used: business-as-usual (BAU), which is similar to the **World Markets** scenario; deep-green (DG), comparable to the **Local Stewardship** scenario, and; a policy-targets (PT) scenario that is located midway between[76]. Controls on agriculture were included in all scenarios; a 20% decrease in loads of nutrients from point sources (predominately sewage treatment works) and managed realignment of 1321 hectares were modelled under the PT scenario. For the DG scenario a 50% reduction in discharges of nutrients from point sources and managed realignment of 7494 hectares was modelled[76].

In terms of cost-effectiveness the study concluded that controls on agricultural production are more effective than upgrading of sewage treatment works. Agricultural controls cost £16,000 to reduce nitrogen loads by one tonne, and £178,000 to reduce phosphorus loads by one tonne, whereas sewage treatment upgrading costs £47,000 to reduce nitrogen and between £202,000 and £559,000 to reduce phosphorus by one tonne[76].

The research also found that managed realignment is a particularly effective means of lowering concentrations of nutrients within an estuary and, ultimately, the loads of nutrients (in particular nitrogen) discharged to the ocean. In the scenarios outlined above, farming practices throughout more than 25,000 km^2 of the catchment would have needed to be changed in order to achieve the same reductions in nitrogen as realised by creating 75 km^2 of new intertidal area around the estuary. Managed realignment was also shown to have a number of environmental benefits (habitat creation, carbon sequestration, etc.) the value of which would more than offset the costs associated with this option[76].

Metals and Organic Contaminants





It is estimated that there are well over 100,000 chemicals currently on the market, and many of these are produced and used in high volumes. The main problem for the marine environment is that some of them are toxic to marine life. If they are also persistent, they can remain in the environment long enough to be assimilated into biota, if they are bioaccumulative, then they can be stored in the tissues of marine animals where they become concentrated and can pass up the food chain and reach alarming levels in top predators. Human activities have drastically altered concentrations of many naturally occurring substances in the environment such as metals, and added numerous new chemicals, such as DDT and PCB. Contamination of marine wildlife, habitats, seafood and seawater is a major cause of concern among coastal communities throughout world. Certain persistent organic substances such as PCBs as well as heavy metals such as cadmium and mercury can accumulate in shellfish and in animal tissues and cause considerable harm to humans[78]. There are also some chemicals known as endocrine disruptors which can adversely affect the hormone systems of organisms resulting in adverse effects on health and reproduction (eg the feminisation of male fish). Until recently, concern has focused on single substances, but it is now clear that mixtures of substances, even if individual pollutants are at low concentrations, can cause significant biological effects.

Persistent organic contaminants, such as DDT, lindane and PCB, have low solubility in water but high lipid-solubility, and they are typically resistant to biodegradation. These properties lead to uptake and accumulation in the fatty tissues of living organisms. The highest concentrations of organic contaminants are found in top predators, such as sea birds, marine mammals and humans. Adverse effects of these contaminants can include disruption of the immune system, disruption of hormone production or transport, impairment of reproduction, embryonic damage or damage to the nervous system[78].

DDT is a synthetic organochlorine insecticide that was first used to control insects that were vectors for human diseases at the end of World War II. Lindane is a chemical that is still used in many parts of the world and is toxic to vertebrates as well as to insects (the target for the pesticide)[78]. PCBs are a group of 209 different compounds of which 150–160 are found in the marine environment. All PCBs are man-made, and since 1929 at least one million tonnes have been produced. Sources of PCB to the environment are mainly diffuse and the highest levels are generally found in estuaries or close to industrialized urban centres[78].

Polycyclic aromatic hydrocarbons (PAH) are produced both naturally (eg in forest fires) and by man's activities. The major sources currently are from industrial processes, and as products of incineration. An assessment of the toxicological significance of the PAH concentrations has suggested that the most heavily contaminated sediments in UK estuaries are likely to be acutely toxic to certain sediment dwelling animals. Furthermore there is evidence of a correlation between the occurrence of liver tumours in North Sea flatfish and contaminants, particularly PAHs. An additional potential risk includes uptake and accumulation of PAHs by deposit-feeding benthic invertebrates which have a well-developed ability to digest and absorb particle-bound organic contaminants. PAH are of concern, from a human health perspective particularly where affected shellfish are sold commercially[78].

Metals are found naturally in marine ecosystems, but human activity has greatly increased local, regional and global fluxes, leading to an increase in the prevalence of potentially harmful metals, including cadmium, mercury and lead. Metals generally bio-accumulate in tissues. In vertebrates, cadmium accumulates in kidneys and liver, whereas lead accumulates in bone[78]. Sources of cadmium to the environment include mining, burning of fossil fuels, the use of phosphate fertilisers, and waste incineration. 'Produced water' (water produced with oil and gas – see Section 2.7) is also a source of direct metal discharge to marine waters[78]. The main anthropogenic sources of mercury are from waste disposal and industrial activities. It is still used in various products, eg batteries and electronics. Furthermore, low quantities in fossil fuels and municipal waste ensure continued emissions of mercury into the atmosphere.

The main anthropogenic sources of lead are from general waste and industrial activities. The major use of lead is in the manufacture of automobiles, it also has important applications in radiation shielding, in roofing and for the sheathing of electric power cables. In 1972, around 400,000 tonnes of tetraethyl lead were consumed throughout the world to improve the octane rating of petrol. Since then, leads concentrations have generally declined because of restrictions imposed through environmental legislation[78].

Direct discharges and riverine inputs of cadmium, mercury, lead, lindane and PCB into the North-East Atlantic have all decreased in recent years (Figure 2.16). Atmospheric inputs of cadmium, mercury and lead also appear to have decreased markedly[78]. The pattern of input reduction has however varied substantially on a local scale, for example there was a strong decrease in lead in the River Elbe but an increase has been reported in the nearby River Weser. Even where particular activities have ceased, historical activity is likely to provide a legacy of contamination for many years to come (eg lead inputs from historic mining activities).The geographical patterns of metal concentrations in fish continue to reflect historical sources of contamination. For example, even though direct inputs from chlor-alkali plants ceased in the Mersey and Wyre estuaries (north-west England) many years ago, there are still higher concentrations of mercury in fish muscle compared to other areas[79].

The key substances implicated as causing endocrine disruption in fish include natural substances such as the human female sex hormone 17beta-oestradiol (released with sewage) and synthetic chemicals such as nonylphenols. Some fish species, particularly rainbow trout, roach and flounder, seem sensitive to exogenous oestrogenic (feminising) substances, as indicated by the presence of the female yolk protein vitellogenin (VTG) in blood plasma of male fish. This phenomenon has now been recorded in a number of UK estuaries including including the Mersey, Tyne and Clyde at up to 20% prevalence[75,154].

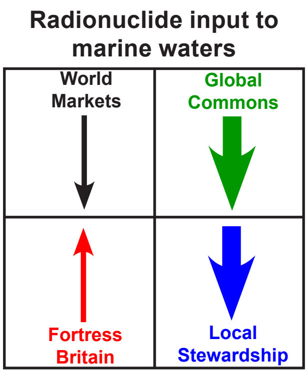
A number of so called 'new contaminants' (eg fragrances, flame retardants etc.) have recently been proposed as potentially problematic, although their impacts on marine biota remain largely unknown. The global consumption of bromine-based flame retardant products amounts to over 300,000 tonnes per annum. High concentrations have been found in water samples from the Rivers Skerne and Tees, downstream of a plant at Newton Aycliffe where such chemicals were manufactured, and in sediments of the lower Tees estuary. Subsequently, a study of invertebrates and fish from the North Sea concluded that the estuary of the River Tees was a major source for tri- to hexa- BDE congeners, and that these compounds were accumulated within North Sea foodchains, from invertebrates to fish and marine mammals. Following EU restrictions concentrations of almost all BDE congeners are likely to fall in the future. In late 2003, the closure of the Newton Aycliffe manufacturing site was announced[154,71].

Inputs of metals and organic contaminants are predicted to continue to decline under the World Markets, Local Stewardship and Global Commons scenarios. Predominantly this will be due to a movement away from resource-intensive manufacturing industries and, in the latter two scenarios this will be coupled with a drive towards eco-efficiency and strict controls on environmental impacts. Pesticide use (including DDT and lindane) is also likely to decline under each of these scenarios, although for differing reasons. Precision farming methods and use of GM crops are envisaged within the World Markets scenario, both of which require fewer pesticide or nutrient inputs than do conventional farming systems. Under the Local Stewardship and Global Commons scenarios pesticide use will be discouraged by the tying of agricultural policy subsidies to sustainable management of rural landscapes and less environmentally damaging practices.

With a less marked decline in manufacturing industry and with weak environmental legislation the Fortress Britain scenario will give rise to increases in levels of some pollutants. Notably, pesticide use will increase, since there will be pressure to enhance indigenous agricultural production and run-off may cause significant problems in estuaries and coastal waters.

OSPAR's 1998 Strategy for Hazardous Substances aims to prevent pollution of the maritime area by "continuously reducing emissions of hazardous substances"[71]. A work programme has been developed to identify those hazardous substances which are of greatest concern, to prepare assessments on the main sources and to develop or promote appropriate measures to achieve a 2020 cessation target for these substances. Around 30 substances for priority action have been identified so far, and the UK has also ratified the Stockholm Convention on *Persistent Organic Pollutants* (POPs). POPs are chemicals that are toxic, persistent, bioaccumulate and biomagnify through the food chain. The Convention seeks the a restriction on the production and use of 10 substances, including PCBs and DDT[71,79].

Radioactivity



Radioactivity has both natural and anthropogenic sources. Natural radiation stems from decay of radionuclides in the Earth's crust and cosmic radiation. The anthropogenic input can be derived from: historic weapons testing, accidents (eg Chernobyl) and industrial processes (eg nuclear reprocessing facilities)[80].

Phosphate fertiliser production can be a major anthropogenic source of radionucleotide emisions, but ore processing and the burning of coal, oil or natural gas in thermal power plants can also contribute. The greatest quantity of the artificial radionuclides caesium-137, technetium-99 and iodine-129 originate from reprocessing facilities (eg Sellafield and Cap de La Hague). Once released into the Irish Sea near Sellafield, soluble radionuclides are transported northwards by the Norwegian Coastal Current to the Arctic and also down into the northern North Sea. The input from Cap de la Hague, France's main reprocessing facility, follow currents through the Channel in to the southern North Sea and subsequently also end up in the Arctic. Radionucleotides reach the Barents Sea four to five years after release and the Iceland and Greenland Seas after seven to nine years[80].

Traces of man-made radionuclides typically decrease with increasing distance from reprocessing facilities. Levels of caesium-137 range from 500 Bq m^{-3} in the vicinity of outlets, down to 2 Bq m^{-3} in the open ocean. The trend in caesium-137 discharges from Sellafield, has been steadily downward in the Irish Sea since 1988. Discharges of technetium-99 from Sellafield have also decreased since 1997[80].

According to a recent Defra report[80], all of the currently operating Magnox power stations in the UK are expected to close by 2010, with consequent major reductions in discharges following defuelling and post-operational clean-out. By 2020, total beta/gamma discharges are expected to be reduced from more than 10 TBq to less than 1.5 TBq a year[80]. In addition, by around 2012, reprocessing of spent Magnox fuel is expected to cease, with consequent significant reductions in discharges (from 165 TBq a year to around 50 TBq a year)[80]. By 2005, radioactive discharges to the Thames estuary from the Atomic Weapons Establishment (AWE) Aldermaston are expected to cease. By 2020, tritium discharges from the defence sector are expected to be reduced from 0.7 TBq to 0.4 TBq a year and other beta/gamma discharges are expected to be reduced from 0.005 to 0.003 TBq a year.

Concentrations of artificial and natural radionuclides in sediments are in general low except near outlets from the reprocessing or phosphate fertiliser industries. Sediments in both sub-tidal and inter-tidal areas can act as a long-term sink for reactive particles, and as such some sediments may contain residual amounts of artificial radionuclides, particularly caesium, plutonium and americium for many years into the future[80]. Seaweeds are good indicators of soluble radionuclides such as caesium and technetium in the surrounding marine environment. The concentration of caesium-137 in the seaweeds around Sellafield and on the east coast of Ireland, decreased by approximately 20% per annum during the period 1983 to 1986. Parallel decreases have been measured in fish and shellfish from the same area during the same period[80].

Under the Local Stewardship and Global Commons scenarios we would expect that the emphasis upon sustainable resource management and on high levels of environmental control will result in a phasing out of nuclear energy production and hence a continuing decrease in emissions of radioactive particles to the marine environment. Similarly under the **World Markets** scenario, low prices of fossil fuels coupled with high discount rates will mitigate against any expansion of nuclear power production or extension of the life of existing plants.

Only under the Fortress Britain scenario might we expect that the operational life of existing nuclear power plants might be extended (see Section 2.7 and 2.8)[3] and possibly new nuclear plants would be commissioned. This might be the case particularly if technology improves to the extent that it is possible for nuclear power but no apparent increase in emissions. With the operating life of nuclear power plants being extended, there might or might not be increased risk of some catastrophic release of radioactive material with consequent devastating effects on nearby marine ecosystems.

Dumping at sea

In the past, disposal at sea was seen as a convenient and cheap outlet for waste material from coastal communities and industry. In 1972 the *Convention on the Prevention of Marine Pollution by Dumping of Waste and Other Matter* was adopted. This was the first major global initiative designed to protect the marine environment from unregulated dumping of waste from vessels, aircraft or platforms. In addition, Annex II of the 1992 OSPAR convention effectively banned all material from being dumped in European waters, except for dredged material, inert material of natural origin and fish waste (ie, 'discards' from fishing boats)[71].

In the UK, dumping of radioactive waste ceased in 1982, incineration of waste at sea has not been permitted since 1990, dumping of industrial waste ended in 1992 and sewage sludge dumping was phased out in 1998. Although the dumping of waste is prohibited under the OSPAR Convention and the dumping of litter from ships in the North Sea is prohibited under MARPOL (see Annex 2), marine litter remains a problem[71]. Under the **World Markets** scenario, because economic costs often override environmental concerns, we might expect a resumption of dumping at sea since this is much cheaper than disposal of waste on land or recycling of materials. In addition, increased shipping traffic might result in greater quantities of marine litter (ranging from micro-particles of plastic to shipping-containers) being released, both accidentally and deliberately. Alternately or in addition, we might see rich nations in the developed world, exporting much of their waste to less developed counties (by ship), where disposal costs are cheaper. Under the Local Stewardship and Fortress Britain scenarios, international controls on waste disposal would be weaker, and hence we might experience dumping or disposal of materials at the boundaries of territories, where currents and tidal flow pass the problem on to neighbouring states or communities. Under the Fortress Britain scenario in particular, the re-emergence of indigenous refining and manufacturing industries would lead to increased demand for waste disposal facilities, possibly necessitating a large-scale resumption of dumping at sea.

Under the Global Commons scenario, waste reduction programmes and recycling would mean that less waste would be produced in the first place. International conventions would prohibit dumping at sea on a global scale. Multi-national disposal facilities might develop to process the most hazardous of substances. We would also expect tight legal controls and active procedures to reduce litter and rubbish in the oceans.

2.6. Aggregate extraction

Introduction

Around 21 percent of the sand and gravel used in England and Wales is now supplied by the marine aggregates industry. Marine aggregates are particularly important in London and the south east where they account for 33% of the total regional demand and in South Wales where they supply 90% of the sand needed[84,85].

As planning constraints are tending to restrict the extraction of sand and gravel (aggregate) from terrestrial sources, attention is increasingly being focused on the importance of seabed resources. Large volumes of marine sand and gravel have been used in construction projects throughout the past century, most of it for the production of concrete. Since 1955, a total of around 500 million tonnes of aggregates have been dredged from the sea and used in the built environment. The demand for marine aggregates is likely to continue in the near future, with massive building projects such as the 'Thames Gateway' now underway. In addition, in recent years there has been a gradual increase in the amount of material exported for use in the construction industry of countries such as the Netherlands, Belgium and France. Exports to Europe currently account for around 28% of the total (6-7 million tonnes in 2003)[81].

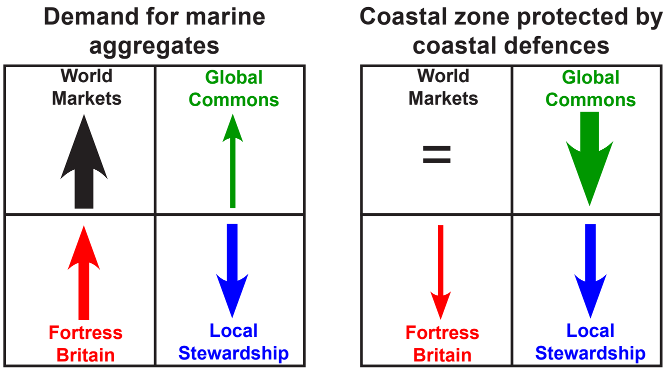
Around 10% of the marine sand and gravel extracted in the UK is used for coastal defences and beach nourishment. During the 1990s over 20 million tonnes of marine aggregate were used in this way. Major schemes included the east coast of England between Mablethorpe and Skegness and between Happisburgh and Winterton in Norfolk. On the south coast, major replenishment schemes have taken place at Hythe, Eastbourne, Hurst Spit and Weymouth[84].

Figure 2.17. Location of licensed marine aggregate extraction areas (red) around the English and Welsh coastlines in January 2004 (Source: Crown Estate, 2004)[83].

In the UK the Crown Estate owns the mineral rights to the seabed and issues commercial licences to explore and extract sand and gravel. Dredging licences currently cover 1300 square kilometres or 0.1% of the UK continental shelf[83]. On average, 15% of the licensed area is dredged in any one year. The nation's marine aggregate needs are currently satisfied by a fleet of 30 vessels. A large dredger can load some 5000 tonnes of sand and gravel in around three hours[81].

Extraction of the UK marine aggregate resource peaked in line with overall demand for aggregates in 1989 and has remained relatively constant in recent years at around 23 million tonnes per annum[82]. There are six main dredging regions, the largest tonnages being extracted from sites on the east and south coasts of England (Figure 2.17). Aggregate extraction can have a number of environmental effects on the seabed including the removal of sediment and resident fauna, changes to the nature and stability of sediments, and increased turbidity and redistribution of fine particulates[81].

Substantial aggregate resources have been discovered in the central Eastern English Channel (~550 million tonnes), and the industry expect that this will provide resources for at least 25 years at current levels of demand, if dredging is permitted in this area[81]. Government predictions assume a level supply of 230 million tonnes nationally for the period 2001-2016[82]. The demand is apportioned regionally such that 120 million tonnes will be required in the south-east of England, 53 million tonnes in London, 32 million tonnes in the east of England and 25 million tonnes throughout the rest of the country[82].



Imports, exports, supply and demand

The annual UK demand for construction aggregates is around 205 million tonnes each year, nearly four tonnes of aggregates are needed per head of the population[82]. As much as 50% of all marine aggregates dredged in the UK are procured for use in large-scale government-led development projects. Marine aggregate was used for an estimated 90 per cent of the 200,000 cubic metres of concrete that went into Bluewater Shopping development and it is the main source for the new Channel Tunnel Rail Link[81].

Presently, the vast majority of supplies to large-scale public projects in the Thames and Medway derives from dredged sources off Great Yarmouth. Many of the reserves off East Anglia are nearing exhaustion, which means having to dredge further afield from sites in the Humber and Isle of Wight. Thus government policy/planning decisions can have far-reaching implications for marine ecosystems throughout UK waters. The government's future regeneration priorities include the Thames Gateway housing development as well as developments on parts of the south coast stretching from Kent through to Portsmouth and Southampton. These are likely to create further demand for marine aggregates in the south of England[81].

The World Markets scenario is characterised by a dramatic increase in the number of households within the UK, (from 24.5 million to 31 million)[3]. This implies a massive programme of house building and since 60 tonnes of aggregates are needed for a typical house, we might expect that much of the demand will need to be met by marine sources. Under this scenario, 24,500 ha per year of land is expected to change to urban usage, half of this from formerly undeveloped land[3]. In addition, substantial quantities of marine aggregates are likely to be required to maintain coastal defences, with no formerly protected areas being abandoned to 'managed retreat' (see Section 2.9). Government intervention in procurement, regulation and supply/demand planning is likely to remain minimal under this scenario, with extraction largely driven by market forces and economics. Aggregates would be obtained from the cheapest sources, throughout the world. Large-scale exports of material to continental Europe would probably continue, and there would be very little recycling, since it would be cheaper to extract new construction materials from the natural environment. Spatial usage of European waters would be largely determined by the economic value of the particular activity. If aggregate extraction is more profitable than fisheries, windfarms or tourism for example, then more seabed might be allocated to this activity. Environmental protection would be viewed as simply another marine activity with associated profits and costs, and as such would probably be given little weighting. Extraction would largely be carried out by powerful multinational companies at large-scale extraction sites. Small companies and small-scale coastal deposits are unlikely to be cost effective. Under this scenario industry restrictions such as the 'aggregates levy', introduced in 2002 to make the price of aggregates better reflect environmental costs (in line with the 'polluter pays principle'), would possibly be scaled-back. Environmental impacts would be assessed by government on a case-by case basis.

Under the Global Commons scenario, the number of UK households is again expected to grow dramatically (from 24.5 million to 27.5 million)[3], although much less undeveloped land is expected to change to urban usage (2000 ha yr^{-1})[3]. Large-scale construction and house-building projects would again demand large quantities of materials, however strong international legislation would ensure that aggregates are extracted only from sustainable or less environmentally sensitive sources. Large areas of previously-protected coastline (~15,000 ha) are expected to be abandoned to 'managed retreat', thus smaller quantities of marine aggregates will be required for beach replenishment, to maintain hard sea defences (see Section 2.9) and because of reuse and recycling of existing construction materials. Strong international controls would protect sensitive habitats, and development would be strongly linked to environmental policy drivers. The European community would have a clear strategy for assessing demand and maintaining supplies (and granting consents). Under this scenario industry restrictions such as the 'aggregates levy', are likely to become even more extensive and restrictive.

Under the Local Stewardship scenario, the number of UK households is expected to decline to 23 million[3], with no further loss of formerly undeveloped land. Consequently, the need for further marine aggregates would be greatly reduced. Much of the demand would be met through recycling of land and materials or replacement with alternative products, and small-scale local extraction would become more important. Export of materials would be greatly restricted (as is currently the case in Wales), resources would be owned locally, and the national government would play only a small role in procurement and regulation. Resources would be obtained from local suppliers who are pledged to exploit the resource sustainably, allowing fallow periods to enable regeneration of biological communities, ie, zoning linked to ecosystem repair. The lack of national planning, governance and monitoring might lead to decreased standardisation and a diverse array of legal instruments and industry levies, throughout Europe. Large areas of formerly protected coastline are expected to be abandoned (10,500 ha), to 'managed retreat', thus there will be little requirement for beach replenishment or maintenance of sea defences.

By contrast, the Fortress Britain scenario is characterised by moderate growth in the number of UK households (to 25.5 million)[3], and large areas of undeveloped land changing to urban usage. The main priority will be maintaining national supplies, and hence aggregate exports would be severely curtailed. Moderate growth in the economy and the number of households would necessitate continued extraction of marine aggregate resources, however a national strategy would ensure that supply meets demand. National government would play a role in procurement of materials for large-scale building projects, and where environmental concerns conflict with the greater good of the nation, economic or social concerns (eg the provision of new housing) may take precedence. Spatial resource usage in coastal waters will be determined by national requirements and extraction would be carried out by UK companies rather than multinational conglomerates. Industry restrictions such as the 'aggregates levy' might be scaled-back or abandoned if they impact on the ability to maintain supplies. Only a small area of formerly-protected coastal land will be given up to 'managed retreat'. Thus, the demand for marine aggregates for construction and beach replenishment is expected to remain moderately high under this scenario.

An independent study carried out by the Centre for Economics and Business Research (CEBR)[84], has predicted that demand for aggregates in the UK is likely to increase by around 20%, from 212 million tonnes in 2001 to 261 million tonnes in 2016. This is in contrast to the lower predictions produced by the Office of the Deputy Prime Minister (ODPM)[82], ie, 220 million tonnes by 2016.

Environmental impact of aggregate extraction

Concern over the potential environmental impacts of sand and gravel extraction were first voiced more than a Century ago and tend to focus on potential impacts to benthic macrofauna and consequential effects on fish resources and marine ecosystems. Other concerns focus on damage to archaeological or wreck sites and disruption of marine navigation[81].

Typically, marine aggregates in UK waters are dredged using trailer suction vessels. Dredging is carried out whilst the ship is underway, leading to shallow linear furrows approximately 1 to 3 m in width and generally 0.2 to 0.3 m in depth. Whilst this is the main method of dredging, a number of typically small vessels are able to dredge by anchoring over the deposit. This is usually referred to as 'static dredging' and is employed in areas where the deposit is spatially restricted or locally thick (eg East of the Isle of Wight and in the Bristol Channel). In this case, dredging usually results in saucer shaped depressions up to 10 m deep and 200 m in diameter[81].

The length of time that trailer-dredged furrows or depressions created by static dredging will remain as distinctive features on the seabed depends on the ability of tidal currents or wave action to erode crests or transport sediments into them. Erosion of dredge tracks in areas of moderate wave exposure and tidal currents have been observed to take between 3 to >7 years after the cessation of dredging. Dredged depressions created by static dredging have been reported to remain as recognisable seabed features for a considerable period of time perhaps decades. Changes in sediment composition as a result of dredging are well documented in the literature. Sometimes dredging can contribute to the fining or coarsening of sediments over time. Dredging can also lead to the production of short-term plumes of suspended material[81].

The most significant consequence of marine aggregate extraction on the seabed is the removal of the substrata and the associated benthic fauna. Most studies on the effects of aggregate extraction have focused on the rates of macrobenthic recolonization upon cessation of dredging. The estimated time required for re-establishment may vary depending on the nature of the habitat, the scale and duration of disturbance, hydrodynamics and the life histories of different fauna. Available evidence, suggests that progress towards 'recovery' could be expected within 2-3 years of cessation of dredging in sandy gravel habitats exposed to moderate wave exposure and tidal currents.

However, the 'recovery' period may be more prolonged (ie, > 4 years), for sites dredged repeatedly, eg off Harwich[81].

Ecosystem impacts would undoubtedly be most severe and widespread under the **World Markets** scenario, largely as a result of the significant expansion of the industry and the little regard for ecosystem considerations. However, since only large deposits of aggregate are likely to prove cost-effective, smaller deposits may well escape exploitation altogether under this scenario.

The smallest overall impact on marine communities might be expected under **Local Stewardship** scenario, whereby demand for new aggregates would be greatly reduced. However, the exploitation of local resources for local needs, under this scenario, might mean that very few deposits escape exploitation completely, and hence the loss of 'virgin' habitat and potential refuges. In addition, the trailer suction vessels which are used for large-scale extraction, and thus would presumably be used under the **World Markets** scenario, can have less long-lasting effect on the seabed than the small-scale static dredgers which would probably be employed under the **Local Stewardship** scenario.

2.7. Oil and gas

Introduction

The North Sea oil and gas industry is at a turning point. Having enjoyed 30 years of broadly uninterrupted growth, the industry now faces real challenges as existing fields decline and new fields become smaller, fewer and more costly to develop. North Sea oil is worth approximately £3bn in expenditure and employs 270,000 workers. There has been growing debate concerning the direction of future global oil production. Several prominent reports have expressed the view that world oil production will peak in the not too distant future, possibly before 2010[86].

There are approximately 35 major Norwegian oil fields and 55 major UK oil fields in the North Sea. Masters *et al.* (1994) assessed the size of these reserves and suggested that the Norwegian fields consist of approximately 30 billion barrels oil (bbo) and the UK approximately 36 bbo[86].

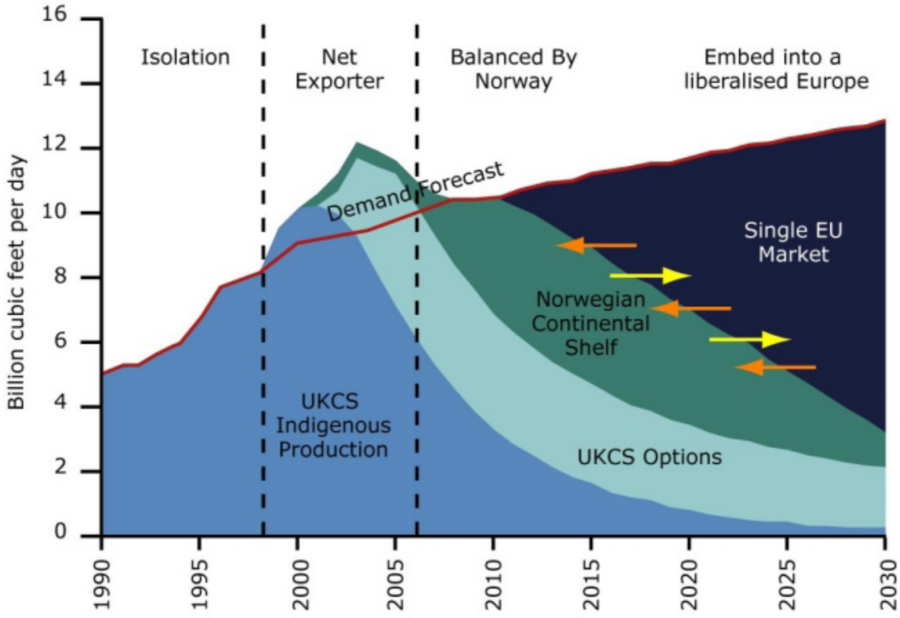
Seven major Norwegian fields peaked prior to 1995 and 29 major UK fields peaked prior to 1994. Many of the remaining fields in the North Sea are now in decline. To counteract the rapid decline of mature fields, new but smaller fields are being brought on-line at an accelerated rate. As an example, in Norway 23 out of 34 current fields have start-up dates after January 1, 1993. In the UK, the 200th oil and gas field was recently brought on-line. It took 25 years for the first 100 fields to be brought on-line but only 6 years to bring online the second 100[86]. The fields that are now opening up in both the UK and Norwegian sectors will have lifetimes of ten years or less. In an extreme example, the Durward and Dauntless fields were brought on-line in August 1997 and were terminated in April 1999.

In the IEO2004 forecast (the U.S. DOE/EIA's International Energy Outlook 2001)[87], North Sea production reaches a peak in 2006, at almost 6.6 million barrels/day (mb/d). Production from Norway, Western Europe's largest producer, is expected to peak at about 3.6 mb/d and then gradually decline thereafter to about 2.5 mb/d by the end of the forecast period (2025). The United Kingdom is expected to produce about 2.2 mb/d through to 2010, followed by a decline to 1.4 mb/d by 2025[29]. Norway presently has only two oil fields that produce over 300,000 b/d, Ekofisk and Troll, and both of those fields will enter their terminal decline phase in the next few years[86].

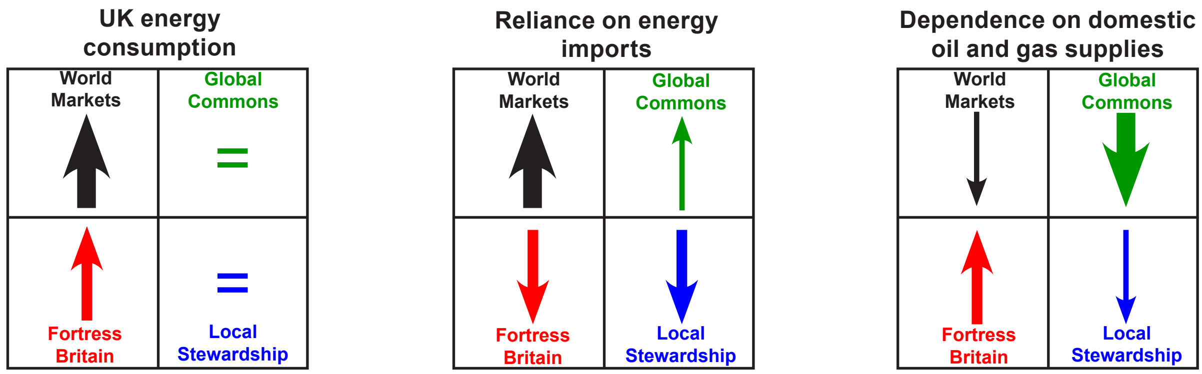
Major natural gas reserves were first discovered in the southern North Sea in 1965 and first brought ashore in 1967[88]. Historically, in the UK, gas was regarded as a premium fuel and sold into the domestic, commercial and certain industrial markets. During the 1990s, however, a new market opened up, using the fuel for power generation which offered higher generation efficiency, fewer carbon emissions and lower fuel costs than conventional coal-fired technology. Combined with market liberalisation, the increase in gas-fired generation caused rapid growth in UK gas use, such that by 2000 demand had risen to over 10 billion cubic feet per day (bcfpd). In 2001, gas represented almost 45% of UK hydrocarbon production, some 37% of UK energy production and 4.3% of world production, making the UK the fourth largest gas producer[88].

Figure 2.18 illustrates the evolution of the UK supply demand balance since 1990 as viewed by BP. This study predicted a gradual shift to gas imports over the next 30 years. Globally, gas resources are abundant and the UK has imported significant gas volumes in the past, for example, from Norway in the 1970s and 1980s. In the medium term it is clear that the UK's gas import requirements will be sourced, mainly from Norway, however the announcement in 2002 of plans to import natural gas from Qatar is evidence that Middle Eastern reserves may become important to the UK. It has been estimated that some 70% of global gas reserves (5500 tcf) lie within economic transportation distance of the EU[88].

Figure 2.18. The UK oil and gas supply-demand balance since 1990 as viewed by BP.



Source: BP



Future imports, exports, supply and demand

Oil and gas from UK offshore installations makes an essential contribution to meeting the UK's energy needs, accounting for around 85 per cent of the nation's primary energy consumption. Furthermore, it has contributed over £170 billion to the Exchequer[71].

As of January 2004, the UK's proven crude oil reserves stood at 4.7 billion barrels. Almost all of the country's reserves are located offshore, on the UK Continental Shelf (UKCS)[88] in the North Sea. The northern North Sea (east of the Shetland Islands) also holds considerable reserves, and smaller deposits are located in the North Atlantic Ocean, west of the Shetland Islands. Total UK oil production in 2003 – 2.38 million barrels per day (bbl/d) – was 20% lower than the record level in 1999 and 7.5% lower than in 2002. Oil production in the UK is expected to continue to decline[88]. According to the Department of Trade and Industry's (DTI) most recent forecasts, oil production is projected to decline to 1.38 million - 1.59 million bbl/d by 2009.

The UK has been a net exporter of oil since 1981. In 2002, the UK exported 22.6% of its crude oil to the United States, 18.4% to the Netherlands, 9.3% to France, 7.5% to Germany, and 12.3% to other destinations. The UK's indigenous refineries took the remaining 29.9% of the country's total crude oil production. In 2002, most of the UK's oil imports came from Norway, with 73% (628,000 bbl/d), followed by Russia (9%), Algeria (5%), the Middle East (3%), and Mexico (2%)[88].

As of January 2004, the UK held an estimated 22.2 trillion cubic feet (Tcf) of proven natural gas reserves, a 9.8% decrease over the previous year. Most of the reserves are located offshore adjacent to the Dutch North Sea sector[88]. The UK shares the declining Frigg field with Norway, which produced 46 million cubic feet per day (Mmcf/d) from December 2002 to November 2003. Frigg's current production is down significantly from its plateau production of 1.6 billion cubic feet per day (Bcf/d) between 1978 and 1987. There are also important reserves in the Irish Sea including the large Morecambe (North and South) and Hamilton fields. In 2002, the UK produced 3.6 Tcf of natural gas, a 5.7% decline since 2000. Transco, the UK's pipeline operator, projected that demand for natural gas in the UK will grow at an annual rate of 1.7% until 2012/13, with natural gas' share of primary energy supply rising to 46%. In order to meet the expected supply gap, the UK industry has been attempting to line up potential international supplies, via liquefied natural gas (LNG) shipments and pipelines. Transco anticipates that the UK will need to import an estimated 1.9 Tcf by the end of the decade[88].

The **World Markets** scenario is characterised by continued reliance on fossil fuels particularly natural gas. Energy prices remain low, and there is little concern for energy efficiency, or the environment. Demand for electricity and fuel continues to grow. Primary energy consumption increases by 1.7% per year, to 280 million tonnes of oil equivalent by 2020[3]. The continued reliance on inexpensive fossil fuels would necessitate large-scale transportation of oil and gas around the world, from the cheapest available sources. Transportation of oil and gas would require new pipelines, tankers and oil terminals and consequently this would infer greater risk of environmental damage and accidental spillage. This scenario is characterised by limited legal controls and few international agreements; consequently some single-skinned tankers would remain in use (see Section 2.3). Installations would be decommissioned in the cheapest way/place, with little regard for environmental considerations. Small domestic reserves would probably become non cost-effective to exploit, and large multinational companies would predominate.

Under the Fortress Britain scenario, the country is again reliant on supplies of fossil fuels. The continued growth in demand for oil and gas would necessitate exploration throughout the continental shelf and into deeper waters in order to extract as much of the indigenous resource as possible, even from very small fields. The increasing difficulty in extracting dwindling resources would lead to relatively high energy prices, and would necessitate considerable government intervention or nationalised industries. This scenario would infer many new (short-lived) installations to tap small reserves, continued decommissioning of rigs and high environmental impacts and risks. In addition, continued prospecting activities may have an impact on wildlife, eg high-power sonic impacts on cetaceans. Consequently this scenario is perhaps the most environmentally damaging. The emphasis is on maintaining national supplies, and there would have to be tight control over exports and possibly a re-examination of the need for nuclear energy. The pursuit of energy efficiency is limited in this scenario and low priority is attached to environmental protection. Primary energy consumption increases by 1.5% per year, to 270 million tonnes of oil equivalent by 2020 (compared to 230 million tonnes of oil equivalent today)[3].

Under the Local Stewardship scenario, the exploitation of local energy resources is a particular feature. Some local coal and oil resources are exploited in this scenario, but with high standards of environmental control. Installations would be commissioned or decommissioned according to regional needs, and this may result in even small fields being exploited. The reduced overall demand for oil and gas, together with reductions in distant imports, would mean lower risk of environmental damage and/or accidental spillage. There would be tighter control (safety standards) of vessels and little need for under-sea pipelines. Smaller companies would benefit under this scenario, although there would be a danger of 'capital flight' whereby large companies move their operations to counties or regions where there are fewer legal restrictions. Strong legal instruments would protect regionally important habitats and wildlife. Under this scenario the Crown Estate would cede regulatory and licensing powers to regional collectives. It is conceivable that Scotland would become owner of much of the UK's oil reserves (in the northern part of the North Sea), whilst England would become the owner of the nation's natural gas (in the southern North Sea and Irish Sea). Green tariffs are taken up by environmentally conscious consumers and reinforce more formal regulatory controls. High energy prices lead to the large-scale adoption of energy efficiency measures. Demand for electricity and fuel remains at current levels ie, around 230 million tonnes of oil equivalent[3], the energy gap being made up primarily through expansion of the renewables sector.

Under the Global Commons scenario, natural gas remains the dominant energy source up to 2010, but renewable energy sources gain a large market share thereafter (see Section 2.8). There would be tight international controls on safety (eg tankers and pipelines), prospecting and decommissioning. Rigs would be decommissioned using methods and in places where the least environmental damage would result. Extraction operations, wherever they are in the world, would comply with strict environmental controls. Small, short-lived fields would not be exploited and there would be international action to protect sensitive habitats and species. Investment in higher cost energy forms and environmental controls mean that the price of energy to the final consumer is likely to be high. Demand for electricity and transportation fuels remain at current levels ie, around 230 million tonnes of oil equivalent[3].

Oil, gas and the environment

All oil-related activity in European waters is carried out under strict licence conditions, with the aim of minimising the effects on marine ecosystems. Direct impacts on the benthic community are usually confined to a few kilometres around platforms. These impacts are largely caused by the disposal of drill cuttings in the immediate vicinity of the installation. Biological changes are not usually detectable beyond 3 km from platforms, but there are a few cases where effects have been detected out to 5 km[79].

'Produced water' is the main source of oil pollution from the offshore oil and gas sector; overall quantities discharged have progressively increased even though the concentration of oil in this water has fallen in line with the OSPAR target standard of 40 mg l^{-1}. There is some uncertainty about the environmental impacts of 'produced water'. 'Produced water' contains a range of natural organic compounds besides oil including monocyclic aromatic hydrocarbons, 2- and 3-ring PAHs, phenols and organic acids. Increased levels of PAHs in caged mussels have been found up to 10 km from 'produced water' discharge site[79].

Accidental and illegal oil spills can result in the oiling of seabirds, shellfish and the coastline, with ecological and often economic consequences. Even very minor accidents can end in disaster where heavy fuel oil or its residues are involved, particularly where releases occur near sensitive habitats or species. When the *Pallas* grounded in the Wadden Sea in 1998, 250 m^3 of heavy fuel oil were released which killed some 16,000 sea-birds over-wintering in the area. The 10,000 – 15,000 t of heavy fuel oil spilt when the '*Erika*' broke apart off the French Atlantic coast in December 1999, killed at least the 80,000 birds. The majority of accidental spills involve < 1 t of oil, but larger spills resulting from tanker accidents have occurred, often in shallow waters[79].

Increasing seismic exploration by the oil and gas companies in the North Sea and along the Atlantic seaboard is seen as a possible cause for concern. Seismic surveys are conducted by vessels towing air gun arrays producing loud, low frequency impulse sounds to build up a picture of the seabed and underlying strata. Sea mammals at short distances from the array may be physically injured by this activity, and those at greater distances may be disturbed, causing interference with their daily activities and displacement from preferred feeding or breeding areas[79].

In terms of the potential for large-scale spillages, the **World Markets** scenario would probably be the most risky, since large amounts of oil would be transported for long distances around the world with only limited safety standards imposed on the necessary vessels and pipelines. In terms of exploration, drilling and decommissioning impacts the **Fortress Britain** scenario would probably be the most damaging to marine ecosystems, with many small fields opening up throughout UK waters for only short-term gain.

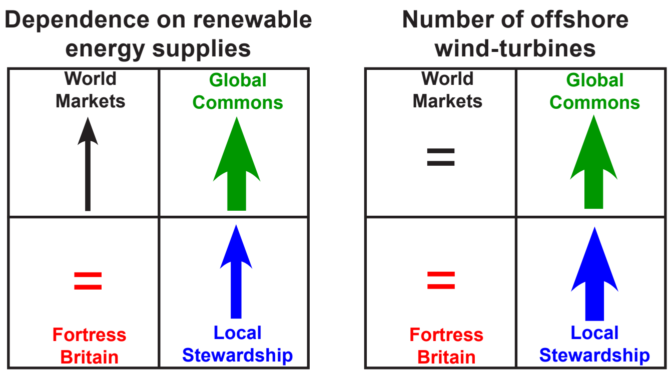
2.8. Offshore energy and construction

Introduction

The UK has significant potential for the generation of electricity from offshore renewable sources such as wind power, tidal stream and waves. Tidal stream and wave power have some way to go before being deployable on a commercial scale but offshore wind technology is already advanced to the extent that the industry is poised for major and rapid expansion[89,90].

The harnessing of power from wind through windmills is a practice adopted since ancient times, but only in the last 20 years have new materials and designs enabled turbines to built offshore on a large scale. Over this period the technology has improved considerably the reliability, efficiency and power output per turbine have all increased, and the cost of installing and running turbines has fallen to a fraction of former levels. Techniques for offshore engineering have also progressed, and the UK is particularly well placed in having a wide skill base owing to its experience of the oil and gas industry[90].

In 2002 the UK Department of Trade and Industry (DTI) published a key strategy document focusing on the future of the offshore wind industry[90]. This document included projections for industry growth, the spatial distribution of proposed sites and it addressed licensing and potential environmental impacts. In addition, in 2003 the DTI published its '*Energy White-Paper*'[89], in which it committed the UK to a reduction in carbon dioxide emissions of some 60% from current levels by about 2050 and a target for renewables to supply 10% of UK electricity by 2010. In the following section we draw heavily on these two key documents, and we attempt to explore the wider implications for the marine environment.



Climate, Carbon Emissions and UK Energy Policy

The main driving force behind the Government's interest in marine renewables - that is, energy from wind, waves, and marine currents, - is the potential benefits for mitigating climate-change and ensuring energy security. The climate change challenge is to limit the concentration of greenhouse gases in the atmosphere by reducing emissions from the burning of fossil fuels. A major policy driver on greenhouse gases has been the Kyoto Protocol. The UK has agreed that by 2012 it will reduce its greenhouse gas emissions by 12.5% relative to 1990 levels[89].

If we are to achieve a 60% reduction in carbon emissions, the DTI estimate that we will need renewables to be contributing at least 30% of our electricity generation and possibly more. The Government's immediate target is that 10% of electricity should be generated renewably by 2010, subject to the costs being acceptable. Whether or not action is actually taken to reduce emissions, and hence whether offshore renewable industries expand, will vary significantly among scenarios[89].

Under the Fortress Britain scenario, ensuring a supply of cheap and secure energy is the main objective of energy policy. There is a drive to exploit domestic sources, including domestic coal, gas and nuclear by extending the lives of existing power stations and possibly building more. The main driver for investment in energy efficiency and renewable sources is national energy security. People, especially the well-off, are concerned about the quality of the local environment; this provokes NIMBY (Not In My Back-Yard) protests. Global climate targets are likely to be viewed as being of only secondary importance. It is possible that development of offshore wind might be stifled at around the current level (ie phase 1 of offshore consents), at least while other resources exist. Currently only 20 offshore wind farms have been commissioned, supplying approximately 1.4GW of renewable energy in 2005[90].

Under the Local Stewardship scenario, energy systems are diverse and are restructured around local energy resources, whether fossil or non-fossil fuel. A wide range of small-scale renewable energy technologies are exploited, particularly wind. Global environmental problems receive less attention. Consequently the main driver for development of renewable energy sources would be energy security, the acquisition of local supplies and to mitigate against local environmental damage, rather than to benefit the global climate.

The World Markets scenario is characterised by an electricity market which continues to be dominated by fossil fuels, increasingly imported natural gas from Russia and Central Asia. Energy prices remain stable and there is little concern for energy security and energy efficiency (see Table 2.7). Renewable electricity generation technologies, such as offshore wind power, become commercially viable but are not widely adopted due to low fuel prices and low priority attached to climate change. A market-driven climate regime develops which fails to reduce greenhouse gas emissions. Under the World Markets scenario, anything which impacts negatively on GDP is unlikely to be tolerated, and trade law (GATT) would have primacy over environmental law. Recent work by the DTI suggests that action aimed at stabilising carbon dioxide atmospheric concentrations at no more than 550ppm would lead to an average GDP loss for developed countries of around 0.5-2% in 2050[89].

Table 2.7. Energy consumption in 2020 and CO_2 Concentration in the atmosphere under each AFMEC scenario (Source: UKCIP[3]).

Scenario (& UKCIP)	Energy Consumption (tonnes oil equivalent)	Primary Energy Consumption (% change per year)	CO_2 (2020 & 2050)
World Markets	280 million	+1.7	437 ppm 593 ppm
Fortress Britain	270 million	+1.5	435 ppm 551 ppm
Local Stewardship	230 million	+0.1	422 ppm 489 ppm
Global Commons	230 million	+0.1	422 ppm 489 ppm
Today	230 million	-	

A Climate Change Levy came into effect in the UK on 1st April 2001 and applies to energy used in the non-domestic sector. The aim of the levy was to encourage energy efficiency and reduce emissions of greenhouse gases. The levy package is expected to lead to reductions in carbon dioxide emissions of at least 2.5 million tonnes of carbon a year by 2010[89]. Currently electricity generated from renewable energy sources are exempt from the climate levy, however under the **World Markets** scenario, such exemptions would be scaled-back, and renewables would be treated in the same way as any other energy source. Under the Fortress Britain and Local Stewardship scenarios it is conceivable that the levy might be discontinued altogether primarily because it would conflict with national or local energy security and it might constrain economic growth.

Only under the Global Commons scenario are we likely to see major international action to reduce greenhouse gas emissions, and hence large-scale expansion of the offshore renewables industry beyond that currently proposed. Natural gas is the dominant energy fuel up to 2010 but thereafter renewable energy sources become fully commercial (encouraged by regulatory incentives) and gain a large market share. In developing scenarios for this project, we have reasoned that renewables might supply 30% of UK electricity by 2020, as compared to the current target of 20% stated in the DTI's Energy White Paper. This would equate to around 30,000 MW[90].

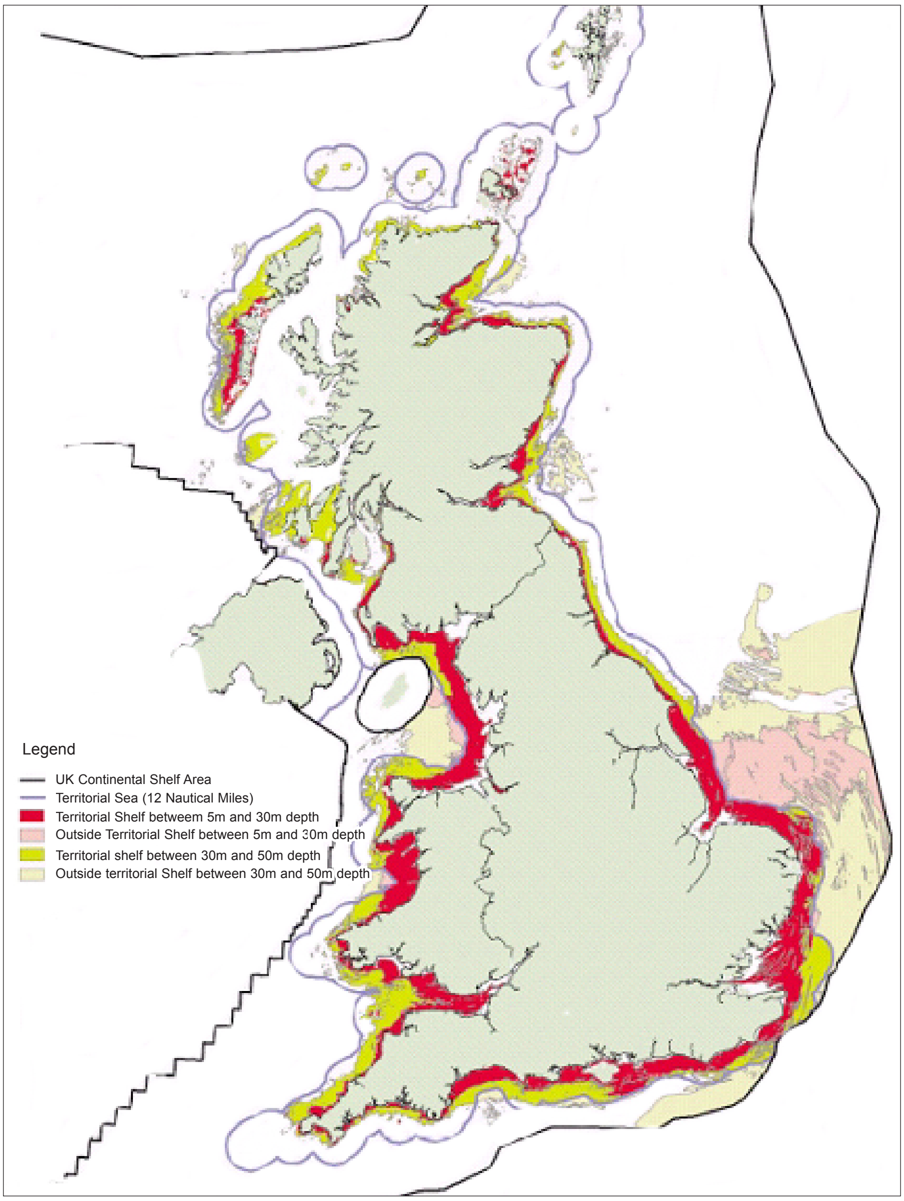
To hit the government's 10% target, the UK will need to install approximately 10,000MW of renewables capacity by 2010, an annual build rate of over 1250MW. Only 1200MW of renewables capacity has been installed so far (2002). Developers have entered into leases for offshore windfarm sites with a total capacity of at least 1400MW of renewable energy (phase 1), sufficient to power a city the size of Greater Manchester. The offshore wind industry considers a further 3000-4000MW can feasibly be built by 2010[90].

A major challenge, highlighted in the DTI's Energy white paper, is the decline of the UK's indigenous energy supplies - oil, gas, nuclear and coal. Already the UK imports nearly half of the coal it uses. By around 2006 the UK will also be a net importer of gas and by around 2010 a net importer of oil. By 2020 it is estimated that the UK could be dependent on imported energy for three quarters of our total primary energy needs. Under the **World Markets** scenario the UK's energy needs would be met by imported raw materials but also, if more cost effective, importation of electricity directly via cables from neighbouring countries. A European energy generation and/or energy transfer/trading policy might be conceivable under the Global Commons scenario, but with the ultimate aim of producing electricity in the most environmentally efficient way. Under the Fortress Britain and Local Stewardship scenarios, imported energy or electricity is likely to become less important and domestic supplies (perhaps including some renewables) are likely to become the main focus. Under Local Stewardship, we would anticipate local generation, in part from medium to small local/community power plants. These will feed distributed networks, which can sell excess capacity into the national grid.

Several eminent scientists, among them Professor James Lovelock, have argued that dwindling oil and gas reserves will necessitate a wide-scale re-opening of the nuclear debate. It could be argued that nuclear represents a 'green' option, at least in terms of carbon emissions, however it is difficult to reconcile the long legacy of radioactive waste with the aspirations and attitudes espoused under Global Commons. New nuclear facilities might be built under Fortress Britain and **World Markets** if cost-effective and possibly even under Local Stewardship if energy supplies became critical and sufficient renewable resources could not be brought on stream quick enough.

Large-scale tidal barrages have the potential to make a significant contribution to carbon reductions in 2020 or beyond. Tidal energy has been extensively researched in the UK under a Government programme which ran from 1978 to 1994. Although potential sites, such as the Severn Barrage project have been identified, the technology is currently commercially unattractive and no development has been undertaken. The theoretical potential from tidal energy in the UK has been estimated to be 50 TWh yr^{-1} - however, assuming that only the most promising and economic schemes were developed only 18 TWh yr^{-1} would be produced, 12.5 TWh yr^{-1} of this from the Severn Barrage scheme alone[89]. It is clear that plans for a Severn Barrage would raise strong environmental concerns, but it is not inconceivable that such a barrier might be built particularly under the Fortress Britain scenario, whereby concerns of national energy security would override environmental concerns. The UK is at the forefront of technologies aimed at exploiting wave power. The island of Islay in north-west Scotland plays host to the only commercially operated wave-power station in the world. DTI estimates that large-scale wave and tidal projects might become commercially viable between 2010 and 2015[89].

Figure 2.19. Prospective areas for offshore wind installations (Source: DTI 2003)[90].



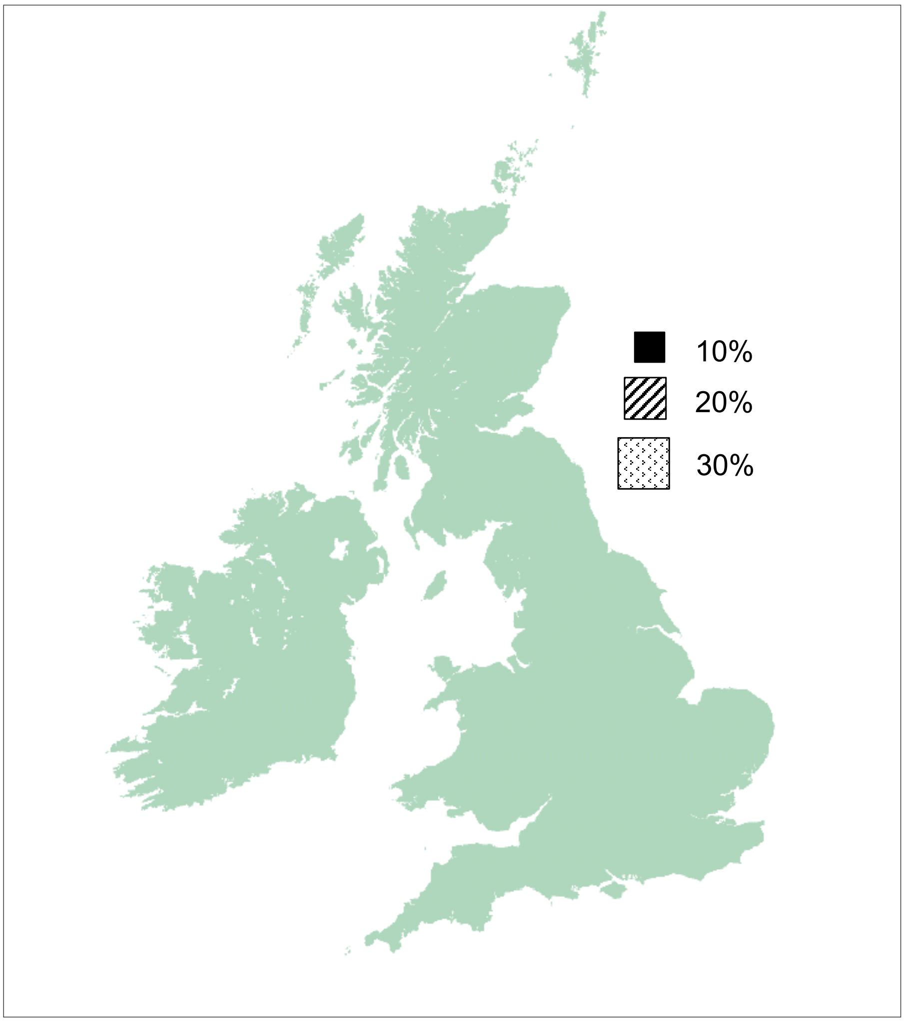
Spatial issues

There can be little doubt that there are vast wind, tide and wave resources available to be tapped in the marine environment. However, depth and substrate will be a major factor influencing economic viability, and for the next few years the majority of development will be concentrated in the coastal area between 5 m and 30 m water depth. (Figure 2.19).

The Crown Estate and the British Wind Energy Authority (BWEA) have compiled a Geographic Information System (GIS) to assess factors that will have a key role in the spatial development of the offshore wind industry. This study estimated that 3213 TWh yr^{-1} (919 GW) of wind resources are potentially available for exploitation around the UK, compared to the much lower 33.6 TWh yr^{-1} required to meet the 2010 renewables target. Despite the considerable potential for expansion of the offshore wind farm sector, the total area of the seabed which might be devoted to power generation from wind energy would be small compared to the total size of the UK's marine resource, as shown in Figure 2.20[90].

Exploitation of renewable energy is only one of many activities which compete for space within the marine environment (others include aggregates extraction, oil and gas exploration, fishing, tourism, shipping). Depending on their location, large wind farms in the sea could conflict with rights of navigation and early wind farms are likely to be located in shallow waters, therefore having an impact on smaller inshore fishing boats and recreational craft. In order to protect offshore installations and structures, and to ensure safe navigation, a coastal state may establish safety zones around them for a distance of up to 500 metres. Excluding fishing activities from generation areas might make it harder for fishing vessels to achieve the same catch, consequently fishing fleet profitability may be affected. Ownership of the seabed and the rights to explore and exploit the continental shelf reside with the Crown Estate. The Crown Estate grants licences to permit developers and operators to make use of these rights. The spatial utilisation of the seabed for fishing currently falls outside this spatial management system[90].

Figure 2.20. Area required to generate 10, 20 and 30% of UK electricity demand (Source: DTI 2003)[90].



Under the **World Markets** scenario, spatial usage of European waters would be largely determined by the economic value of the particular activity. If renewable energy technologies were to become more profitable than fisheries or tourism, then it might be that more seabed would be allocated to this activity. Similarly, under the Fortress Britain scenario, spatial planning/allocation would be largely determined by value and potential revenues, particularly given that there is only a finite national resource (ie the UK territorial sea and Continental Shelf Area). Activity would be determined by the greater good of the country (or national economy). Under the Global Commons scenario we might expect an organised system of international spatial planning, ie, marine waters treated as a 'global commons', with specific areas set-aside at the EU-level for electricity generation, fisheries and environmental protection purposes etc. Under the Local Stewardship scenario we might envisage a similar system involving allocation of marine areas for specific purposes, but at a local level, with greater emphasis on sustainable development and utilisation.

Ecosystem impacts

Construction of offshore wind-farms and other structures can have both negative and positive implications for ecosystems and biodiversity. The main negative effect on the environment will be physical impact of installing turbine foundations, but also visual amenity, as well as possible interference with sedimentary processes. In addition, impacts on bird populations and the potential effects of electromagnetic fields on marine mammals and fish are also considered important. Positive effects might include the exclusion of fishing vessels thus creating a refuge from trawling, creation of new habitats or 'artificial reefs' and a reduction in carbon emissions as a result of a switch to renewable energy sources[90].

A report commissioned by the DTI concluded that the following key ecological issues should be considered in the environmental assessment of offshore wind farm developments:

- likely changes in benthic communities within the affected area and resultant indirect impacts on fish, populations and their predators such as seabirds and sea mammals;

- potential changes to the hydrography and wave climate over a wide area, and potential changes to coastal processes and the ecology of the region;
- likely effects on spawning or nursery areas of commercially important fish and shellfish species;
- likely effects on mating and social behaviour in sea mammals, including migration routes;
- likely effects on feeding water birds, seal pupping sites and damage of sensitive or important intertidal sites where cables come onshore;
- potential displacement of fish, seabird and sea mammals from preferred habitats;
- potential effects on species and habitats of marine natural heritage importance;
- potential cumulative effects on seabirds, due to displacement of flight paths, and any mortality from bird strike, especially in sensitive rare or scarce species;
- possible effects of electromagnetic fields on feeding behaviour and migration, especially in sharks and rays;
- potential marine conservation and biodiversity benefits of offshore wind farm developments as artificial reefs and 'no-take' zones.

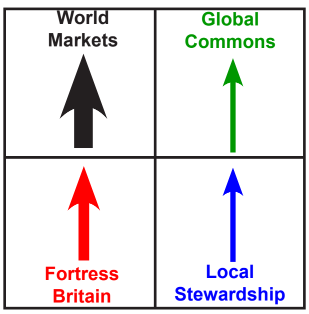
The ecological implications of generating electricity in the coastal zone has recently been reviewed by Gill (2005)[159]. Under the AFMEC future scenarios, the impact of offshore construction would depend largely on the scale of the industry in 2020-2050. The greatest expansion is expected under the Global Commons scenario, and hence the direct negative impacts on the marine environment would be greatest under this scenario. However, the positive effects (reduction of carbon emissions, spatial area closed to fishing, creation of artificial reef habitat) would also be greatest under this scenario.

2.9. Coastal geomorphology and defence

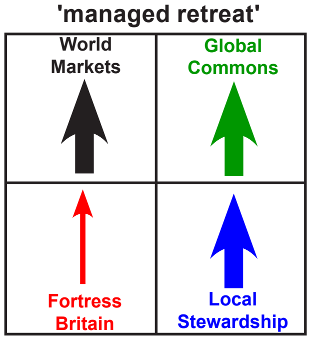
Throughout history, people have tried to control the coastline and how it behaves, often to minimise the loss of land or to gain land through reclamation. People have erected defences to maintain the shoreline, protect assets and to prevent the loss of hinterland.

England and Wales have a coastline of approximately 3700 km. Analysis of shoreline change suggests that around 28% of the coast is experiencing erosion greater than 10 centimetres per year (0.1 m yr^{-1})[91]. A large proportion of this coastline is artificially held in position by sea defences. Work conducted for Defra (2001)[92] has established that at present levels of expenditure, approximately one-third of existing coastal defences may have to be abandoned in the near future. This is without considering the long-term impacts of the four climate-change scenarios proposed by UKCIP that we use in this project (Section 3.2).

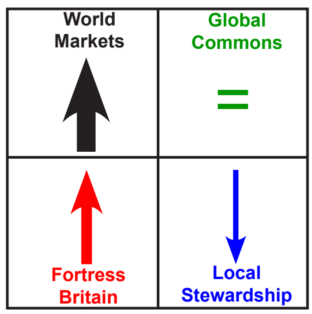
Coastal erosion



Coastal land flooded as 'managed retreat'



£ invested annually in coastal defence



A great deal of work has been carried out to assess future patterns of coastal erosion, flood risk and impacts on geomorphology. This includes Defra's FutureCoast[93] initiative and DTI's 'Foresight' Flood & Coastal Defence (FFCD)[91] programme (published in 2004). The FFCD programme adopted the same basic scenario framework as has been used in the AFMEC project, and their key predictions are reported here.

Under the World Markets scenario, the state largely withdraws from funding coastal defence projects. Maintenance and construction of new defences becomes to a larger extent privately funded, the high economic value of coastal assets justifies the increasingly high investments. Overall coastal defence investment increases to around £350 million per year (from £200 million). Sea defences protect almost all vulnerable coastal assets (240,000 ha) and no formerly protected land is flooded or eroded as a result of 'managed retreat'[3,91].

Under the Fortress Britain scenario, public funding of coastal defence projects would continue or expand in order to protect housing, commercial, industrial and infrastructure as well as agricultural production (235,000 ha) of importance to the national economy and maintaining food security. Withdrawal from formerly protected land occurs only in small areas where the costs of protection exceed the derived benefits. Formerly protected areas flooded or eroded as a result of 'managed retreat' amount to around 2500 ha. Coastal defence investment reaches £230 million per year, which is higher than today (£200 million) [3,91].

Under the Global Commons scenario, coastal zone management follows a two-fold strategy leading to diverse regional outcomes. Developed areas and high value assets are protected (225,000 ha) through hard sea-defences and these will also be used to experiment with alternative energy technologies such as wave energy. On the other hand, there will be 'managed retreat' in areas where ecological conditions are favourable to the development of biologically diverse habitats. Formerly protected areas flooded or eroded as a result of 'managed retreat' amount to around 15,000 ha. The majority of investments in coastal defence are publicly funded (either at the EU level or nationally). Overall, coastal defence investment remains the same as today (£200 million per year)[3,91].

Under the Local Stewardship scenario 'managed retreat' becomes an increasingly important policy option, especially where artificial sea defences are costly. Formerly protected areas flooded or eroded as a result of 'managed retreat' amount to 10,000ha. Coastal defence investment is only £150 million per year, which is significantly lower than today (£200 million)[3,91]. As local public bodies try to keep maintenance investments at a low level, the quality of defence structures is relatively poor. There is a significant increase in risks of economic loss through defence failure. Only the most valuable, built-up or productive land is protected by sea defences (~220,000 ha). Longer-term sustainable approaches are sought, including the wholesale relocation of communities where necessary, away from the most vulnerable coastlines and estuaries.

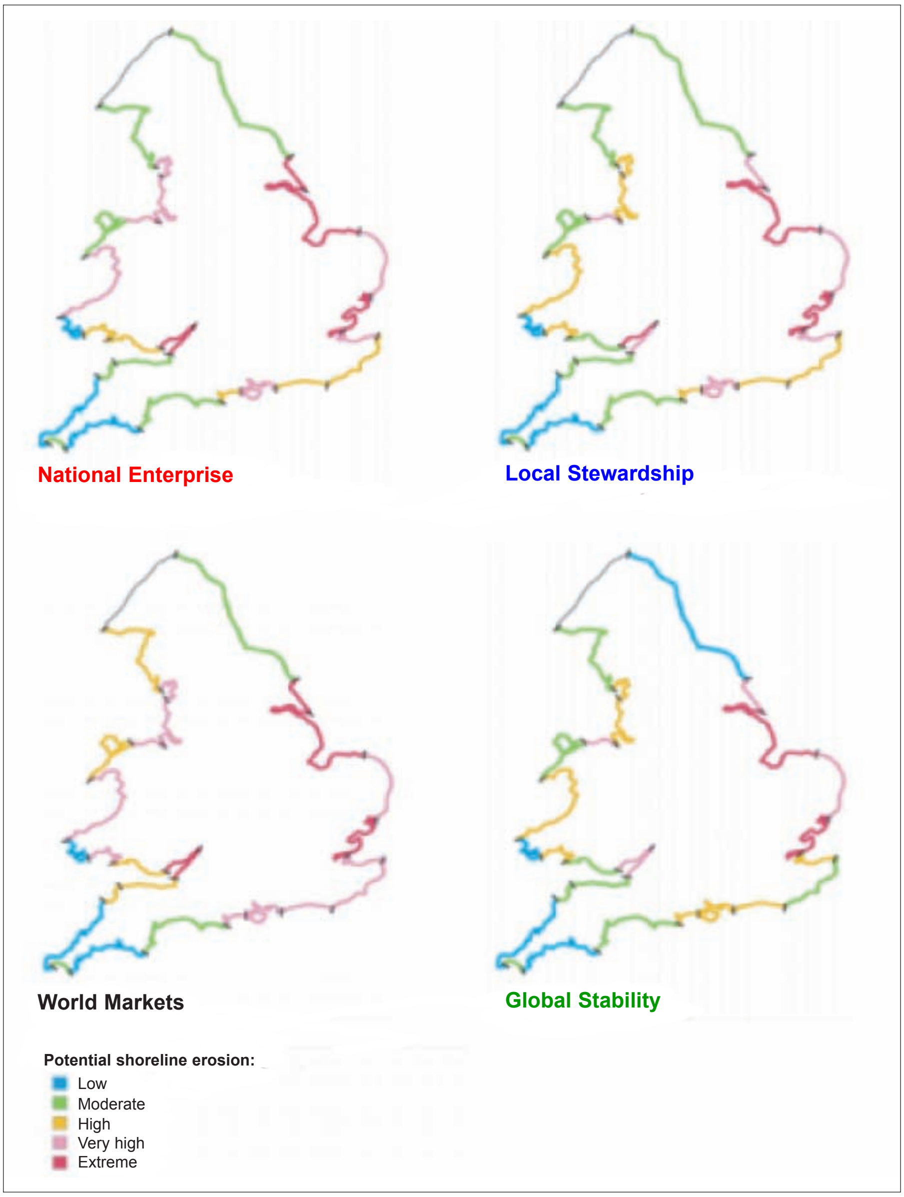
Estimating future erosion rates

FFCD[91] assessed relative differences between their four scenarios in terms of coastal erosion rates using basic assumptions on changes in sea level, surge activity, wave height, littoral drift, sediment transport etc. (see Table 2.8). The forecasts suggest that there will be considerable variation in erosion rates, both between and within regions.

Table 2.8. Damage caused by coastal erosion, and money spent on protecting coastlines under each AFMEC scenario (Source: OST-FFCD 2004[91], UKCIP 2000[3]).

	Present Conditions	World Markets	Fortress Britain	Local Stewardship	Global Commons
Average coastal erosion over 100 years for England and Wales	20–67 m	141–175 m	113–150 m	99–138 m	82–123 m
Annual Damage due to coastal erosion in the 2080s (£ million per annum)	14.4	126	87	51	46
Zones protected by coastal defences (2020s)	240,000 ha	240,000 ha	235,000 ha	220,000 ha	225,000 ha
Annual investment in coastal defence (2020s)	£200 million	£350 million	£230 million	£150 million	£200 million

Figure 2.21. Regional differences in potential shoreline erosion under the four scenarios (Source: FFCD)[91].



Many areas will experience little or no erosion of shorelines, while others will experience erosion of several hundred metres. Figure 2.21 shows that for all four of the future scenarios, coastal erosion will be severe on the east coast and in major estuaries such as the Severn, Thames and Humber. The figure shows several areas of 'extreme risk' - the east coast from Flamborough Head to North Foreland, and around the Bristol Channel. Other areas of High or Very High risk are eastern sections of the south coast, Cardigan Bay, North Wales and the Lancashire coast[91].

Economic losses as a result of coastal erosion could increase by a factor of between two and seven, depending on the socioeconomic scenario (see Table 2.8). The risk is highest under the **World Markets** scenario, and lowest under Global Commons. These figures do not, however, take full account of the constraints imposed on the shoreline by human intervention, which might mitigate against such damage[3].

The interaction between the coast and coastal defences

The placement of shore defences has typically depended on the economic justification and the value of the hinterland as well as the natural geomorphology. There are less artificial coastal defences in Cornwall, where cliffs resist erosion, than in Norfolk, where the cliffs succumb to erosion more readily. Through holding the shoreline's position with seawalls, beach stabilisation or groynes, we perturb the sediment budget, both by restricting the input of sediment from cliffs, and by interrupting the sediment pathways, i.e longshore drift. As well as affecting beaches locally – beach steepening in front of coastal defences is ubiquitous around the south and east coasts – there have also been down-drift impacts. Defences have restricted the ability of dunes to move landward in response to rising sea level. In many areas, this has disturbed the natural dynamic equilibrium of the coastal system[91].

Under all four climate scenarios, the coastline will be increasingly out of balance with coastal forcing. The result will be deeper water at the coastline and increased wave energy inshore. Higher water levels, as a result of sea-level rise, will mean that waves overtop defences more often. An increase in surge heights (see Section 2.1) will result in higher extreme water levels (see Section 4.2). This will increase the probability of overtopping during storms. We should also expect changes to tidal and flood regimes in estuaries, especially where these are lined by fixed defences. Larger waves will mean that defence structures will reflect more wave energy, increasing scour of the beach, which in turn increases the undermining of the defence.

Economic costs of coastal erosion

Economic analysis of coastal erosion data indicates that associated losses, as absolute costs, could increase by up to nine times current values, depending on the geographic locality (Table 2.9).

Locally, erosion may have significant economic implications, but on a national scale these losses, even under the **World Markets** scenario, would be small compared to damage associated with tidal flooding[93]. In terms of major infrastructure located on eroding coastlines, many of the installations that currently exist will no longer be operating in 20 to 100 years' time. North Sea oil and gas may be exhausted by then (see Section 3.7), reducing the need for oil and gas terminals and refineries. Nuclear power stations are perhaps among the few major installations which would require continued protection. Several of these are located in coastal zones where erosion rates are moderate to high (Figure 2.21), for example, Sizewell and Dungeness (very high under '**World Markets**'), Hinckley Point (high under '**World Markets**'), and Bradwell ('extreme' under '**World Markets**'). Hence, while coastal erosion will not pose a significant problem at a national scale, there may still be local issues. Assets, such as coastal towns, will be difficult to relocate and erosion would threaten beaches and therefore tourism.

Coastal flood risk

Flooding (coastal and inland), and preventative action to avoid flooding, costs the UK around £2.2 billion each year. We currently spend around £800 million per annum on maintaining flood and coastal defences, and, even so we experience an average of £1400 million in damages per year at the coasts[91].

Extreme water levels at the coast result from the combined impacts of changes in the sea level and the increased frequency and intensity of storm surges, driven by and tides and high winds. The most severe storm surge in the last century occurred in 1953. It generated elevated water levels of 2.97 m at King's Lynn and 3.36 m in the Netherlands[91]. Coastal flooding events are predicted to become much more frequent under the high-emissions scenarios (**World Markets** and **Fortress Britain**), requiring ever-more coastal sea defences.

FFCD[91] suggest that under **World Markets** scenario, responsibility for flood management and prevention would ultimately lie with the property owner, although in practice it would largely be managed through a weak public agency which contracts out most of its activities. There would be little incentive to implement environmentally-oriented flood management measures, and indeed little demand for actions to reduce development in flood prone areas. Inadvertent benefits to the environment might occur, such as the abandonment of low-quality agricultural land. Some coastal grazing marsh areas would be abandoned due to increasing flood risk and insufficient economic resources to upgrade sea-defences, but again environmental benefits are largely inadvertent.

Table 2.9. Estimates of expected annual damage due to coastal erosion in England for the 2080s (£ million per annum)[93].

	Today	World Markets	Fortress Britain	Local Stewardship	Global Commons
North east	2.6	13	10	7	6
East Anglia	1.2	13	9	5	4
South east	6.4	53	36	18	17
South west	3.2	38	27	16	15
North west	1.0	8	6	4	4
Total	14.4	126	87	51	46

Under the Fortress Britain scenario, responsibility for flood management would lie with the state as well as with property owners. Emphasis would be placed on "traditional" flood defence measures, and protecting nationally important infrastructure and resources, with little consideration given towards the environment. Measures would be more locally-oriented than those favoured under the World Markets scenario. There would be little need for agencies to undertake flood protection in order to attract inward investment from overseas, and actions would be focused on meeting immediate local needs.

Under the Global Commons scenario there would be a strong presumption in favour of environmental protection, with a preference for implementing flood management measures that have minimal environmental impact. Flood management would be seen as a component of broader environmental management, and integrated with land use and water supply policies. There would be strong national and supra-national agencies and standards with strong public participation, and a consistent approach would be applied everywhere. Losses of coastal grazing marshes and other freshwater habitat would be compensated via habitat creation taking a national or larger perspective – losses in East Anglia might be replaced by gains in neighbouring regions, or even neighbouring countries, assuming that the overall natural capital is sustained.

Under Local Stewardship scenario there would again be a strong presumption in favour of environmental protection, with a preference for implementing flood management measures that have minimal environmental impact. Measures to reduce exposure and vulnerability to flood would be favoured over measures to reduce the physical hazard, and again where these are necessary there would be a preference towards "soft" engineering approaches. Flood management would be undertaken by local flood management agencies with public participation, but each would work to its own standards and seek tailored solutions for local problems.

Implications for coastal ecosystems

Coastal and estuarine areas contain a diverse range of important habitats, including vegetated shingle ridge, saltmarsh, saline lagoons, reed beds, mudflats, coastal grazing marsh, sand dunes, and various cliff environments. All of these habitats are sensitive to flooding and erosion.

Ecosystem change on the coast will be driven by both sea-level rise and flood-management policy. Coastal grazing marsh appears to be the most threatened coastal habitat under all four scenarios, as intertidal losses of saltmarsh and mudflat are likely to be offset by coastal realignment or abandonment of grazing marsh (planned or unplanned). In other words, saltmarsh and other intertidal habitats could benefit from increased flood frequencies, however, coastal grazing marsh is threatened under all scenarios[91].

While almost all coastal grazing marshes are artificial and require active flood management to survive, they are now often seen as valuable habitats worthy of protection. Concern over the loss of coastal grazing marshes relates largely to their high value for biodiversity conservation. Large populations of breeding and wintering waterfowl are supported by the UK's extensive coastal marshes[91].

Instead of an assumption of protection and 'hold the line', managed realignment of flood defences is now being actively considered for many locations and implemented in some. At the same time, the increasing importance of environmental regulation, particularly of EU directives and designations should be noted. Lee (2001)[94] examined the possible implications of these changes over the next 50 years and concluded that there could be a net loss of about 4000 ha of freshwater habitat (including coastal grazing marsh), while there could be a net gain of about 700 ha of marine flat and saltmarsh habitats.

It is widely recognised that many coastal habitats are experiencing 'coastal squeeze', as hard defences prevent landward migration[96]. These include sand and shingle habitats which are intrinsically dynamic in nature and often dependent upon continued sediment nourishment. Sand and shingle habitats are known to have contracted in recent decades and we might expect erosion to accelerate in response to sea-level rise under all future scenarios. Shingle habitats support a distinctive flora and nesting birds of conservation concern, such as terns. Populations of Little Tern, for example, inhabit a diminishing number of nesting locations. Mudflats and sandflats in estuaries are also likely to suffer from coastal squeeze, with concomitant impacts on the highly productive invertebrate and bird populations that they support[91].

Case Study:

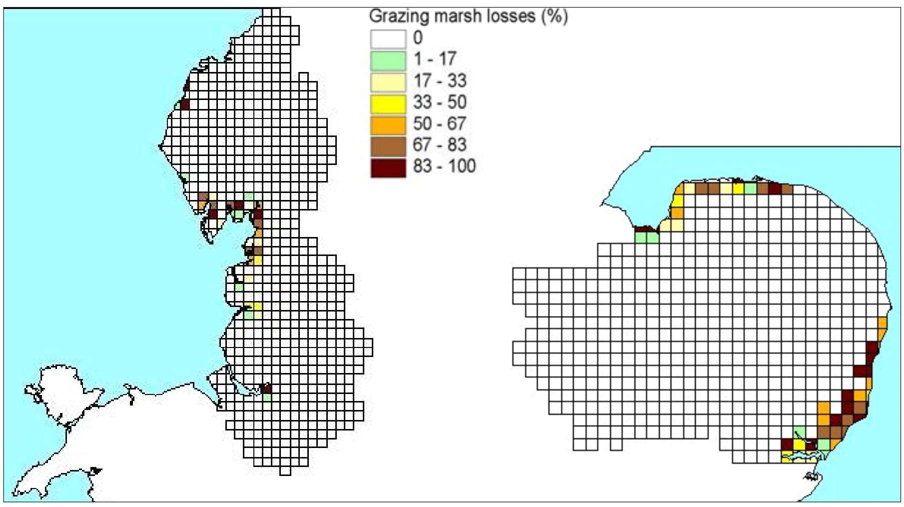
The RegIS[95,98] project examined changes in both saltmarsh and coastal grazing marsh habitats in East Anglia and the North West (Figure 2.22) up to the 2050s. Two climate change scenarios (low and high) and two socio-economic storylines were evaluated: Global Commons and Fortress Britain.

Figure 2.22. Saltmarsh (A) and coastal grazing marsh (B) in East Anglia.

Under Global Commons scenario the results were qualitatively similar to those of Lee (2001)[94,97], predicting major gains in saltmarsh habitat at the expense of coastal-grazing marsh (see Figure 2.23). Outcomes were quantitatively even larger, as the RegIS[95] project made more radical assumptions concerning the potential for managed realignment.

Under Fortress Britain it was assumed that there would be no managed realignment. Saltmarshes declined in East Anglia, although in the North West, they appear less sensitive to sea-level rise. Many flood compartments containing coastal grazing marsh were estimated to see a dramatic increase in flood frequency, suggesting that unplanned coastal abandonment is possible. Potentially this would result in a large net gain in saltmarsh (and other intertidal habitats) and a decline in coastal grazing marsh. Hence coastal grazing marsh is threatened under both futures (Figure 2.23), and by implication these results are applicable to Local Stewardship (losses due to managed realignment) and World Markets (losses due to unplanned coastal abandonment).

Figure 2.23. The worst case scenario for the loss of grazing marshes in the north-west of England and East Anglia[95,98].



3. How likely are the scenarios?

Scenarios are neither predictions nor forecasts of future conditions. The true purpose of a set of scenarios is to illuminate uncertainty, as they help in determining the possible ramifications of an issue along one or more plausible paths. Scenarios go beyond a single best estimate, or a 'high' and 'low' projection, and encourage us to explore a number of different, logically-consistent pathways. Like any good story, scenarios have a set of circumstances or constraints within which they occur; a plot or logic that guides how events unfold, and characters-individuals, groups or institutions – that take part in the drama and give them a human context[97].

Some 'futurists' have chosen to offer a 'best-guess' scenario (eg Delgado *et al*., 2003[14]), i.e what they judge to be the most likely future outcome. Whether or not to use a "best guess", "business-as-usual" or "central" case scenario was a conundrum faced by IPCC when developing their SRES storylines[5] and also a conundrum which became apparent when developing the AFMEC scenarios.

The problem with this approach, is that readers tend to confine their attention only to the 'best-guess' and do not consider the other plausible outcomes. Thus by simply labelling one vision as 'best-guess' or 'business-as usual' readers become blinkered to the full range of possibilities and complacent about the inherent unpredictability of the future. Also, an even number of scenarios helps to avoid the impression that there is a "central" or "most likely" case. When presented with three or five scenarios, readers tend to focus their attention on the one they perceive as being in the middle, with the others considered as extreme (and therefore unlikely) variants.

Neither the OST[1] or UKCIP[3] chose to have a 'best-guess' scenario, in an effort to encourage readers to consider each possible future with an open-mind. However, UKCIP[3] sometimes provided simple (linear) extrapolations from historic data (usually over the last 20 years), and these were often labelled "2020s Linear". Furthermore, in the four-quadrant pictorial representation of the OST 'Foresight Futures' and UKCIP socio-economic scenarios, there has often been an insert which indicates where 'conventional development' lies (see Figure 3.1, adapted for AFMEC Scenarios). This is usually placed slightly off-centre, indicating that current trends seem to point towards a '**World-Markets**' world-view, but with aspects of all four possible futures.

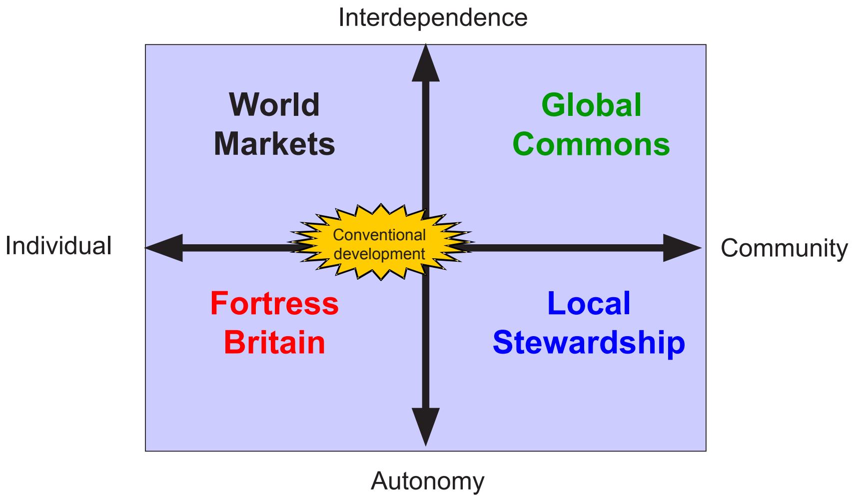
When preparing the AFMEC scenarios, we chose to follow the example of OST, IPCC and UKCIP and not present a 'best-case' vision of the future, in spite of urging to do so from some participants at the stakeholder workshops. As such, we do not present numerical information about the probability of different 'futures' actually occurring. We do however recognise that for scenarios to be a useful tool, they must all be possible, plausible and credible. A balance needs to be struck between scenarios which challenge present-day assumptions and the need for work to be relevant to policy-makers and decision takers who might be more comfortable with normative (prescriptive) scenarios. Plausibility is a necessary criterion of a scenario, otherwise it simply becomes science-fiction[3].

The OST and UKCIP socio-economic scenarios have now benefited from wide usage by many sectors and organizations. Much has been learnt about the perceived plausibility of each of the four 'futures'[1]. A regional scoping study for South-east England for example, suggested that only the **World Markets** scenario was instantly recognizable to most people involved. Work by CSERGE at the University of East Anglia however, found that 'Global-Sustainability' (here called '**Global Commons**') was also widely recognizable to most participants. Questions have been raised about the plausibility of the National-Enterprise scenario (here titled '**Fortress Britain**') and particularly when applied at the regional level[98]. The problem identified with this scenario seems to stem from apparent inconsistency between low economic growth (associated with an introvert and insular world out-look) and yet relatively high carbon emissions.

When looking at all 'domains' together, such inconsistencies become commonplace as there is a pre-defined constraint on the number of possibilities. For this reason many (including participants at our AFMEC workshops) have argued that we need more scenarios (or at least sub-scenarios – see Section 1.8).

In preparing their SRES[5] scenarios, the International Panel on Climate Change have always maintained that it is not possible to attach objective probability estimates to their four basic storylines. However, in a dialogue which erupted in the pages of the scientific journal Nature in 2001[99,100,101], one expert argued that policy analysts needed probability estimates in order to assess the seriousness of the implied climate impacts and hence act to mitigate these[99]. This author also warned about the dangers of arbitrarily picking a too limited set of scenarios or storylines and suggested that there are formal – if somewhat subjective – methods of assigning probability which might be suitable.

Figure 3.1. Four AFMEC Scenarios, and the perceived position of 'conventional development'.



In a reply several weeks later, Grűber and Nakicenovic (2001)[101] argued:

"Although we agree with most of what Schneider says, we disagree with him about the appropriateness and feasibility of assigning subjective probabilities of occurrence to alternative, unknown futures described by the SRES scenarios. In an interdisciplinary scientific assessment, the concept of probabilities as used in natural sciences should not be imposed on the social sciences. Probability in the natural sciences is a statistical approach relying on repeated experiments and frequencies of measured outcomes, in which the system to be analysed can be viewed as a 'black box'. Scenarios describing possible future developments in society, economy, technology, policy and so on, are radically different. First, there are no independent observations and no repeated experiments: the future is unknown, and each future is 'path-dependent': that is, it results from a large series of conditionalities ('what if… then' assumptions) that need to be followed through in constructing internally consistent scenarios. Socioeconomic variables and their alternative future development paths cannot be combined at will and are not freely interchangeable because of their interdependencies. One should not, for example, create a scenario combining low fertility with high infant mortality, or zero economic growth with rapid technological change and productivity growth — since these do not tend to go together in real life any more than they do in demographic or economic theory. – There is a danger that Schneider's position might lead to a dismissal of uncertainty in favour of spuriously constructed 'expert' opinion[101]."

For a more detailed account and discussion of this debate readers should consult the recent working paper by Dessai and Hulme (2003)[102].

Finally, it is possible that marine 'futures' are not free to evolve unconstrained since future pathways are dependent upon existing legislation, obligations and conventions[177]. Annex 2 lists current and forthcoming international legislation/obligations, which may affect activities in the marine environment, and to which the UK is a full signatory. It is acknowledged that these agreements have generally not been factored into the scenarios, but they do affect the likelihood of the scenarios unfolding.

4. Taking account of major shocks

The exploratory and synthetic approach used in these scenarios suggests that change occurs gradually along a single trajectory. Future states are seen as the logical outcome of an accumulation of changes over time, all pointing in the same direction. But not all change is like this[1]. Change may take place slowly (as part of the process of economic and social development), or it may happen suddenly as a result of major, surprise events such as terrorist attacks, or rapid changes in the natural environment. If the change is slow it may be possible for one scenario to be completely superseded by another (a shift from World Markets to Global Commons, for instance). If the change is sudden, the question to be asked is "how 'resilient' is a given scenario to its impact?" Answering this question will be very difficult, mainly because large-scale, unanticipated events are hard to foresee.

Here we have attempted to assemble an inventory of 'shock events', by consulting conventional and unconventional data sources, and through brainstorming workshops. Individuals from a wide range of stakeholder backgrounds were asked to list possible low-probability high-impact events that might conceivably impact upon the marine environment. Many different 'shock events' or 'discontinuities' were proposed (Table 4.1), and these can be categorised into four broad types: (1) those concerned with the human environment, (2) climatic events, (3) biological/ecological events, and (4) geological and astronomical events.

Ecosystems may evolve through a regime of 'punctuated equilibrium', ie, they remain stable for long periods of time, but then change very rapidly as a result of a major shock. It is possible to differentiate between two distinct types of 'shock events': (a) those which occur very suddenly and inexplicably, eg meteorite strikes, or (b) 'break-point' events which follow a slow build-up (eg weakening and then sudden breakdown of the thermohaline circulation). Generally, most systems (political or natural) are resilient to a point, but beyond a critical threshold ('tipping-point'), serious change and/or damage may ensue. Some 'shock events' occur only when the ecosystem is weakened by other factors, for example fish stocks which are otherwise resilient to occasional climatic events and sustained fishing pressure, may collapse because of reduced genetic diversity in the stock or long-term exposure to hazardous substances.

Some 'shock events' (eg earth-quakes) are causes in themselves, others are consequences (eg tidal-waves or ecosystem regime shift). Sometimes 'shock events' interact and have multiple impacts on the human and biological environment, eg sudden climate change can affect the transmission of diseases, the ability of exotic species to become established, or even catastrophic release of methane from gas-hydrates, all of which have secondary consequences. Some events have very short-term, localised impacts (eg oil spills or hurricanes), whilst others result in long-term, irreversible changes with global implications.

The occurrence of 'shock events' can put an end to aspirations about long-term sustainability and/or sustainable development (eg under the Local Stewardship or Global Commons scenarios).

4.1 Geological and astronomic events

Many of the most highly feared and often debated low-probability high-impact events, are those involving geophysical phenomena. Such events often nick-named "Gee Gees" (Global Geophysical Events), are notoriously difficult to predict and yet, in some cases, extensive modelling exercises have been carried out in order to investigate their probability of occurring or to mitigate against their likely impacts[103].

On 1st November 1755 a giant earthquake is known to have occurred southwest of Portugal, beneath the Atlantic Ocean[104]. The earthquake demolished much of the city of Lisbon, killing tens of thousands of people. This was followed by three great tsunamis resulting from displacement of the sea floor. These swept the Atlantic coast, attaining heights in excess of 12 m. The damage caused in Lisbon was immense. The tsunamis also caused damage further afield: at Cadiz in southern Spain; along the coast of North Africa; and in the Caribbean, where wave heights were raised up to 6 m.

During the past two decades, it has become apparent that our understanding of the tsunami hazard in the North Atlantic has been skewed by the shortness of the historic record[104]. It has been suggested that scientists may have severely underestimated the level of tsunami risk along the margins of the Atlantic Ocean, not only caused by earthquakes, but also due to rare but very large land-slips at the edge of the continental shelf.

The continental slopes of Europe, Africa, North and South America are, for the most part, regions of low seismic activity but high rates of sediment accumulation. Sediments accumulated especially rapidly during recent ice ages[104]. At intervals, these unconsolidated sediments are disturbed by an earthquake or major storm, the most recent example occurring in 1929 and causing the 'Grand Banks tsunami'. This tsunami reached heights in excess of 10 m and killed 30 people on the sparsely populated

Newfoundland coast[104]. An earthquake at the start of this event shook loose a broad, relatively thin layer of sediment at the top of the continental slope. A dense mixture of sediment and water moved downslope and spread out over the ocean floor to the south, breaking telegraph cables between Europe and North America in sequence from north to south. The timing of the cable breaks yielded the speed of movement, up to 70 km h^{-1}, whilst recent mapping of the sediment layer on the floor of the Atlantic has suggested that 175 km^3 of material may have been involved.

Even larger events are known to have occurred along the Atlantic margins in pre-history. Amongst the largest were the 'Storegga Slides', off the continental margin west of Norway. The largest of these land-slides, involved a sediment volume of at least 2500 km^3, that slid downslope around 7000 years ago. Associated tsunami deposits have been found in Norway, Scotland and Iceland extending several metres above contemporary sea levels and up to one kilometre inland. Recent archaeological studies indicate that at least one Neolithic settlement on the coastline of eastern Scotland may have been overwhelmed by this tsunami, making its inhabitants the earliest known victims of such an event[105].

The tsunami which occurred on Boxing Day (26th December) 2004 is thought to have killed in excess of 230,000 people in 13 different countries around the Indian Ocean. This was caused by an undersea earthquake now thought to have been 9.15 on the Richter scale, making it the second largest earthquake ever recorded on a seismograph[160]. In February 2005 the Royal Navy vessel *HMS Scott* surveyed the seabed around the earthquake zone and revealed large ridges about 1500 m high which have subsequently collapsed in places to produce landslides several kilometres across. The sudden vertical rise of the seabed dispersed massive volumes of water resulting in a tsunami wave which reached a height of 24 m when coming ashore in Ache province Indonesia[164]. One estimate places the total energy of the tsunami at about five megatonnes of TNT, more than twice the total explosive energy used during all of World War II (including the two atom bombs). The tsunami wave was noticed as far as Struisbaai in South Africa some 8500 km from the epicentre. Beyond the toll on human lives in the Indian Ocean, the tsunami caused enormous environmental damage. According to experts, one of the most serious effects has been the poisoning of freshwater supplies and soil by saltwater infiltration. It has been reported that in the Maldives 16 to 17 coral atolls that were overcome by seawater are now totally without freshwater and could be deemed uninhabitable for decades[160].

Volcano collapses have also been recognised as a potential cause of tsunamis. A number of historic collapses have occurred within living memory at volcanoes in so-called 'island arcs', mainly around the Pacific Rim (eg in Indonesia in 1928 and 1979). Volcanic 'island arcs' occur in the Atlantic, at Cape Verde and the Canary Islands[104]. Estimates of the global frequency of volcano collapses vary, but at least 11 have occurred in the past 200,000 years. A number of currently active ocean island volcanoes are presently showing signs of flank deformation. Amongst Atlantic volcanoes, the geologically very recent onset of flank deformation at the Cumbre Vieja volcano on La Palma (Canary Islands) and at Cha das Caldeiras (Cape Verde Islands), suggest an elevated risk of collapse[104]. Such collapses are most likely to be triggered as a result of stressing of volcanoes by eruptions.

A recently developed model at the University at Santa Cruz, USA[106] has been used to make estimates concerning the spread of tsunamis across the Atlantic Ocean during the hours after a collapse of the Cumbre Vieja volcano (Figure 4.1). Within three hours, a wave of water in excess of 50 m high would swamp the east coast of Africa, within five hours it would reach southern England. New York, Washington DC, Boston and Miami could all be decimated[106]. A recent estimate indicates that around three trillion dollars of property along the Atlantic and Gulf of Mexico coasts of the United States is vulnerable to storm surges[104]. An ocean island collapse would put a large fraction of this simultaneously at risk (in contrast to the much smaller fraction at risk from any one storm surge event).

While ocean volcano collapses are rarer events in the Atlantic than either very large earthquakes such as the 1775 Lisbon quake or continental slope failures; their magnitude means that they arguably present a greater long-term threat[104]. Indeed, on time-scales of thousands to hundreds of years, they may present a more significant hazard than asteroid or comet impacts. Volcano collapse frequency in the North Atlantic is in the order of 0.00003 $year^{-1}$, whereas asteroids of comparable energy are expected to strike the North Atlantic with a frequency in the order of 0.000002 $year^{-1}$ [107].

Asteroid or meteorite impacts are known to have occurred in the North Atlantic in the past. In 2002, a meteorite impact crater (named Silverpit after the local fishing grounds) was discovered by petroleum geophysicists, 140 km off the east coast of Britain in the central North Sea (Figure 4.2)[108,109]. It is thought that an asteroid between 200 and 500 metres across may have caused this crater, which is around three kilometres

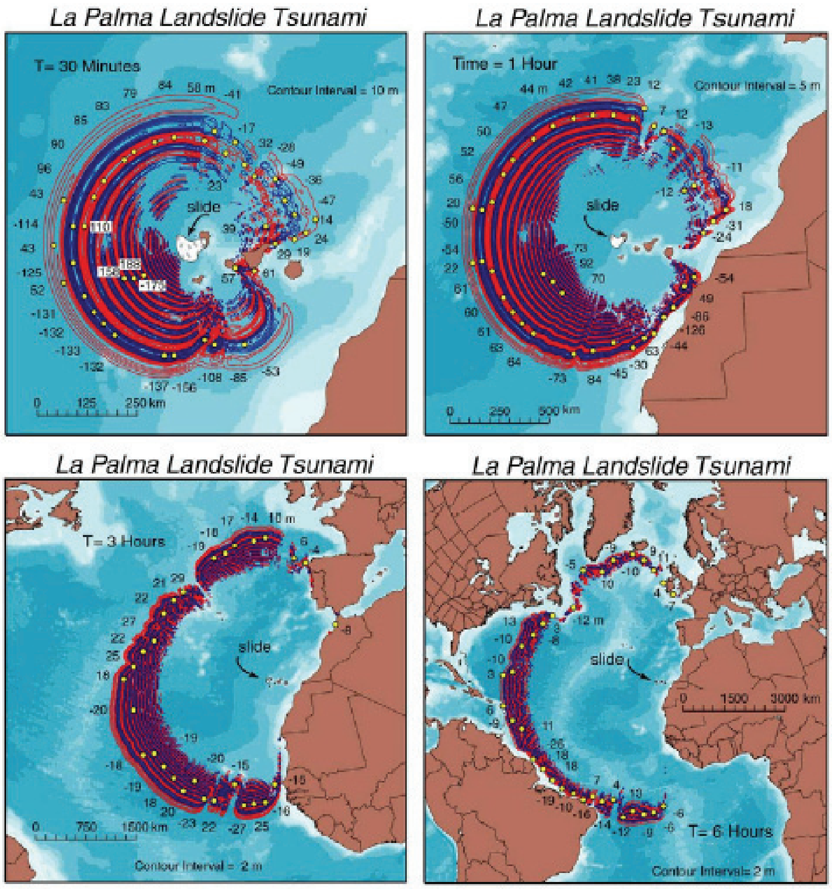


Figure 4.1. Spread of a tsunami across the Atlantic Ocean during the hours after a collapse of the Cumbre Vieja volcano, as modelled in the study of Ward & Day (2001)[106]. Red areas denote crests of waves above initial sea level, blue areas – troughs below initial sea level. Yellow spots give heights above or below sea level. (Source: Benfield, Hazard Research Centre, 2003).

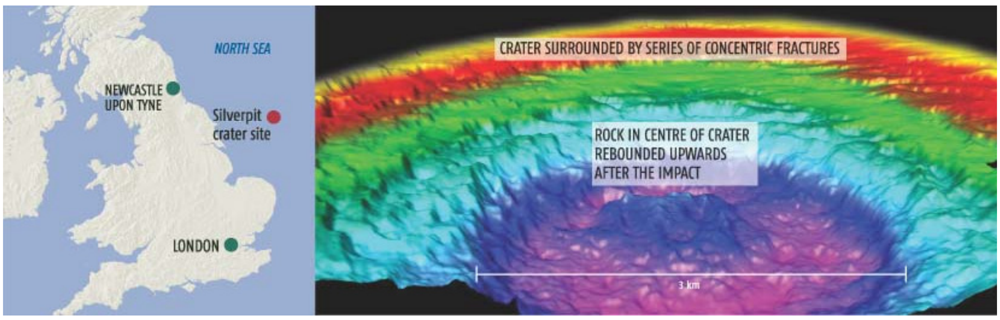


Figure 4.2. The structure of the North Sea meteorite impact crater as revealed by seismic imaging[109]. (Source: BBC).

across and 300 m deep. The impact occurred between 60 and 65 million years ago, and the collision, although not powerful enough to scatter debris across the planet, would have created a huge tsunami that inundated the few rocks poking up above the ocean surface in what is now Scotland[108].

Scientists state that for an impacting body to cause global consequences, it would have to have a mass in the range of tens of billions of tons, resulting in a ground-burst explosion with energy in the near vicinity of about a million megatons of TNT. Such an object would have a 1 or 2 km diameter. The probability of such an object coming near enough to the Earth to be drawn in is extremely small, but there is always the possibility that it could happen.

Gas hydrates are ice-like deposits containing a mixture of water and gas. Gas hydrates are stable under high pressures and at relatively low temperatures and are found underneath the oceans and in permafrost regions. There could be as much as 10,000 Giga (US billion) tons of carbon stored naturally as gas hydrates; more than ten times the amount of carbon currently in the global atmosphere[110].

Gas hydrates may constitute a serious geohazard in the future due to the adverse effect of global warming on their stability. Future warming at intermediate depths in the world's oceans, as predicted by climate models, may destabilize gas hydrates resulting in the release of large quantities of methane. As methane is 21 times more powerful as a greenhouse gas than carbon dioxide, this release would accelerate global warming. This in turn could lead to more oceanic warming, more methane release and ever increasing warming. Currently predicted sea level rise associated with global warming will, however, tend to stabilize marine gas hydrate deposits. The potential global threat posed by gas hydrates is therefore finely balanced and depends upon the rate of oceanic warming versus the rate of future sea level rise[110].

There is good evidence that gas hydrate decomposition has triggered a number of massive submarine slides over the last few thousand years, the most famous being the Storegga Slides off Norway (see above). Also, if sufficient methane is released suddenly in relatively shallow water this can have catastrophic implications for both shipping and marine oil and gas production. The volume of gas in the water could result in negative buoyancy and cause ships to sink. This has already been put forward as a possible cause of the so-called 'Bermuda Triangle' phenomenon, despite statistical analysis failing to show any greater loss of vessels here compared with other busy shipping lanes. A more likely and serious problem involves the increased risk to oil and gas platforms in deeper water (ie between 200-1500 m water depth), a localised increase in water temperatures could cause gas hydrates to breakdown, leading potentially to significant or catastrophic out-gassing[110].

As far as 'extreme events' go, reversal of the Earth's magnetic field occurs relatively slowly although still very rapid in geological terms. The history of the Earth's polarity is a long series of minor fluctuations over billions of years, punctuated by total reversals that take place over just a few thousand. Evidence has started to emerge which suggests that the Earth is now beginning a magnetic reversal[111] and the Earth's magnetic poles have been getting steadily weaker over the past 150 years. At the current rate of decrease, the dipole field will vanish, early in the next millennium. This is an amazingly rapid change, given that the north-south dipole field has existed for the last 3 billion years[112].

As the magnetic field weakens, it will impact our ability to navigate at sea using magnetic compasses. It may also impact the migration behaviour of animals, such as birds, fish, and turtles which use magnetite crystals in their brains or retinas to navigate over long distances[113]. A combination of factors may cause whales and dolphins to strand but one theory to explain some strandings relates to the fact that they may be navigating using the earth's magnetic field. Crystals of magnetite have been detected in the brains and skulls of some cetaceans and a magnetic "sense" could be an important navigational aid, especially in the deep oceans. An analysis of strandings around the UK has found that live strandings occur more often on those unusual shores where lines of equal magnetic force meet the coastline perpendicularly. In other words, the dolphins or whales are disoriented by these abnormalities and follow them ashore[115]. Whether or not such phenomena will become more common as the Earth's magnetic field weakens remains unclear. Sharks and rays may also be adversely affected, since some can detect the Earth's field inductively by swimming through field lines[114]. The Earth's magnetic field is expected to decrease to around one-tenth its current strength, and it will remain this way for around 3000 years.

4.2 Extreme climatic events

Whilst the possibility of climate change has been considered for some time (see Section 2.1), recent stories in the media have highlighted the disastrous consequences of an abrupt change in global climate[116,117]. A BBC *Horizon* programme suggested that Britain may soon face a new Ice Age, a report from the Pentagon examined the potential violent conflict and mass movement of refugees resulting from abrupt climate change[118], and the Hollywood film '*The Day after Tomorrow*' presented apocalyptic scenes, supposedly resulting from an abrupt change in ocean circulation.

The possibility of abrupt climate change triggered by human perturbation of the climate and ocean circulation system, is frequently mentioned as a 'wild-card' in the climate change debate, a card invoked both by those who urge stronger and earlier mitigative action than is currently being contemplated[119,120] and also by those who argue that the unknowns in the Earth System are too large to justify such early action[121].

One possible example of abrupt climate change would occur as a result of the weakening or halting of the thermohaline circulation (see Section 2.1). The result for the climate of Northwest Europe would be dramatic, with temperatures no longer rising as expected with 'global warming' but suddenly cooling. Such a change could cool selective areas of the globe by 3° to 5°C. To put this into context, the average air temperature difference between the 'Medieval Warm Period' when vineyards thrived in southern England and the 'Little Ice Age' when the River Thames froze over was only 1-2°C[122]. Currently, there are insufficient data to say how likely this scenario is (see Section 2.1). However, most climate models do predict that there will be a weakening in the present warming influence of the thermohaline circulation, but it seems unlikely that there will be a complete shut-down in the near future (see Section 2.1).

Climate change will not only cause changes in average temperatures, but will also trigger more so-called extreme weather events. Global warming is predicted to change the frequency, intensity and duration of events, leading to more hot days, heat waves, flash floods and heavy down-pours.

The 'return period' for a climatic event is defined as the average elapsed time between events of a given magnitude. The UK Climate Impacts Programme (UKCIP)[2] predicts that extremely hot August temperatures, such as those experienced in 2003, whereby the average temperature was 3.4°C above normal in the UK, may occur as often as one year in five by the 2050s, and three years in five by the 2080s. Even under the Global Commons scenario, about two summers in three may be as hot or hotter than the summer of 2003 by the 2080s. Similar changes are expected for intense precipitation events (snow or rainfall), such as that which caused devastation in the Cornish village of Boscastle on 16th August 2004[123] and 52 years earlier, whereby 12 people were killed in flash-floods at Lynmouth, Devon.

UKCIP estimates that the magnitude of the 'once in two year' daily precipitation event will increase markedly over the next 80 years, ie, what we currently consider extremely heavy downpours will become much more common in the future[2]. In winter, all of the UK with the exception of north-west Scotland will experience an increase in the magnitude of the 'two-year event'. In some areas, notably the south of England and southern Scotland, the increase might be as much as 20 per cent under the Fortress Britain (Medium-High Emissions), and World Markets (High-Emissions) scenarios. By contrast, during summer the pattern is inverted with the 2-year daily rainfall intensity falling by 10 and 30 per cent respectively. Furthermore, the probability that on any given winter day heavy rainfall will occur also increases throughout the whole of the UK. In Central-south England for example, the probability that any given winter day by the 2080s will have precipitation in excess of 20 mm is about 2.5%, compared to 1% at present[2].

Most climate experts now agree that throughout the 21st Century climate change could significantly influence the strength and seriousness of hurricanes in the western Atlantic and typhoons in the Pacific. Warmer oceans and increased moisture could intensify the showers and thunderstorms that fuel hurricanes[165]. Consequently although it is not clear whether there will be more or fewer hurricanes in the future compared to the present, the seriousness of the damage caused looks set to escalate[165]. In August 2005, Hurricane Katrina caused devastation in and around New Orleans, Louisiana and Mississippi. Katrina is estimated to have been responsible for $75 billion in damages, making it the costliest hurricane in U.S. history. The storm is thought to have killed at least 1604 people, making it the deadliest U.S. hurricane since 1928[161]. Hurricanes well in excess of this magnitude may become commonplace in the future.

In England and Wales, an estimated five million people, two million homes and 185,000 businesses are at risk of flooding every year, according to insurance experts[124]. A government study[22] has calculated that by 2080, flash-floods from sudden downpours could affect up to 700,000 in Britain's cities. Recently the Marine Conservation Society (MCS) has warned that an increase in the prevalence of flash-floods and heavy storms, might result in greater risk of pollution on Britain's otherwise very clean bathing beaches[125]. Many UK beaches or rivers have emergency over-flows on or near them, which reduce the risk of disastrous surges in the sewer system of towns and cities, and thereby prevent the flooding of homes and streets. During a heavy storm, valves are opened and untreated effluent is sometimes released. During heavy rains in August 2004 for example, more than 5.5 million tonnes of raw sewage entered the Thames at Stratford and Battersea in London, killing hundreds of thousands of fish further down-river at Brentford and Isleworth. Such inputs placed bathers in Kent and the south-east of England at greater risk of short-term health problems such as gastroenteritis, ear or eye infections for a short period afterwards[125].

A further risk accompanying major rain events is that the waters can carry a higher load of contaminants than usual from non-point sources (ie diffuse pollution such as pesticides from agricultural practices and petroleum hydrocarbons from road surfaces). In addition, erosion due to major storm events may cause relocation of contaminated terrestrial (eg, metal mining areas) or aquatic sediments to estuarine and marine ecosystems.

For many years, stories of freak or rogue-waves as tall as 10 storey buildings, and responsible for the mysterious sinking of ships, were written off as nautical fantasy[126]. Scientists clung to statistical models stating that monstrous deviations from the normal sea state would only occur once in every 1000 years, or only following major geological upheavals (see Tsunamis, above). However, a recent study using satellite data from the European Space Agency has confirmed that such phenomena do in-fact, occur regularly. The study detected 10 giant waves, all of which were 25 m high, within a three week period[126]. Over the last two decades more than 200 super-carriers - cargo ships over 200 m long – have been lost at sea. Eyewitness reports suggest that violent walls of water rose up out of calm seas and claimed some of these.

Understanding how wave heights may change as climate warms is important; waves can cause damage to coastlines, including coastal defences, and can be hazardous to shipping and offshore structures (UKCIP). The heights of offshore waves depend on the strength of the wind, and on both the distance and the length of time over which the wind acts on the ocean surface. Swell waves can travel vast distances away from the windy region in which they were generated, so that strong winds on the western side of the Atlantic can affect the height of waves in UK coastal waters. In the future, because average wind speeds are expected to change, the height of waves around the UK could also change.

UKCIP have attempted to model changes in the 2-year return period wind-speed (ie the wind-speed which on average, occurs only every two years)[2]. The south and east coasts of England are anticipated to experience the largest wind speed increases (2-8%) in winter and spring, which is to say that wind speeds we currently consider dramatic, will become evermore commonplace. However, in the summer and autumn, wind-speeds will decrease as climate warms, especially off the west coast of the British Isles and in the Irish Sea[2].

In Section 2.1 we consider future predictions for changes in storm surges; temporary increases in sea level caused by low atmospheric pressure and strong winds. UKCIP provide additional model analyses, concerning the frequency of extremely large surges, as an example for the port of Immingham on the East Coast of England[2]. Currently, an elevated water level of 1.5 m would be expected once every 120 years at Immingham, however under the 'Fortress Britain' (Medium-High Emissions) scenario for the 2080s, such surges might occur every seven years; a seventeen-fold increase in frequency. Another implication is that a water level that occurs on average, once every 50 years at present might occur as often as every three years by the end of the Century[2].

The Thames Barrier, commissioned in 1982, is closed whenever high-water levels at Southend, and the flow of the river at Teddington (the tidal limit of the Thames), reach critical levels. Currently the major threat to central London is from storm surges. Over the past 17 years the number of times that the barrier has needed to be closed per year has generally increased. Closures over the 1993-1999 period greatly exceeded those for the preceding 10 years, reaching a high of 24 closures in 2000/2001[162]. A study by the Environment Agency indicates that the estimated frequency of closures will be 20-35 closures per year in 2020, as many as 75 by 2050 (depending on the climate scenario used), up to 325 by 2100[162].

4.3 Biological/ecological events

Most biological or ecological 'shock' events occur as consequences of some other, often human-related factor, e.g the 'fishing-out' of a keystone species, the sudden arrival of invasive animals via ballast-water, escape of organisms from captivity. However, sudden and inexplicable outbreaks of disease among marine organisms may occasionally occur, with wide-ranging and often devastating impacts throughout the food-web.

One recent example has been the sudden and inexplicable emergence of Phocine Distemper Virus (PDV) in seals. In 1988 an outbreak of PDV, caused the death of over 18,000 common seals in Northern Europe. The disease was first detected in populations located around the island of Anholt in Denmark, and spread to infect seals in the Wadden Sea, Baltic Sea, North Sea, and Irish Sea. In the UK, the disease was first reported from the Wash in July, spreading throughout the East Coast of Scotland in August. The population of common seals in the Wash was the worst affected with almost half of the population dying as a result of the epidemic[127].

During June and July 2002 a virus virtually identical to the 1988 PDV strain emerged. The 2002 outbreak showed similarities to the 1988 epidemic; the same original location, a similar time of year and a similar starting level of seal population density[127]. Less severe than the 1988 epidemic, the 2002 outbreak affected approximately 4000 seals in the UK.

Scientists believe that marine life is at growing risk from a range of diseases whose spread is being hastened by global warming, accelerated global transport by man and pollution[128,129]. They cite a number of well-documented cases such as Crab-eater seals in Antarctica infected with distemper by sled-dogs, sardines in Australia infected with herpes virus caught from imported frozen pilchards, and sea-fans in the Caribbean killed by a soil-borne fungus.

In the past few decades, there has been a world-wide increase in the reports of diseases affecting marine organisms[128,129]. A disease outbreak is favoured by changing environmental conditions that either increase prevalence and virulence of an existing disease or facilitate the establishment. Climate variability and human activity appear to have played roles in epidemics by undermining host resistance and facilitating pathogen transmission.

Habitat degradation and pollution inputs, can facilitate catastrophic disease outbreaks. Work on aquatic mammals indicates that pollutants, for example organochlorides, have immuno-toxic properties[130]. Because most coastal waters are typically affected by a cocktail of anthropogenic pollutants and inputs, it is often difficult to identify any one specific cause of deteriorating health or disease.

Marine biological invasions are increasingly recognised as a threat to biodiversity and industry, including fisheries. The introduction of non-native species to a marine ecosystem and their subsequent establishment may cause effects ranging from the almost undetectable to the complete domination and displacement of native communities[131]. Globally, efforts are underway to contain, if not eradicate many high-impact marine invasive species[132].

15 marine algae, five diatoms, one flowering plant (*Spartina anglica*) and 30 invertebrates have been identified by JNCC[131] as non-native species now commonplace in British marine waters. Species can be introduced directly from their point of natural origin, or secondarilly from locations which they have colonised as non-natives. For the non-native marine species in British waters, it is clear that most have come from similar latitudes, in particular from the east coast of the USA (especially the fauna) and from the western Pacific (especially the flora)[131].

There are a number of known methods for the sudden introduction of marine species:

- Deliberate commercial introductions (including escapes);
- Associated unintentional introductions (eg in association with aquaculture stock);
- Transport on ship's hulls (and on flying boats) either of sessile (fouling), boring or vagile (clinging) species;
- Transport with ship's ballast, especially ballast water;
- Movement through canals linking biogeographically distinct water bodies (eg the movement from the Black Sea to the Baltic by Round Goby *Neogobius melanostomus*).

Deliberate commercial introductions can be for aquaculture, including direct human consumption, for the pet and aquarium trade, as bait for use by anglers or as biocontrol organisms for pest control[131]. Other species and pathogens can be brought in unintentionally in association with cultured species. Utting and Spencer (1992)[133] gave an account of introductions of marine bivalve molluscs into the UK for commercial culture and detailed the species that arrived with them.

Transport on ships has been possible for millennia and, more recently, flying boats have been implicated. There have been a number of changes over the years which will have facilitated the transport of species. Transport of solid ballast has been replaced by water, although sediment is often present in ballast tanks which allows for the spread of cysts of diatoms and dinoflagellates. Historically, major European ports were some distance from the coast, sometimes 30-40 miles from the open sea and therefore in reduced salinity. In the 1970s there was a rapid move to container transport by large vessels which were restricted to coastal deep-water ports, eg Felixstowe and Rotterdam. This changing practice may have accounted for an observed increase in the number of introductions, and hence survival when ballast water is discharged. Furthermore, the amount of transoceanic shipping has increased greatly. Shorter travel times may increase the probability of survival of both fouling species and those carried in ballast water[131].

There are a number of clearly discernible patterns in the distribution of non-native species in British waters, notably there are far more introduced species on the south and west coasts. There are also areas which seem to abound with non-natives, eg the Solent, probably as a result of the large volume and history of shipping in the area; and the Essex coast, in connection with oyster grounds. A survey of the southern part of Poole Harbour in the early 1980s revealed that non-native species represented 60% of the biomass of all species present[131].

Elsewhere in Europe, the accidental introduction of non-native species has had a devastating impact on ecosystems and in an ominously short period of time. Notably the introduction of the seaweed *Caulerpa taxiflora* to the Mediterranean Sea[134] and the establishment of the comb-jelly *Mneumiopsis leidyi* in the Black Sea[135].

In the early 1980s, the curator of the tropical saltwater aquarium at Wilhelmina Zoo in Stuttgart noticed the exceptional properties of a bright green alga *Caulerpa taxiflora*, used as tank decoration. Exposure to abiotic stressors had altered and switched on genes not expressed or active in the wild-type found across the Pacific. This genetically altered seaweed, in contrast to other algae, grows with astonishing vigor and can withstand cool water temperatures. In 1982, a sample found its way to the Oceanographic Museum in Monaco. During routine cleaning of aquarium tanks, a quantity of *Caulerpa* was deposited into the Mediterranean Sea. An expert on algae noticed some days later, that the tiny amount discarded had grown to cover a square metre. He suggested that the alga be removed, but the suggestion went unheeded. Two decades later, *Caulerpa taxiflora* has spread throughout the Mediterranean basin, covering 10,000 acres and displacing native algae, invertertebrates and fish[134].

Invasion by the alien ctenophore *Mneumiopsis leidyi* in the Black Sea has been relatively well documented[135,136]. In the 1980s the system was dominated by small pelagic fishes and the jellyfish *Aurelia aurata*. Introduction of *Mneumiopsis* in 1989 and 1990 corresponded with a sudden decrease in abundance of most fish stocks, a 2-fold rapid reduction in zooplankton biomass and a corresponding doubling in the phytoplankton standing stock. The frequent phytoplankton blooms and the bulk of non-utilised algal biomass produced a shift in water quality to a state characterised by low transparency and high production of detritus, causing oxygen depletion near the bottom. Increased mortality of mussels and other benthic organisms, subsequently contributed to non-utilised detritus, and hydrogen sulphide production on the Black Sea shelf[136].

Since the 1970s, the frequency and spatial distribution of phytoplankton blooms and associated fish kills have been increasing in coastal seas throughout the world. Why such events are becoming more frequent remains a matter of conjecture, but eutophication of the coastal zone by human activity, together with increasing global temperatures are often suspected[137]. Blooms are often spectacular events and in Britain the most common types include *Phaeocystis* and *Noctiluca* (see Figure 4.3). Although not all blooms are directly harmful, many cause aesthetic nuisance[138]. Some result in fish kills and even chronic health problems in humans who eat contaminated seafood or are exposed to contaminated water (eg the blue green algae *Alexandrium* and *Dinophysis*). *Gyrodinium* is harmless to humans but can cause mass-mortalities among fish. This dinoflagellate produces a potent neurotoxin, which is known to bioaccumulate in the zooplankton food-chain[138]. The coastlines of northern France, Belgium, the Netherlands and Great Britain are regularly afflicted by *Phaeocystis* blooms, which form an unpleasant foam which is often mistaken for sewage pollution[139]. Although not itself toxic, the adverse conditions caused by the degeneration of a *Phaeocystis* bloom results in an anoxic, mucilaginous layer over the seabed and hence mass suffocation of invertebrates and juvenile flatfish[140].

A recent study[141] has attempted to evaluate whether harmful algal blooms are likely to occur more or less often over the next 100 years in the North Sea. As stated in Section 2.1, change in climate is expected to lead to an increase in extreme precipitation events (intense rainfall) in Britain, this will result in sudden pulses of freshwater being released at the coast and hence intermittent salinity stratification in an area extending 30-40 km offshore[141]. During such conditions, surface phytoplankton benefit from a decrease in salinity, greater availability of terrestrial nutrients, rapid increases in daily irradience and higher

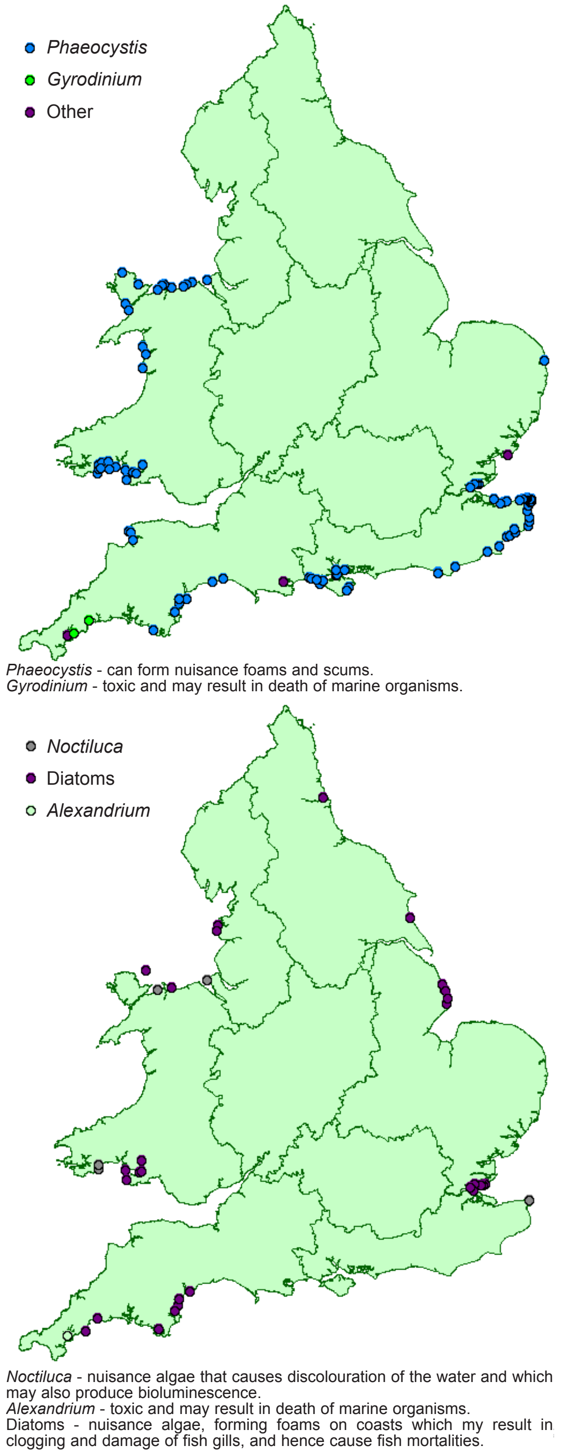


Figure 4.4. The distribution of selected nuisance and potentially toxic algal blooms around the coast of England and Wales during 1999[138]. (Source: Environment Agency, 2000).

water temperature, all of which are conducive to bloom formation. Indeed, following the catastrophic flash-floods in August 2004, enormous blooms of *Phaeocystis* were observed in the Camel Estuary and off Cornwall[139]. Increasing global temperature may also lead to faster growth rates, particularly for highly toxic phytoplankton varieties such as *Prorocentrum* (producers of shellfish toxins), *Chattonella* and *Fibrocapsa* (toxic to fish).

4.4 Events in the human environment

Humans can have many impacts in the marine environment, and sudden changes in economies, political regimes, personal tastes can have wide-ranging implications for marine ecosystems and/or the organisms which live in them.

For centuries, war and terrorism have involved not only human casualties but also environmental destruction. Wars vary in scale (from global to local) and duration (from minor skirmishes to hundreds of years). However, as military technology has become increasingly advanced so impacts on the environment have become more severe and longer-lasting.

The environmental impacts of modern war can be grouped into three areas:

1) The consequences of preparing for war (including military tests).
2) The immediate effects of war.
3) The aftermath of war.

In this section we are primarily concerned with the sudden, immediate effects of war and terrorism on the marine environment.

Probably the best documented war, in terms of damage to the marine environment was the first Gulf-War of 1991[142,143]. The military hostilities in Kuwait in January 1991 resulted in the discharge of vast quantities of oil into the Gulf's marine environment from sunken vessels (including Iraqi tankers) and oil transfer facilities. Although the total volume of the spill is still not fully agreed upon, most estimates indicate c. 6-8 million barrels, making it by far the world's largest oil spill[142].

Reports suggest that approximately 30,000 marine birds perished as a result of this incident, and this figure excludes those that were trapped in oil pools in the desert. Furthermore, approximately 20% of mangroves were contaminated, 50% of coral reefs, and hundreds of square miles of sea grass[143]. Iraq's decision to deliberately destroy Kuwaiti oil production facilities resulted in an approximate 5-6 million barrels per day of oil being engulfed in flames. Tons of gaseous pollutants such as carbon dioxide and sulfur dioxide (the primary constituent in acid rain) were released into the atmosphere, causing black, greasy rains to fall in Saudi Arabia and Iran and black snow in Kashmir (1500 miles away). Such ecological disasters have an immediate impact not only on humans but also on the flora and fauna of affected areas[142,143].

'Secondary' environmental effects of the war included destruction of sewage treatment plants in Kuwait, resulting in the discharge of over 50,000 m^3 day^{-1} of raw sewage into Kuwait Bay, threatening the intertidal systems, polluting public beaches and downgrading the quality of seawater used for desalination[144]. Analysis of fisheries catches suggest a real and sudden decline in shrimp stocks. In 1991-92 the Saudi Gulf stock showed a decline in spawning biomass to about 1-10%, and a decline in total biomass to about 25%, of the pre-war level[143].

By contrast, during the second world war fish stocks in Europe may have actually benefited from this otherwise terrible event[145]. Because of the laying of mines at sea, and the requisitioning of fishing vessels for other duties, the level of fishing mortality was very low for stocks during the period 1939-1945. Cod, haddock and whiting numbers all increased, in spite of relatively low recruitment (the number of juveniles entering the system each year). In subsequent years however, these stocks have suffered, at least in part, because of the invention of sonar fish-finding devices which evolved as a result of wartime technology.

In the aftermath of the September the 11th 2001 attacks, the world has been alerted to the potential threat of nuclear terrorism[146]. The head of the International Atomic Energy Agency (IAEA), the UN nuclear watchdog, stated in October 2002, that it is now "far more likely" that terrorists could target nuclear facilities, nuclear material and radioactive sources world-wide. The reactor accident at Chernobyl in May 1986 changed the inventory of artificial radionuclides in the North Sea and Baltic Sea as well as in the European polar Seas. The highest input of Chernobyl fallout was recorded in the Bay of Bothnia. Today, Cs-137 levels in the entire Baltic Sea are still markedly higher than before the accident, and little is understood about the long-term impact of radioactive contamination on marine organisms[147].

Occasionally there may be a sudden change in social attitudes, which can impact on the wider marine environment or on the value that society places on a particular resource. Until 1966 Roman Catholics were required not to eat meat on Fridays and tended to eat fish instead. In 1966 Pope Paul VI declared (in his 'Apostolic Constitution On Penance') that henceforth Catholics could eat meat on Fridays and this resulted in a noticeable drop in fish prices and quantities of fish sold on markets world-wide[148]. The converse can happen when a particular product is promoted or aggressively marketed. In the United Kingdom, monkfish (*Lophius* spp.) has become particularly fashionable in restaurants in recent years, at least in part due to promotion by celebrity television chefs[163]. It was not until the mid-1980s that fishermen began to actively target monkfish, which had previously been used as a low-value substitute for more expensive products such as scampi. Many monkfish stocks are now in a perilous state of decline.

New discoveries can also lead to society suddenly placing greater value on a particular natural resource, and in recent years there has been much discussion about the potential for 'bio-prospecting', in the marine environment. The ocean is a rich source of biological and chemical diversity. It hosts more than 300,000 described species of plants and animals. This diversity has been the source of many unique chemical compounds with great potential for industrial development as pharmaceuticals, cosmetics, nutritional supplements, molecular probes, enzymes, and agrichemicals. A relatively small number of marine plants, animals, and microbes have already yielded more than 12,000 novel chemicals[149].

The potential for marine natural products as pharmaceuticals was first explored in the 1950s led by to two marine-derived pharmaceuticals that are still in use today. Ara-C is an anti-cancer drug (used against acute myelocytic leukemia and non-Hodgkin's lymphoma) and Ara-A is used as an antiviral drug for treating herpes. Both drugs were derived from natural compounds found in sponges off the coast of Florida. Sponges have provided over 30% of the chemical compounds derived from marine organisms to date[149].

Sudden economic recession (whether local or global) has the potential to 'check' the development of particular industries/sectors and hence may divert marine policy away from its present course towards something radically different (eg towards a different AFMEC Scenario). Following separation from the Soviet Union in the early 1990s, Latvia, Lithuania and Estonia endured a prolonged economic recession. During this period the intensity of agriculture and consequently nutrient inputs to the Baltic Sea reduced substantially, as did the input of industrial pollution, because many factories ceased operating. By contrast, Lamb[150], talking of the limited outcomes in terms of actual actions following the Rio 'Earth Summit' in 1992, stated that "It is perhaps one of those inevitable ironies that at exactly the moment when the world realised that a massive financial input would be needed to tackle environmental problems, the global economy went into a violent dip. Promises of international largesse evaporated as the industrial world struggled with a sharp economic downturn"[150].

Table 4.1. Inventory of 'shock events' and 'discontinuities'.

Human environment	Climate and hydrography	Biological and ecological events	Geological and astronomical events
• Outbreak/emergence of human disease (impacts population size, demands placed on ecosystem, activities, travel routes)	• Sudden climate change, eg collapse of the thermohaline circulation	• Outbreak/emergence of animal diseases and impact on marine communities (e.g PDV in seals, fish kills, shellfish poisoning)	• Earth quakes and under-sea land-slips
• War (has effects at many scales depending on the nature of the conflict, nuclear, global, European, local). Can lead to oils spills, contamination but also respite from fishing etc.	• Gulf stream and temperatures becoming more erratic. 'Spikes' can be very damaging for biological communities (eg coral bleaching).	• Invasion by exotic species and impact on marine communities (eg comb jellies in Black Sea, *Caulerpa taxiflora* in the Mediterranean). Depends on shipping routes and ballast waters.	• Freak waves and tsunami (eg as a result of break-up of La Palma, Canary Islands)
• Sudden change in social attitudes (eg health scares, or changes in consumer tastes) or political landscape (eg break-up of EU)	• Drought (sudden release of water following a drought can result in pollution peaks; also drought can affect livestock and therefore demand for marine protein)	• Sudden regime shift (alternative stable states in ecosystems). Can have many causes, eg overfishing, climate, invasive species.	• Volcanic eruption (emergence of new islands, or change in the global climate, eg Mt. Pinutubo)
• Food or fuel shortages (often a consequence of other 'events', can lead to mini-wars)	• Flooding or storm surges (eg, 400 year wave event or local tidal waves)	• Algal bloom events (can lead to fish kills and anoxia etc.)	• Meteorite strike (eg Silver Pitt, North Sea)
• Technology failure (eg GPS system, computer viruses, nuclear/biotechnology accident & contamination)		• Escape of farmed or GM organisms (with impacts on native population)	• Magnetic pole switch (impact on navigation and satellites, also migration patterns of birds and turtles etc.)
• Terrorism (disruption of energy supply or pipelines, nuclear or oil contamination)			• Catastrophic release of methane from gas-hydrate deposits.
• Global or local economic recession (therefore change in activities and attitudes)			
• New discoveries (new values for marine products or new uses of the marine environment)			

5. How should the AFMEC scenarios be used?

5.1 Scenario planning & other techniques

The prime purpose of scenarios and scenario building is to enable decision-makers to detect and explore all, or as many as possible, alternative futures so as to clarify present actions and subsequent consequences. Scenarios support strategic thinking and decision making.

Scenario planning differs from contingency planning, sensitivity analysis and computer simulations[151].

- 'Contingency planning' is a "what if" tool, that only takes account of one uncertainty, whilst 'scenario planning' considers combinations of uncertainties. Planners can select especially plausible but uncomfortable combinations of social developments.
- 'Sensitivity analysis' considers the implications of changes in one variable only. 'Scenario planning' by contrast tries to expose policy makers to significant interactions of major variables.
- While scenario planning can benefit from computer simulations, it often tends to be less formalised. Scenario planning can include elements that are difficult to quantify or parameterise, such as subjective interpretations of facts, shifts in values, new regulations or inventions[151] (see Section 4.4).

Scenario planning can help policy-makers anticipate hidden weaknesses and inflexibilites in organisations and methods. When found years in advance, the weaknesses can be repaired or reduced more easily and more correctly than if a real-life problem emerges and costly mitigation measures are required immediately. For example, an organisation may discover that it needs to change contractual terms to protect against a new class of risks, or amass cash reserves to purchase anticipated technologies or equipment.

Broadly, the benefits of scenario planning are[23]:

- It expands the range of future outcomes considered in strategic decision-making, so strategies are developed to be more robust to changing circumstances. This avoids the risk of 'putting all eggs in one basket'. It places under scrutiny the assumptions underlying current strategic decisions.
- Policymakers can trial ideas in a pleasant, unthreatening, game-like environment. It allows policy-makers to make and learn from mistakes without risking important failures in real life.

5.2 How might the AFMEC 2020 scenarios be used?

The scenarios developed by UKCIP and OST have been widely used by stakeholders throughout the UK; by countryside and conservation managers, regional land-use planners, coastal and flood-defence managers[1] etc. Uptake has been encouraged through provision of tools and discussion documents, housed on a centralised web-based 'scenarios gateway'.

The AFMEC scenarios are also aimed at a wide variety of potential users including: government departments, fisheries organisations, offshore operators, coastal engineers, marine biologists, conservationists, regional development agencies and tourist authorities etc. The AFMEC 'Futures' can be used in a range of different ways, depending on the needs of the individual users and the resources available. Users are encouraged to develop their own conclusions about the futures, employing the scenarios as a starting point and elaborating or evaluating them in ways that are in tune with their own needs. Scenarios can help map-out future 'destinations'. If you have a clear idea of where you want to go or even where you definitely do not want to go, it is easier to take decisive action to achieve a particular outcome some years hence. The scenario framework needs to be adaptive however, and respond as new challenges emerge or new threats unravel, ie, an evolving 'living system'. Two fundamentally different approaches to the use of scenarios can be distinguished[23]. Most frequently, scenarios are taken-up in small-scale brain-storming exercises, often one-off events that contribute to a medium-term business and planning strategy. These processes usually:

- Are a qualitative exploration of trends
- Are participative
- Are based on the experience of practitioners
- Use the scenarios mainly as a communication tool

Frequently their use depends on a 'champion' of scenario planning at a senior level of management. Their function is to attract interest and to stimulate creative thinking (eg the scenarios produced by Defra, see Section 1.6).

Less frequently the scenarios have been used in the context of rigorous research-based studies carried out over longer periods and sometimes requiring considerable additional resources. In these assessments, the main focus is to provide a heuristic framework. Such an approach is often taken where there is much uncertainty in an area of research: for example in climate change impact assessments. These processes usually involve:

- Quantitative assessment of potential outcomes
- Scientific methods combined with consultation
- Use of data, complex statistical methods and expert knowledge

The main challenge for this approach is to combine the 'soft' scenario tool with 'hard' quantitative methods. In this AFMEC report we have offered a number of key indicators as an illustration of future trends, but these should be seen only as a starting point. If it seems appropriate, they can be revised, specified or complemented by other indicators.

5.3 Specific recommendations

Some degree of change is inevitable and marine stakeholders will therefore need to adopt policies, strategies and long-term plans to take account of these future changes. Several organisations, including UKCIP, have developed tools (eg guidance on handling uncertainty in decision making, risk assessment packages, and costing methodologies) to aid stakeholders in their planning for the future. UKCIP also provided a centralised 'scenarios gateway' to assist stakeholders in developing and assessing possible adaptation strategies.

(a) a centralized marine 'scenarios gateway'

In considering how the AFMEC scenarios might be used further, we suggest that an equivalent marine scenarios 'gateway' might be useful, possibly within the context of existing programmes funded through Defra such as the Marine Climate Change Impact Partnership (MCCIP). Adaptation of the UKCIP tools specifically for marine purposes might also be beneficial; in the first instance this might involve:

1. Provision of a guidance document/web-site *"how will changes in the marine environment" affect your organisation?"*
2. Provision of a guidance document/web-site *"how will changes in the marine environment" affect your region?"*
3. Provision of a guidance document/web-site "*Principles of good adaptation strategies*", based on the UKCIP example.

Only through developing tailored and locally relevant outputs might we expect stakeholders to maintain their interest. Stakeholders would immediately be able to understand how future change could affect them and what they might do about it. In the longer term the development of a database of adaptation case-studies, complementary to that existing for UKCIP, might be beneficial. This would be populated with suitable examples of where AFMEC, Foresight, or UKCIP scenarios have been used within a marine context.

Other UKCIP tools (eg 'Adaptation Wizard', costing methodology, risk-uncertainty and decision making framework) might also be adopted and adapted, thereby providing a complete toolbox and a 'one-stop-shop' for thinking about marine futures.

(b) creative workshops using the AFMEC scenarios as a discussion tool

A further recommendation is the focused dissemination of the scenarios among organizations with which Defra shares responsibilities in the marine environment (eg, English Nature, JNCC, Royal Commission on Environmental Pollution, Environment Agency, Crown Estates). A series of creative workshops might yield discussion materials in preparation for the planned UK Marine Bill, EU Marine Strategy (and accompanying framework directive) and future marine stewardship reports.

Consequently, the AFMEC scenarios might be used to inform and promote debate during this process. One of the advantages of using the scenarios is that, by their nature, scenarios highlight the importance of consultation and multi-disciplinary thinking.

On 8th December 2004, Tony Blair and Margaret Beckett the then Secretary of State for Environment, Food and Rural Affairs launched Defra's five year strategy, which included plans for a new Marine Bill to ensure greater protection of marine resources and to simplify regulation so that all users of the sea can develop in a sustainable and harmonious way. There have been a number of commitments regarding the marine bill and its inclusion in the 2005 Queens speech requires that a draft be prepared during the first session of the current Parliament (ie by November 2006). Many of the issues and key messages raised by the AFMEC scenarios will be addressed and examined during the development of the Marine Bill, for example the need for marine spatial planning (MSP), marine nature conservation and fisheries resource management within the broader context of environmental sustainability.

(c) establishment of a 'scientific forum' under Defra and NERC

In early 2005 Defra, SEERAD (the Scottish Executive Environment and Rural Affairs Department) and NERC (the Natural Environment Research Council) jointly commissioned a study looking at current and future research into marine biosciences in the UK. This study recommended greater cooperation and collaboration between government and university institutes and particularly with regard to modelling marine ecosystems. One recommendation of the AFMEC project might be the establishment of a 'scientific forum', jointly supported by Defra and NERC, to discuss how the AFMEC scenarios marine might be quantified further, also to outline and refine possible research project ideas which might be taken up by Defra and NERC in the future. It is anticipated that such projects would make use of complex ecosystem and bio-physical models.

(d) wider dissemination of the AFMEC scenarios in the UK and within the European Community

In an effort to encourage wider uptake and dissemination of the AFMEC scenarios among non-government and non-academic sectors in the UK it would be beneficial to promote and describe the scenarios at the widely attended 'Coastal Futures' conference held each year in London. This platform has already been used by Elliot Morley Defra's Minister of State (Climate Change and the Environment) to outline the possible scope and potential benefits of a Marine Bill. Other media, widely consulted by the marine community include newsletters such as '*Challenger Wave*' produced by the Challenger Society for Marine Science or the '*Marine Scientist*' produced by The Institute of Marine Engineering, Science and Technology.

The European Commission, in setting it's priorities for the coming five years (2005-2009), has recognised that there is a "particular need for an all embracing maritime policy aimed at developing a thriving maritime economy and the full potential of sea-based activity in an environmentally sustainable manner". In its Communication of 2 March 2005 "Towards a Future EU Maritime Policy: A European Vision for Oceans and Seas," the Commission committed itself in the first half of 2006 to presenting a Green Paper, defining the scope and priority issues to be considered . Following extensive consultation with stakeholders, the following over-arching principles have emerged:

- To protect and, where practicable, restore the function and structure of marine ecosystems in order to achieve and maintain good environmental status of these ecosystems.
- To phase out pollution in the marine environment so as to ensure that there are no significant impacts or risks to human and/or on ecosystem health and/or uses of the sea.
- To control the use of marine services and goods and other activities in marine areas that have or may have a negative impact on status of the marine environment to levels that are sustainable and that do not compromise uses and activities of future generations nor the capacity of marine ecosystems to respond to changes.
- To apply the principles of good governance both within Europe and globally.

Clearly the AFMEC scenarios could provide cross-cutting insights, and useful discussion material as the EU Marine Strategy, Marine Policy and finally the EU 'Marine Framework Directive' develop. The scenarios help to outline the logical implications of going (or not going) down a particular policy route, they also help to highlight internal conflicts and inconsistencies for example between the aspirations of different resource users or nations etc. In terms of uptake and exploration of the scenarios, one recommendation might be the proposal of a scenario themed 'Network of Excellence' within the forthcoming Framework 7 programme, whereby experts from around the European Community could meet and discuss such issues as well as funding small research projects on the theme of marine future scenarios at many different institutes.

Under call 5 of the EU Framework VI Programme (policy call SP1 – SSP5, sub-task 13.4) the Commission has specifically requested a Foresight exercise in the field of marine sciences with the objective to define the key challenges and risks facing research in the marine sector in the next few years. It is intended that the successful project will allow a better anticipation of research needs in the field of fisheries and aquaculture in the medium term (10 years) and the AFMEC scenarios have been held up as a useful basis on which to build scenarios for the marine environment.

Other international fora where the AFMEC scenarios might be of use, include the International Geosphere-Biosphere Programme (IGBP; GLOBEC), ICES and OSPAR. The 1992 OSPAR Convention is the current instrument guiding international cooperation on the protection of the marine environment of the North-East Atlantic. Work carried out under this convention is managed by the OSPAR Commission made up of reprisentatives from the Governments of 15 Contracting Parties and the European Commission.

ICES is the organisation that coordinates and promotes marine research in the North Atlantic. ICES provides a meeting point for a community of more than 1600 marine scientists from 19 countries. ICES plans and coordinates marine research through a system of committees, more than 100 working groups, symposia, and an Annual Science Conference. Future ICES working groups or symposia might focus their attention on cross-cutting marine 'futures' (such as those provided by AFMEC), an area which has experienced little attention to-date even though a major focus of both OSPAR and ICES in recent years has been the 'ecosystem approach' to management of marine resources.

GLOBEC (Global Ocean Ecosystem Dynamics) was initiated by SCOR and the IOC of UNESCO in 1991, to understand how global change will affect the abundance, diversity and productivity of marine populations comprising a major component of oceanic ecosystems. GLOBEC has a very broad scope from small scale National Activities to Regional Programmes covering ocean basins. An obvious recommendation might be to develop a new GLOBEC programme in collaboration with the International Project Office (in Plymouth), focusing on 'marine futures' and using the AFMEC scenarios as a staring point.

(d) the AFMEC summary report

A key output of the AFMEC project is the summary report (Viner *et al.*, 2006) produced by the Climatic Research Unit (CRU) of the University of East Anglia. It is intended that this document will be widely distributed both within the UK and also elsewhere in Europe. It is hoped that this very accessible document (which has achieved certification from the UK Plain English Campaign), will promote wide-scale discussion and enliven debate about marine futures, and possibly lead to further development work.

5.4 Necessary steps for refining the scenarios

One of the most problematic issues in scenario elaboration concerns 'quantification'. It is difficult, but essential, if the scenarios are to be taken seriously that numbers are attached wherever possible. However, quantification can easily reduce the scenario exercise to little more than a sensitivity analysis, unless there are clear, highly significant qualitative differences in the first place[152]. The need for quantification implies a balancing act. Quantification and modelling versus flow and imaginative speculation. We should not try to quantify everything, and we can not add certainty where there isn't any.

During consultation exercises as part of the AFMEC project, there was marked skepticism about the precision of some indicators (eg managed realignment). Participants agreed however that, qualification is probably more important than quantification, ie, we need to be clear about what is 'fact' and what is 'fiction'; speculation versus expert opinion.

For any given sector or marine area of interest, the further elaboration of AFMEC scenarios will require:

1. The identification of key drivers in the sector (eg international markets, social preferences, new legislation)
2. An assessment of the links between drivers and relevant sectoral trends
3. Specialist knowledge of the sector

Producing four scenario elaborations can be time-consuming, with diminishing returns[1]. If elaboration of these scenarios was desired, one approach might be to choose a smaller number of scenarios for in-depth analyses (say two or three). Some studies have chosen to look only at a pair of diametrically-opposed scenarios (eg World Markets and Local Stewardship). We recommend however, that the symmetric two-by-two matrix approach be retained during the first phase to avoid narrowing down the imaginative thinking too soon.

The AFMEC project has so-far, primarily been a 'scoping-study', aimed at outlining basic storylines but not providing a full quantification. A similar approach was taken by OST 'Foresight' programme[1,23], where scenarios were initially developed and published in 1998 but refined at a later stage (in 2003) or used in more detailed assessments for specific sectors, e.g the 2004 report on flood and coastal defence.

Indicators may help illustrate particular storylines. For example when developing the UK Climate Impacts programme (UKCIP) socio-economic scenarios[3], the following steps were taken to produce illustrative indicators:

- Identification of data needs of climate change impact modellers
- Identification of suitable indicators and data sources on the basis of criteria (significance, sufficient knowledge, sufficient stability)
- Consultation about indicators; drawing on expert knowledge to assess proposed indicator values for scenarios.

As part of the AFMEC stakeholder consultation process (described in Chapter 1), participants were asked to outline what additional modelling work might be beneficial, firstly to improve the present scenario outlines (reported in this document) but also issues to be addressed if the AFMEC project were to continue to be funded into a 'Phase 2'. The following ideas were proposed:

- Indicators of 'where we are now' and possible legal implications of acting or not-acting.
- Making available models/simulations as 'active' decision making tools.
- Baseline marine habitat maps illustrating habitat vulnerability under each scenario (linked to offshore development).
- Spatial 'ocean-use' planning tools (above sea level, below sea level).
- Elaboration of 'cause' and 'effect' chains as well as financial costs and benefits.
- Flow-charts of likely consequences and possible mitigation options.

6. Indices, acknowledgements and appendices

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Chapter 3 was written jointly by David Viner and John Pinnegar, drawing on the scattered literature base discussing likelihood and probability. In particular we made use of a recent working paper by Professor Mike Hulme (CRU).

Chapter 4 (shock events) was based almost entirely on ideas and ouputs supplied by stakeholders at the second AFMEC workshop. These ideas were subsequently elaborated upon through literature searches by Stephen Dye, John Pinnegar and David Viner.

Chapter 5 was written by John Pinnegar using outputs from the second AFMEC workshop as well as existing work by Julia Hertin and Frans Berkout (SPRU). This section was substantially altered following comments and suggestions from the AFMEC reviewers and steering panel.

The AFMEC summary document was written by David Viner, Nicola Sheard (CRU) and John Pinnegar (Cefas). It was amended and accredited by the Plain English Campaign.

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6.3 List of abbreviations

AFMEC	Alternative Future Scenarios for Marine Ecosystems
AWE	Atomic Weapons Establishment
BAU	‘Business as usual’ scenario
BHRC	Benfield Hazard Research Centre
BRA	British Resort Association
BWEA	British Wind Energy Association
CEBR	Centre for Economics & Business Research
Cefas	Centre for Environment, Fisheries & Aquaculture Science
CFP	Common Fisheries Policy
cpue	Catch-per-unit-effort
CRU	Climatic Research Unit
CSERGE	Centre for Social & Economic Research on the Global Environment
Defra	Department for Environment Food & Rural Affairs
DDT	Dichlorodiphenyltrichloroethane (insecticide)
DG	‘Deep green’ scenario
DTI	Department of Trade & Industry
EEZ	Exclusive Economic Zone
ENSO	El Niño-Southern Oscillation
ETC	European Travel Commission
EU	European Union
FFCD	Foresight – Flood & Coastal Defence
GATT	General Agreement on Tariffs and Trade
Gee-Gee	Global Geophysical Event
GDP	Gross Domestic Product
GM	Genetically Modified
grt	Gross registered tonnes
GW	Gigawatt
HadRM3	Hadley Centre, Regional Climate Model
hPa	hectopascal (a measure of atmospheric pressure)
IAEA	International Atomic Energy Agency
ICES	International Council for the Exploration of the Seas
IMO	International Maritime Organisation
IPCC	Intergovernmental Panel on Climate Change
JNCC	Joint Nature Conservation Committee
ka	Thousand years
Lo-Lo	Load-on, load off
MCCIP	Marine Climate Change Impacts Partnership
MCS	Marine Conservation Society
MPA	Marine Protected Area
MSC	Marine Stewardship Council
mt	Metric tonnes
MW	Megawatt

NAO	North Atlantic Oscillation
NIMBY	‘Not in my back-yard’
NVZ	Nitrate Vulnerable Zones
OSPAR	Oslo and Paris Convention
ODPM	Office of the Deputy Prime-Minister
OST	Office of Science & Technology (DTI)
PCB	Polychlorinated biphenyl
POL	Proudman Oceanographic Laboratory
Ro-Ro	Roll-on, roll-off
RSPB	Royal Society for the Protection of Birds
SME	Small and medium enterprise
SPRU	Science & Technology Policy Research Unit
SRES	Special Report on Emissions Scenarios (IPCC)
SSB	Spawning Stock Biomass
SST	Sea Surface Temperature
Sv	Sverdrups unit (1 Sv = 1 x 10^6 m^3 per second)
TCI	Tourism Comfort Index
THC	Thermohaline Circulation
TWh	Terawatt hour
UK	United Kingdom
UKCIP	UK Climate Impacts Programme
UNEP	United Nations Environment Programme
USPs	Unique Selling Points

6.4 Index (by text section)

Annex 1. List of organisations consulted

- Associated British Ports (ABP)
- British Marine Aggregates Producers Association (BMAPA)
- British Wind Energy Association (BWEA)
- Centre for Ecology & Hydrology (CEH)
- Centre for the Economics & Management of Aquatic Resources (CEMARE)
- Centre for Environment, Fisheries & Aquaculture Science (Cefas)
- Centre for Social & Economic Research on the Global Environment (CSERGE)
- Climatic Research Unit (CRU)
- Crown Estate
- Defra – Marine & Waterways
- Defra – Science Directorate
- DTI –Offshore Energy Licensing & Consents
- English Nature
- Environment Agency
- Fisheries Research Services, Aberdeen (FRS)
- GLOBEC International
- Hanson Aggregates Marine Ltd.
- 'Invest in Fish' South West Project (IiF)
- Joint Nature Conservation Committee (JNCC)
- Marine Biological Association (MBA)
- Maritime & Coastguard Agency (MCA)
- Ministry of Defence (MOD)
- National Federation of Sea Anglers (NFSA)
- NRC-Europe, National Research Council
- Sea Fish Industry Authority (Seafish)
- Science & Technology Policy Research Unit (SPRU)
- School Of Earth, Ocean & Environmental Sciences, University of Plymouth
- UK Climate Impacts Programme (UKCIP)
- Water UK
- Whale & Dolphin Conservation Society (WDCS)
- World-wide Fund for Nature, UK (WWF-UK)

Annex 2. International Conventions[153] which might constrain the development towards certain marine 'futures' (also see Section 2.5)

Instrument	Description
CITES - Convention on International Trade in Endangered Species of Wild Fauna and Flora	The Convention came into force in 1975 and has been ratified by well over 100 countries throughout the world, including the UK in 1976. The objectives of CITES are to protect endangered plant and animal species from illegal trade and over-exploitation. Commercial trade in endangered species listed in Appendix I is forbidden. Controlled trade is allowed for species which, although not currently threatened with extinction, may become so unless restrictions are applied, listed in Appendix II. Basking Shark and whale shark are now listed under CITES Appendix II.
Bern Convention - on the conservation of European wildlife and natural habitats	The Council of Europe 'Convention on the conservation of European wildlife and natural habitats' (the 'Bern Convention') aims to "conserve wild flora and fauna and their natural habitats", to promote co-operation between countries and their conservation efforts, and to give "particular emphasis to endangered and vulnerable species, including endangered and vulnerable migratory species". In order to achieve its objectives, the Convention provides for the conservation of wildlife and wildlife habitats in general and for special protection of species listed in Appendix I (strictly protected plants), Appendix II (strictly protected animals) and Appendix III (protected animals). The requirements of the Bern Convention are mandatory on its contracting parties. Britain is a party to this convention and ratified its provisions in May 1982.
OSPAR - Oslo and Paris Convention	The OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic came into force in 1998. The OSPAR Convention merged the 1974 Oslo convention (Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft) and the 1978 Paris Convention (Convention for the Prevention of Marine Pollution from Land-Based Sources). The OSPAR Convention includes the following Annexes: • Annex I: Prevention and elimination of pollution from land-based sources; • Annex II: Prevention and elimination of pollution by dumping or incineration; • Annex III: Prevention and elimination of pollution from offshore sources; • Annex IV: Assessment of the quality of the marine environment; and • Annex V: Protection and conservation of the ecosystems and biological diversity of the maritime area.
Rio - UN Convention on Biological Diversity	The Convention on Biological Diversity was signed in 1992 in Rio de Janeiro, in connection with the United Nations Conference on Environment and Development (UNCED). The objectives of the Convention are the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising from the utilization of genetic resources. Each contracting party is required to develop national strategies, plans or programmes for the conservation and sustainable use of biological diversity. A UK Biodiversity Action Plan (BAP) was published in 1995. Species Action Plans or Habitat Action Plans have been prepared for priority species and habitats, (now referred to as UK BAP species and habitats). Maritime species and habitats were first listed by the UK Biodiversity Group in 1999.
UNCLOS - United Nations Convention on the Law of the Sea	The 1982 United Nations Convention on the Law of the Sea (UNCLOS), which entered into force in November 1994, provides coastal states exclusive sovereign rights to explore, exploit, conserve and manage natural resources (mineral and biological) within 200 nautical miles (370.4 kilometres) of their shores (ie an Exclusive Economic Zone -EEZ).

Instrument	Description
UNFA - UN Fish stocks Agreement	The UN Fish stocks Agreement (UNFA), provides a framework for the global conservation of fish stocks, and important aspects of Common Fisheries Policy reform such as overall limits on the capacity of EU fishing fleets, and a ban on EU subsidies for new vessels after 2004. UNFA also provides a framework for the conservation and management of straddling stocks and highly migratory fish in high seas areas. It obliges signatories to use the 'precautionary approach' and the 'ecosystem approach' when managing fisheries on the high seas. It obliges States to minimize pollution, waste and discards of fish. The most innovative aspect of the Agreement is the right of States to monitor and inspect vessels of other state parties, to verify compliance with internationally agreed fishing rules of regional fisheries organisations such as ICES and the International Commission for the Conservation of Atlantic Tunas (ICCAT).
EC Wild-birds Directive	In 1979, the European Community adopted Council Directive 79/409/EEC on the conservation of wild birds (the 'Birds Directive'), in response to the 1979 Bern Convention. The Directive provides a framework for the conservation and management of, wild birds in Europe. It sets broad objectives for a wide range of activities, although the precise legal mechanisms for their achievement are at the discretion of each Member State.
EC Habitats Directive	The central aim of the Directive is to conserve biodiversity across the area of the European Union through a coherent network of Special Areas of Conservation (SACs). Seven marine habitat types are listed in the Directive and nine of the species listed are marine or spend part of their life in the sea and have breeding populations in the United Kingdom. SACs together with 'Special Protection Areas' (SPAs) identified under the Birds Directive will create a network of sites described as 'Natura 2000'.
EC Water Framework Directive	This Directive (implemented in December 2000) requires all inland and coastal waters to reach "good status" by 2015. It will do this by establishing plans for whole a river basins, within which demanding environmental objectives will be set, including ecological targets for surface waters.
EC Bathing Water Directive	The objective of the 1976 Bathing Water Directive (which entered force in the early 1990s) is to protect public health and the environment from faecal pollution at bathing waters. The Directive requires Member States to identify popular bathing areas and monitor the bathing waters for indicators of microbiological pollution throughout the bathing season which runs from May to September.
EC Marine Equipment Directive	This directive was ratified on 30th June 1998 and came into force on 1st January 1999. The Marine Equipment Directive (MED) covers certain equipment carried and used on ships registered under the flags of European Union member states. It is aimed at ensuring that equipment which has to meet the requirements of international conventions (eg, SOLAS, MARPOL, etc.) agreed at IMO (the International Maritime Organisation), additionally meets a common standard of safety and performance.
SOLAS - International Convention for the Safety of Life at Sea, 1974	The SOLAS Convention in its successive forms is generally regarded as the most important of all international treaties concerning the safety of merchant ships. The first version was adopted in 1914, in response to the Titanic disaster. The main objective of the SOLAS Convention is to specify minimum safety standards for the construction, equipment maintenance and operation of ships.
COLREGs - Convention on the International Regulations for Preventing Collisions at Sea, 1972	The 1972 Convention was designed to update and replace the Collision Regulations of 1960 which were adopted at the same time as the 1960 SOLAS Convention. One of the most important innovations in the 1972 COLREGs was the recognition given to traffic separation schemes - Rule 10 gives guidance in determining safe speed, the risk of collision and the conduct of vessels operating in or near traffic separation schemes. The first such traffic separation scheme was established in the Dover Strait in 1967. It was operated on a voluntary basis at first but in 1971 the IMO adopted a resolution stating that that observance of all traffic separation schemes be made mandatory.

Instrument	Description
SAR - International Convention on Maritime Search and Rescue, 1979	The 1979 Convention, adopted at a Conference in Hamburg, was aimed at developing an international SAR plan, so that, no matter where an accident occurs, the rescue of persons in distress at sea will be co-ordinated by a SAR organization and, when necessary, by co-operation between neighbouring SAR organizations. Although the obligation of ships to go to the assistance of vessels in distress was enshrined both in tradition and in international treaties (such as the International Convention for the Safety of Life at Sea (SOLAS)), there was, until the adoption of the SAR Convention, no international system covering search and rescue operations. In some areas there was a well-established organization able to provide assistance promptly and efficiently, in others there was nothing at all.
MARPOL - International Convention for the Prevention of Pollution from Ships	The International Convention for the Prevention of Pollution from Ships (MARPOL) was adopted on 2 November 1973 at IMO and covered pollution by oil, chemicals, harmful substances, sewage and garbage. Measures relating to tanker design and operation were also incorporated into a Protocol of 1978 in response to a spate of tanker accidents in 1976-1977. As the 1973 MARPOL Convention had not yet entered into force, the 1978 MARPOL Protocol absorbed the parent Convention. The Convention includes regulations aimed at preventing and minimizing pollution from ships - both accidental pollution and that from routine operations.
International Convention on the Control of Harmful Anti-fouling Systems on Ships	The International Convention on the control of harmful anti-fouling systems on ships was adopted on 5 October 2001 following a conference held at IMO Headquarters in London. Under the terms of the new Convention, Parties are required to prohibit and/or restrict the use of harmful anti-fouling systems on ships flying their flag, as well as ships not entitled to fly their flag but which operate under their authority and all ships that enter a port, shipyard or offshore terminal of a Party.
CSC - International Convention for Safe Containers, 1972	The 1972 Convention for Safe Containers has two goals. One is to maintain a high level of safety of human life in the transport and handling of containers by providing generally acceptable test procedures and related strength requirements. The other is to facilitate the international transport of containers by providing uniform international safety regulations, equally applicable to all modes of surface transport. The requirements of the Convention apply to the great majority of freight containers used internationally, except those designed specially for carriage by air.
INTERVENTION - International Convention Relating to Intervention on the High Seas in Cases of Oil Pollution Casualties, 1969	The Torrey Canyon disaster of 1967 revealed certain doubts with regard to the powers of States, under public international law, in respect of spillage incidents on the high seas. In particular, questions were raised as to the extent to which a coastal State could take measures to protect its territory from pollution where a casualty threatened that State with oil pollution. The Convention which resulted affirms the right of a coastal State to take such measures on the high seas as may be necessary to prevent, mitigate or eliminate danger to its coastline from pollution by oil or the threat thereof, following upon a maritime accident. The Convention applies to all seagoing vessels except warships or other vessels owned or operated by a State and used on Government non-commercial service
Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972	This Convention (which came into force on 30 August 1975) has a global character, and contributes to the international control and prevention of marine pollution. It prohibits the dumping of certain hazardous materials, requires a prior special permit for the dumping of a number of other identified materials and a prior general permit for other wastes or matter. "Dumping" has been defined as the deliberate disposal at sea of wastes or other matter from vessels, aircraft, platforms or other man-made structures, as well as the deliberate disposal of these vessels or platforms themselves. Wastes derived from the exploration and exploitation of seabed mineral resources are, however, excluded from the definition.
ASCOBANS - Agreement on the Conservation of Small Cetaceans of the Baltic and North Sea	The Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS) was concluded in 1991 under the auspices of the Convention on Migratory Species (UNEP/CMS or Bonn Convention) and entered into force in 1994.

Instrument	Description
KYOTO PROTOCOL - UN Framework Convention on Climate Change	Under the Kyoto Protocol, industrialised countries and those in transition to a market economy (the so-called "Annex I countries") are committed to limit or reduce their emissions of greenhouse gases. Targets define the amount of greenhouse gases that the countries are allowed to emit in the 'commitment period' of 2008 to 2012, relative to the amount emitted in 1990. These targets represent either a cut in emissions or a lower rate of increase in emissions. To achieve its emission targets, the Annex I country is expected to make changes to reduce domestic greenhouse gas emissions. The UK target is a 12.5% reduction in greenhouse gas emissions from 1990 levels, by 2008 to 2012.
IWC - International Convention for the Regulation of Whaling	The International Whaling Commission (IWC) was set up under the International Convention for the Regulation of Whaling which was signed in Washington DC on 2 December 1946. The original purpose of the Convention was to provide for the proper conservation of whale stocks and thus make possible the orderly development of the whaling industry.
International Convention for the Control and Management of Ships' Ballast Water and Sediments	This Convention (which was adopted on 13 February 2004) will enter into force 12 months after ratification by 30 States, representing 35 per cent of world merchant shipping tonnage.This Convention includes technical standards and requirements for the control and management of ships' ballast water and sediments. Under Article 2, Parties will act to prevent, minimize and ultimately eliminate the transfer of harmful aquatic organisms and pathogens.

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