Part IV

Climate Change Impacts on Socio-economic Sectors

Socio-economic Impacts—Fisheries

12

John K. Pinnegar, Georg H. Engelhard, Miranda C. Jones,
William W.L. Cheung, Myron A. Peck, Adriaan D. Rijnsdorp
and Keith M. Brander

Abstract

Fishers and scientists have known for over 100 years that the status of fish stocks can be greatly influenced by prevailing climatic conditions. Based on historical sea surface temperature data, the North Sea has been identified as one of 20 'hot spots' of climate change globally and projections for the next 100 years suggest that the region will continue to warm. The consequences of this rapid temperature rise are already being seen in shifts in species distribution and variability in stock recruitment. This chapter reviews current evidence for climate change effects on fisheries in the North Sea—one of the most important fishing grounds in the world—as well as available projections for North Sea fisheries in the future. Discussion focuses on biological, operational and wider market concerns, as well as on possible economic consequences. It is clear that fish communities and the fisheries that target them will be very different in 50 or 100 years' time and that management and governance will need to adapt accordingly.

12.1 Introduction

The North Sea remains one of the world's most important fishing grounds. In 2013, around 3.5 million tonnes of fish and shellfish were taken from the region (2.6 million tonnes by EU countries), approximately 55 % of the total for EU countries as a whole. European fisheries are very diverse, ranging from highly industrialised distant-water fisheries to small-scale artisanal fisheries that typically operate near the coast. EU citizens consume large quantities of seafood each year (currently around 23.3 kg on average per person), and rely on fisheries for health and well-being, as well as for supporting more than 120,000 jobs directly and a further 115,000 in fish processing (STECF 2013). There has been

J.K. Pinnegar (✉) · G.H. Engelhard
Centre for Environment, Fisheries and Aquaculture Science (Cefas), Lowestoft, UK
e-mail: john.pinnegar@cefas.co.uk

G.H. Engelhard
e-mail: georg.engelhard@cefas.co.uk

J.K. Pinnegar · G.H. Engelhard
School of Environmental Sciences, University of East Anglia (UEA), Norwich, UK

M.C. Jones
NF-UBC Nereus Program, Fisheries Centre, University of British Columbia, Vancouver, Canada
e-mail: Miranda.c.jones@gmail.com

W.W.L. Cheung
Institute for the Ocean and Fisheries, University of British Columbia, Vancouver, Canada
e-mail: w.cheung@oceans.ubc.ca

M.A. Peck
Institute of Hydrobiology and Fisheries Science, CEN, University of Hamburg, Hamburg, Germany
e-mail: myron.peck@uni-hamburg.de

A.D. Rijnsdorp
Institute for Marine Research and Ecosystem Studies (IMARES), Wageningen University, IJmuiden, The Netherlands
e-mail: adriaan.rijnsdorp@wur.nl

K.M. Brander
National Institute of Aquatic Resources, Technical University of Denmark, Charlottenlund, Denmark
e-mail: kbr@aqua.dtu.dk

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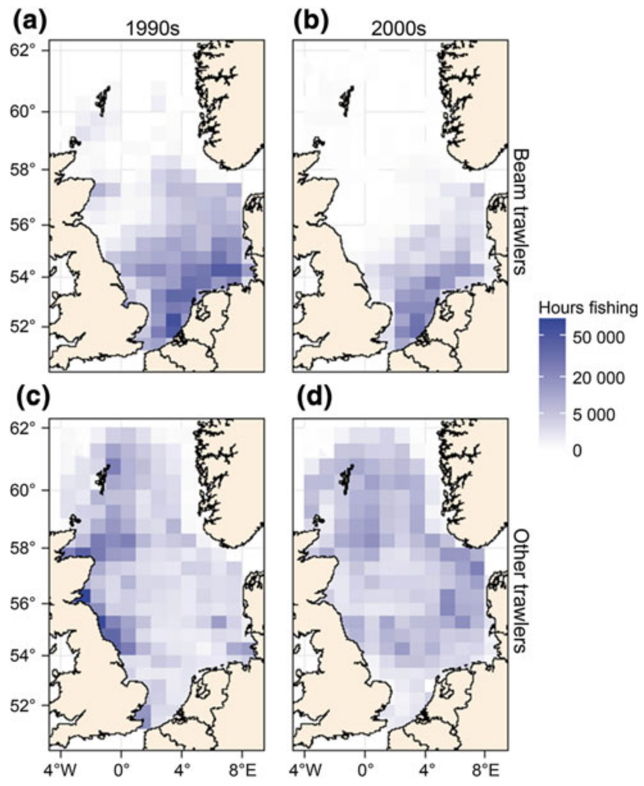

Fig. 12.1 Spatial distribution of international fishing effort in the North Sea by beam trawlers (*upper*) and demersal otter trawlers (*lower*), averaged by year over the periods 1990–1995 (*left*) and 2003–2012 (*right*). *Light to dark shading* indicates the number of hours fishing in each ICES rectangle (redrawn from Engelhard et al. 2015)

much debate in the literature with regard to the extent to which fisheries might be sensitive to climate change and a number of national-scale assessments have been conducted, for example for the United Kingdom (Cheung et al. 2012; Pinnegar et al. 2013). To date, however, no North Sea-wide assessment of climate impacts on the fisheries sector has been carried out and there is limited information for many countries despite the wide-scale and well-documented implications.

12.2 Overview of North Sea Fisheries

Commercial fishing activity in the North Sea is mostly undertaken by fishers from the UK (England and Scotland), Denmark, the Netherlands, France, Germany, Belgium and Norway (Fig. 12.1). Total fish removals are dominated by pelagic species (those that swim in the water column, above the seabed) such as herring *Clupea harengus* (986,471 tonnes), sprat *Sprattus sprattus* (143,581 tonnes), and mackerel *Scomber scombrus* (644,762 tonnes), although demersal fishes are also important. Demersal fish are those that live close to the sea floor and are typically caught by 'otter trawlers'. The most important demersal species include Atlantic cod *Gadus morhua*, haddock *Melanogrammus aeglefinus* and whiting *Merlangius merlangus*, although a wide variety of other species such as saithe *Pollachius virens* and monkfish *Lophius piscatorius* are also caught. Total demersal fishing effort has decreased dramatically over the past 10 years. The estimated overall reduction in effort (kW days at sea) by 2013 amounted to 43 % compared to the average for 2004–2006. Most landings in the demersal otter-trawl fishing sector are taken from the northern North Sea (Fig. 12.1) and the fishery is overwhelmingly dominated by Danish, UK, Norwegian and German vessels.

Major *Nephrops norvegicus* (langoustine) grounds in the North Sea include the Flåden Ground, the Farne Deeps (NE England), Botany Gut (central North Sea) and Horns Reef (west of Denmark). Landings of *Nephrops* have increased in recent years, from 10,613 tonnes in 1990 to a maximum of 90,996 tonnes in 2010, and this reflects restrictions on gear types with larger mesh-size, targeting demersal white-fish.

The North Sea beam trawl fishery mainly targets flatfish (sole *Solea solea* and plaice *Pleuronectes platessa*), but is also known to catch cod, whiting and dab *Limanda limanda*. The average distribution of fishing effort in this sector is illustrated in Fig. 12.1 which suggests that beam trawlers typically operate in the southern North Sea. The Dutch beam trawl fleet is the major player in the mixed flatfish fishery, although Belgian and UK-flagged vessels also operate in this fishery. Total fishing effort by the North Sea beam trawl fleet has reduced by 65 % over the last 15 years and there has also been a shift towards electronic pulse trawls more recently (ICES 2014a).

Fisheries for herring use midwater trawl gears (50–55 mm mesh) and target discrete shoals of fish that are located using echosounding equipment. There is also a purse-seine fishery for herring in the eastern North Sea (Dickey-Collas et al. 2013). The stock is fished throughout the year, with peak catches between October and March. Landings of herring in the autumn are predominantly taken from Orkney and Shetland, off Peterhead, northwest of the Dogger Bank and from coastal waters off eastern England. Landings in the spring are concentrated in the south-western North Sea.

The North Sea is subject to major industrial fisheries targeting sandeel *Ammodytes marinus*, Norway pout *Trisopterus esmarkii*, blue whiting *Micromesistius poutassou*, sprat, and juvenile herring. These fish are mainly caught on offshore sand-banks using fine-meshed (8–32 mm) midwater trawls (Dickey-Collas et al. 2013). The sandeel fishery was the largest single-species fishery in Europe with peak landings in 1997 exceeding 1 million tonnes. The fleet has since declined in size. Total sandeel landings in 2013 were 529,141 tonnes (15 % of total landings), Norway pout

Table 12.1 Factors related to the North Sea fishing industry that could be affected by climate change

Biology—Fish and shellfish	Fishery operations	Fish markets and commodity chains
• Year-class strength (recruitment) • Migration patterns • Distribution/habitat suitability • Growth rate • 'Scope for growth' and energetic balance • Phenology (timing of spawning etc.) • Activity levels • Prey availability (match/mismatch) • Exposure to predators • Pathogen and pest incidence • Calcification and internal carbonate balance (shellfish) • Damage/disturbance of key nursery/spawning habitats	• Catchability (performance of the fishing gear) • Vessel safety and stability (e.g. storminess) • Fuel usage (to follow the shifting fish) • Restrictive TACs and quotas (EU relative stability arrangements) • Effectiveness of spatial closures in protecting spawning/nursery areas • New resource species, requiring new fishing gears • Storm damage to ports, harbours and onshore facilities • Damage to gear and vessels (e.g. storm damage to fixed gears) • Preservation of catch on-board vessels • Fouling of vessel hulls • Unwanted 'choke species' that constrain fishing operations	• New markets for novel species • Demand for fish (nationally and internationally) • Storm damage to processing facilities on land • Storm/flooding disruption to transport routes to market • Availability of alternative resources (nationally and internationally) including imports • Changes in processing requirements • Stability of incomes for fishermen and processors • Quality/robustness of product (e.g. shellfish)

landings were 155,752 tonnes (4 %) and blue whiting 17,645 tonnes (0.5 %). All of these short-lived industrial species are thought to be heavily influenced by climatic variability (e.g. Arnott and Ruxton 2002; Hátún et al. 2009).

12.3 Climate Change and Fisheries

There can be many different manifestations of climate change. The most noticeable effect is an increase in average seawater temperature over time, but the seasonality of warming and cooling is also expected to change. The North Sea has witnessed significant warming over the past century at a rate of around 0.3 °C per decade (Mackenzie and Schiedek 2007). The region has been identified as one of 20 'hot spots' of climate change globally, i.e. discrete marine areas where ocean warming has been fastest, as quantified from historical sea surface temperature data (Hobday and Pecl 2014). Projections suggest that the region will continue to experience warming, by around 2–3 °C over the next 100 years (Lowe et al. 2009). Climate change can also encompass other environmental influences or parameters such as changes in precipitation and run-off (and hence salinity and stratification), and storm frequency and intensity (Woolf and Wolf 2013) that may in-turn greatly impact fishing operations, and changes in chemical conditions such as dissolved oxygen concentrations, carbonate chemistry and seawater pH (Blackford and Gilbert 2007).

In this overview of climate change impacts on North Sea fisheries, all of these climatic influences are considered. Climate change will have consequences not only for the animals supporting fisheries (biological responses—see Table 12.1) but also direct and indirect implications for fishery operations—such as storm damage to gear, vessels and infrastructure, changes in catchability of species and maladaptation of quota allocation, etc. (Table 12.1). Furthermore, climate change elsewhere in the world can have consequences for the fishing industry closer to home, via globalised fish markets and commodity chains.

The following sections outline available evidence for climate change effects on fisheries in the North Sea as well as available projections for North Sea fisheries in the future. This assessment is based on Table 12.1, with a discussion of biological, operational and wider market concerns, including analyses of possible economic implications.

12.3.1 Biological Responses

12.3.1.1 Changes in Fish and Fishery Distribution

Long-term changes in seawater temperature and/or other ocean variables often coincide with observed changes in fish distribution. In an analysis of 50 fish species common in waters of the Northeast Atlantic, 70 % had responded to warming by changing distribution and abundance (Simpson et al. 2011). Specifically, warm-water species with smaller maximum body size had increased in abundance throughout northwest Europe while cold-water, large-bodied species had decreased in abundance.

Distribution and abundance are the traits that are the most readily observed responses. However, many processes interact when considering fisheries and climate change, and these are a manifestation of both biological and human processes. None of these factors act in isolation and many are synergistic. The responses are rarely linear. In fish, it is clear that climate affects physiology and behaviour. These processes interact to influence migration, productivity (growth of populations minus decline in populations), susceptibility to disease and interactions with other organisms. Changes in distribution and abundance are the aggregate responses to these changed processes.

Archaeological evidence can sometimes yield useful insights into historical changes in the distribution and productivity of fish and the response of fisheries. The bones of warm-water species such as red mullet *Mullus surmuletus* have been recovered from archaeological excavations throughout northern Europe. This species has only recently returned to the North Sea in reasonable numbers (Beare et al. 2005), but was apparently widespread during the Roman period (AD 64–400) (Barrett et al. 2004). Enghoff et al. (2007) listed a number of occurrences of warm-water species (e.g. red mullet, seabass *Dicentrarchus labrax*, anchovy *Engraulis encrasicolus*, and seabream *Spondyliosoma cantharus*) among bone assemblages, surrounding the North Sea, from the 1st to the 16th century AD. Alheit and Hagen (1997) identified nine periods, each lasting several decades, during which large quantities of herring were caught close to the shore in the North Sea. Each of these coincided with severe winters in western Europe with extremely cold air and water temperatures and a reduction in westerly winds; physical factors associated with negative anomalies of the North Atlantic Oscillation (NAO) index.

Highly-cited studies using time-series from fishery-independent surveys (Beare et al. 2004a; Perry et al. 2005; Dulvy et al. 2008) have revealed that centres of fish distribution in the North Sea shifted by distances ranging from 48 to 403 km during the period 1977–2001, and that the North Sea demersal fish assemblage has deepened by about 3.6 m per decade over the past 30 years (Dulvy et al. 2008). Species richness increased from 1985 to 2006 which Hiddink and Ter Hofstede (2008) suggested was related to climate change. Eight times as many fish species displayed increased distribution ranges in the North Sea (mainly small-sized species of southerly origin) compared to those whose range decreased (primarily large and northerly species). For a more localised region of the Dutch coast, van Hal et al. (2014) demonstrated latitudinal range shifts and changes in abundance of two non-commercial North Sea fish species, solenette *Buglossidium luteum* and scaldfish *Arnoglossus laterna* that were strongly related to the warming of the coastal waters. For pelagic fish species, a recent paper by Montero-Serra et al. (2015) investigated the patterns of species-level change using records from 57,870 fisheries-independent survey trawls from across the European continental shelf between 1965 and 2012. These authors noted a strong ‘subtropicalisation’ of the North Sea as well as the Baltic Sea. In both areas, there has been a shift from cold-water assemblages typically characterised by Atlantic herring and sprat from the 1960s to 1980s, to warmer-water assemblages typified by mackerel, horse mackerel *Trachurus trachurus*, sardine *Sardina pilchardus* and anchovy from the 1990s onwards. The primary measure correlated to changes in all species was sea surface temperature (Montero-Serra et al. 2015).

Analyses of Scottish and English commercial catch data in the North Sea spanning the period 1913–2007 have revealed that the locations where peak catches of target species such as cod, haddock, plaice and sole were obtained have all shifted over the past 100 years, albeit not in a consistent way (Engelhard et al. 2011, 2014b). For example, catches of cod seem to have shifted steadily north-eastward and towards deeper water in the North Sea (Engelhard et al. 2014b) and this reflects both climatic influences and intensive fishing. Plaice distribution has shifted north-westwards (Fig. 12.2) towards the central North Sea, again reflecting climatic influences, in particular sea surface temperature as also confirmed by van Keeken et al. (2007). Somewhat confusingly, sole seems to have retreated away from the Dutch coast, southwards towards the eastern Channel although this too is thought to have been a response to warming. Sole is a warm-water species that traditionally moved offshore in winter to avoid excessively low temperatures in the shallows. Cold winters are known to have coincided with mass die-offs of sole (e.g. Woodhead 1964), but in recent years shallower waters surrounding the North Sea have remained habitable all year round (winter conditions are less severe), and hence the apparent southward and shallowing shift (Engelhard et al. 2011). Haddock catches have moved very little in terms of their centre of distribution, but their southern boundary has shifted northwards by approximately 130 km over the past 80–90 years (Skinner 2009).

Theoretically, in the northern hemisphere, warming results in a distributional shift northward, and cooling draws species southward (Burrows et al. 2007). Heath (2007) looked at patterns in international fisheries landings for the whole Northeast Atlantic region. Densities of landings of each species were summed by decade and expressed as a proportion of the total. Both northerly and southerly shifts were observed between decades for individual species, however more species shifted south than north between the 1970s and 1980s (a relatively cool period) and vice versa between the 1980s and 1990s (a relatively warm period). This seems to parallel observed inter-decadal changes in sea and air temperatures.

Distribution shifts will have ‘knock on’ implications for commercial fisheries catches because changes in migration or spawning location affect the ‘availability’ of resources to fishing fleets. Populations may move away from or towards the area where particular fishing fleets operate and/or where spatial restrictions on fishing are in place. Furthermore, species distributions may migrate across political boundaries where quotas belong to different nations. A notable example has arisen recently as a result of quota allocations between

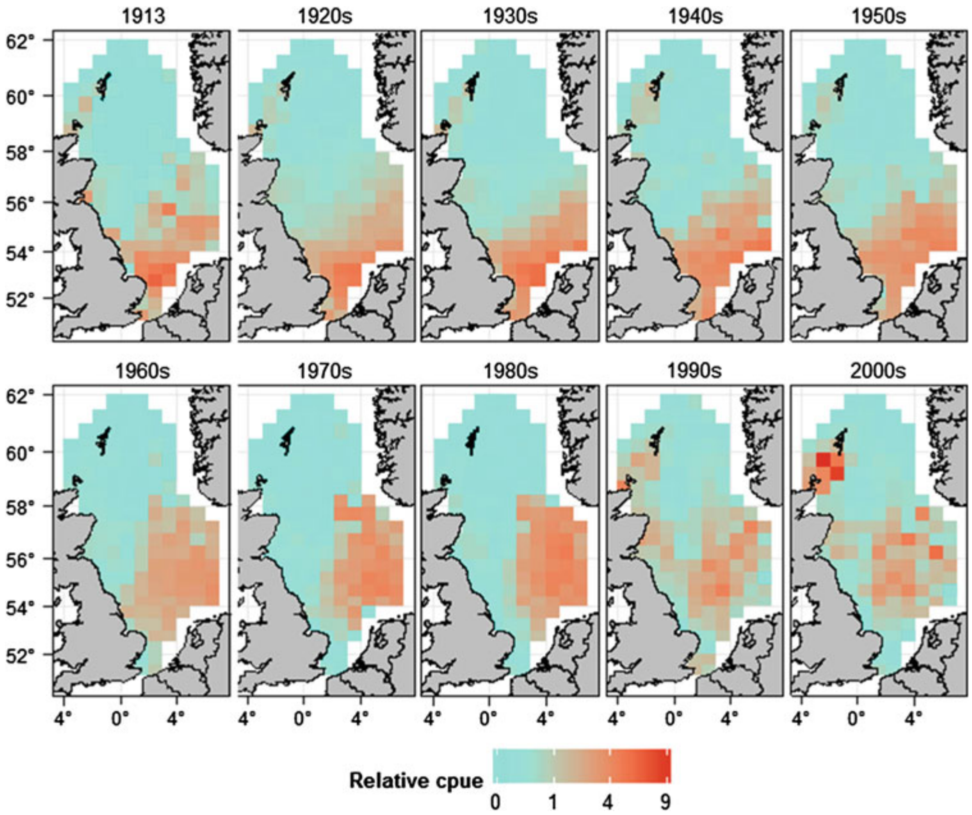

Fig. 12.2 Decadal change in North Sea plaice distribution, 1920s to 2000s, based on fisheries catch-per-unit-effort (CPUE). Shading is proportional to plaice CPUE, normalised by decade and corrected for the average spawning stock biomass (SSB). Adapted from Engelhard et al. (2011)

Norway and the EU, and between Iceland, the Faroe Islands and the EU. In October 2009, North Sea mackerel appeared to have moved away from the Norwegian Sector (possibly as a result of excessively cold conditions near the Norwegian coast), resulting in disagreements over permissible catches by Norwegian boats in EU waters. Norwegian vessels were forcibly evicted by UK fishery patrol vessels, once they had caught their allotted quota (see *Fishing News*, 9 October 2009). At the same time Iceland and the Faroe Islands unilaterally claimed quota for mackerel (146,000 and 150,000 tonnes respectively in 2011 or 46 % of the total allowable catch, TAC), since the species had suddenly attained high abundance in their territorial waters. Whether the apparent changes in mackerel distribution westwards across the northern North Sea were a result of long-term climate change or not remains unclear. Hughes et al. (2014) suggested that sea surface temperature had a significant positive association with the observed northward and westward movement of mackerel, equivalent to a displacement of 37.7 km per °C (based on spring mean sea surface temperature for the region). By contrast, historical appearances of mackerel in the western North Sea and off the coast of Iceland (Beare et al. 2004a) coincided with warming periods linked to the Atlantic Multidecadal Oscillation (AMO) and might not be symptomatic of long-term climate change. Whatever the case—with climate change in the future, more territorial disagreements of this type could be anticipated (Hannesson 2007) and fisheries management will need to adapt accordingly (Link et al. 2011).

A similar phenomenon is now occurring in the English Channel and southern North Sea region with regard to access to European anchovy. Anchovy stocks are currently depleted in the Bay of Biscay where Spanish and French vessels operate, but are increasing further north along southern coasts of the UK and especially along Dutch coasts (Beare et al. 2004b) where they are starting to be targeted by pelagic fishing vessels. Detailed political negotiations are underway to determine whether Spanish and French vessels should be allowed exclusive access in areas where previously they had no quota, and indeed whether the more northerly distributed anchovy represent the same or a genetically different sub-stock to those in the Bay of Biscay. In 2012 a study was published (Petitgas et al. 2012) drawing on four different strands of evidence: genetic studies, larval transport modelling, survey time series and physical oceanographic models. The study concluded that anchovy in the southern North Sea are most likely to be a distinct remnant sub-stock that was previously present (see Aurich 1953), but is now benefiting from greatly improved climatic conditions rather than an invasion of animals from further south. According to

Alheit et al. (2012), the anchovy population from the western Channel (not from the Bay of Biscay) invaded the North Sea and Baltic Sea during positive periods of the AMO. Given this evidence and according to the rules of 'relative stability' within the EU Common Fisheries Policy, Spanish and French vessels would not necessarily be granted exclusive access to this expanding resource, unlike the present situation in the Bay of Biscay.

Under the EU Common Fisheries Policy, a number of closed areas have been implemented as 'technical measures' to conserve particular species and to protect nursery or spawning grounds. In the North Sea, these include closure areas to protect plaice, herring, Norway pout and sandeel. If species shift their distribution in response to climate change then it is possible that such measures will become less effective in the future (van Keeken et al. 2007). Juvenile plaice are typically concentrated in shallow inshore waters of the southeast North Sea and move gradually offshore as they grow. In order to reduce discarding of undersized plaice, thereby decreasing mortality and enhancing recruitment to the fishery, the EU 'Plaice Box' was introduced in 1989, excluding access to beam and otter trawlers larger than 300 hp. However recent surveys in the Wadden Sea have shown that 1-group plaice are now completely absent from the area where they were once very abundant. Consequently, the 'Plaice Box' is now less effective as a management measure for plaice than was the case 10 or 15 years ago. The boundaries of, and expected benefits from marine protected areas (MPAs) may need to be 'adaptive' in the future in the context of climate change. Cheung et al. (2012) looked at other fishery closure areas in the North Sea and noted that they will most likely experience between 2 and 3 °C increases in temperature over the next 80–100 years and consequently it is unlikely that the species they are designed to protect now will occur there in the same numbers in the future given defined temperature tolerances or preferences of specific fishes (Freitas et al. 2007; Pörtner and Peck 2010).

Fishers have witnessed and responded to a number of new opportunities in recent years, as warm-water species have moved into the North Sea and/or their exploitation has become commercially viable for the first time. Notable examples include new or expanding fisheries for seabass, red mullet, John dory *Zeus faber*, anchovy and squid *Loligo forbesi*.

Biomass estimates for seabass in the eastern Channel quadrupled from around 500 tonnes in 1985, to in excess of 2100 tonnes in 2004/2005, with populations also increasing rapidly in the southern North Sea (Pawson et al. 2007). This was attributed to an increase in seawater temperature, especially in the winter and has resulted in a dramatic expansion of seabass fisheries both within the commercial sector and the recreational fishing sector. Seabass are caught by angling on the east coast of Scotland and in Norway, but the northernmost limit of the commercial seabass fishery is around Yorkshire (54°N) in the North Sea. In 2013, 2243 tonnes of seabass were landed by countries surrounding the North Sea and eastern English Channel (Fig. 12.3), compared with only 210 tonnes in 1990. However recent anecdotal evidence (ICES 2012) seems to suggest that the increase in catches may have slowed slightly, as a result of successive cold winters in 2009/10, 2010/11, and 2011/12 likely leading to poor recruitment (Fig. 12.3).

Red mullet is a non-quota species of moderate, but increasing, importance to North Sea fisheries. From 1990 onwards, international landings increased strongly. France is the main country targeting this species although UK and Dutch commercial catches have also increased. Total international landings rose from only 537 tonnes in 1990 to a peak in landings of 4555 tonnes in 2007. Beare et al. (2005) demonstrated that red mullet is one of many species that have become significantly more prevalent in North Sea bottom trawl surveys in recent years, rising from near-absence during surveys between 1925 and 1990, to about 0.1–4 fish per hour of trawling between 1994 and 2004. Red mullet is also among the fish species that have entered the North Sea from both the south and north-west, through the Channel and along the Scottish coast, respectively (Beare et al. 2005).

Although numbers are highly uncertain, there are strong indications that squid are generally becoming more abundant in the North Sea, possibly in response to a change in climate (Hastie et al. 2009a). Cephalopod populations are suggested to be highly responsive to climate change (Sims et al. 2001; Hastie et al. 2009a) and growth in squid availability in the North Sea is generating considerable interest among fishers off the Scottish coast (Hastie et al. 2009b). Off north-east Scotland, where most of the squid are found, more boats are now trawling for squid than for the region's traditional target species, such as haddock and cod (Hastie et al. 2009b). New squid fisheries are also emerging in the Netherlands using bright lamps and hooked lines (*Fish News* September 2007). Total international landings have risen from 2612 tonnes in 1990 (375 tonnes in 1980) to 3417 tonnes in 2013 (see Fig. 12.3). In the English Channel, loliginid squid catches seem to be related to mean sea surface temperature (Robin and Denis 1999). Temperature appears to influence recruitment strength and overall distribution (Hastie et al. 2009a).

The North Sea bottom trawl fleet typically catches many different species in the same haul, thus making it virtually impossible to devise effective management measures that are well suited to the protection or rebuilding of any particular stock without affecting others. In October 2014, the EU introduced reforms to the Common Fisheries Policy that included a ban on discarding and thus a requirement to land all fish caught. To allow fishers to adapt to the change, the landing obligation will be introduced gradually, between

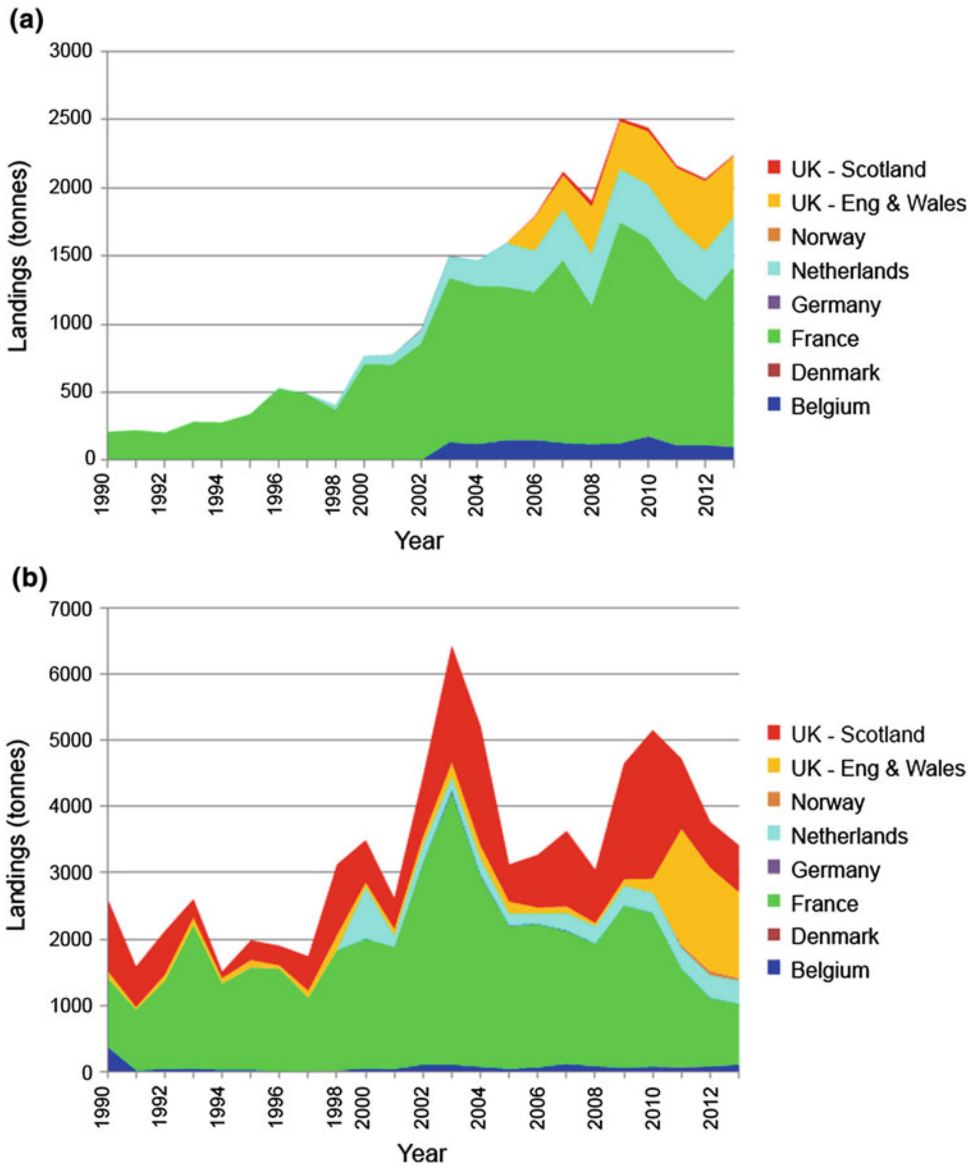

Fig. 12.3 International fishery landings of seabass (*upper*) and squid (*lower*) in the North Sea and eastern English Channel (data for 1999 were excluded as no French data were submitted to ICES in that year)

2015 and 2019 for all commercial fisheries (species under TACs, or under minimum sizes), however this new measure necessitates that once the least plentiful quota species in a mixed fishery—the 'choke species'—is exhausted, the whole fishery must cease operation. Baudron and Fernandez (2015) have argued that many commercial fish stocks are beginning to recover under more sustainable exploitation regimes and, in some cases, as a result of favourable climatic conditions. For example, northern European hake *Merluccius merluccius* a warm-water species, witnessed a dramatic increase in biomass between 2004 and 2011 and has recolonised the northern North Sea where hake had largely been absent for over 50 years. These changes have implications for the management of other stocks. Notably, if discards are banned as part of management revisions, the relatively low quota for hake in the North Sea will be a limiting factor (the so-called 'choke' species) which may result in a premature closure of the entire demersal mixed fishery (Baudron and Fernandez 2015).

Modelling strategies for predicting the potential impacts of climate change on the natural distribution of species and consequently the response of fisheries have often focused on the characterisation of a species' 'bioclimate envelope' (Pearson and Dawson 2003). In other words, by looking at the current range of temperatures inhabited by a species, it is possible to predict future distribution, on the basis that the physical environment in an area is likely to change in the future. Model simulations suggest that distributions of exploited species will continue to shift in the next five decades both globally and in the Northeast Atlantic specifically (Cheung et al. 2009, 2010, 2011; Lindegren et al. 2010).

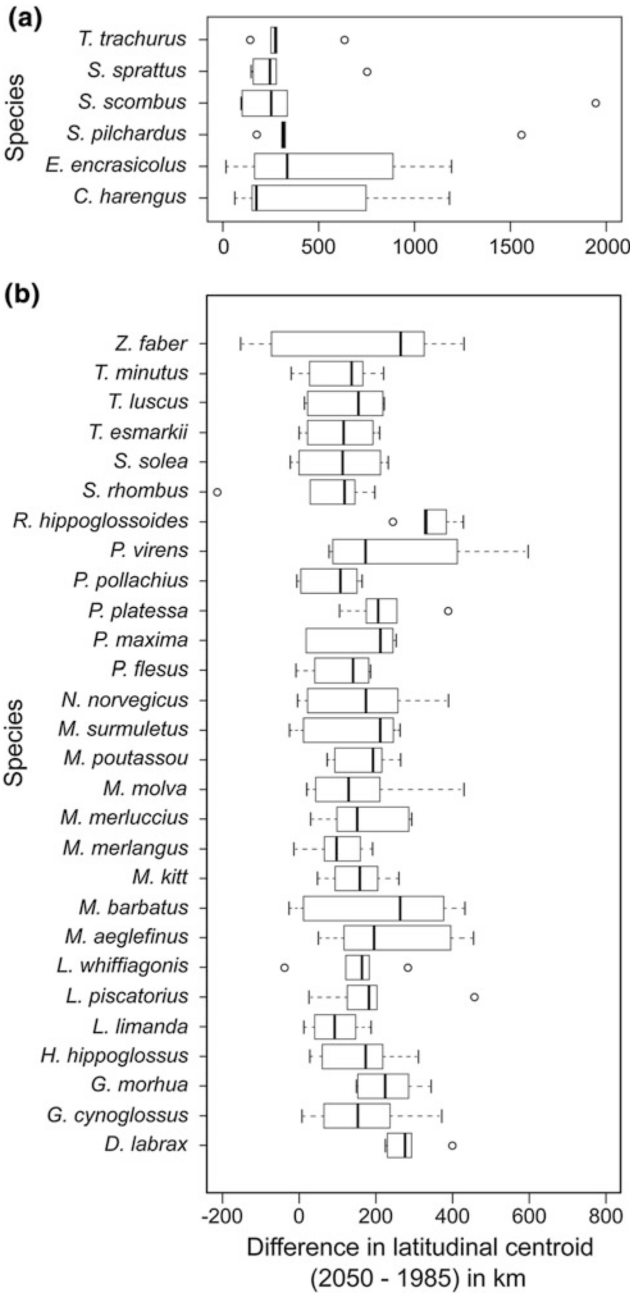

Fig. 12.4 Projected change in latitudinal centroids of habitat suitability surfaces from 1985 to 2050 across species distribution models and climatic datasets for pelagic species (*upper*) and demersal species (*lower*) (Defra 2013). *Thick vertical lines* represent median values, the left and right ends of each *box* show the upper and lower quartiles of the data and the whiskers the most extreme data points no greater than 1.5 times the inter-quartile range. Outliers that were more extreme than whiskers are represented as *circles*

It is important to test the reliability and robustness of tools projecting climate-driven shifts in fisheries resources. Jones et al. (2012) published a localised analysis for the North Sea and Northeast Atlantic whereby three different bioclimate envelope models (AquaMaps, Maxent and DBEM) were applied to the same present distribution datasets and the same environmental input parameters. As indicated by the test statistics, each method produced a plausible present distribution and estimate of habitats suitable for each species (14 commercial fish). When used to make projections into the future, the ensemble of models suggested northward shifts at an average rate of 27 km per decade (the current rate is around 20 km per decade for common fish in the North Sea, Dulvy et al. 2008). This modelling approach was extended to include several additional, commercial species (squid *Loligo vulgaris*, seabass, sardine, sprat, John dory, anchovy, plaice, herring, mackerel, halibut *Hippoglossus hippoglossus*, red mullet etc.) as part of a Defra study (Defra 2013). The species predicted to move the furthest were anchovy, sardine, Greenland halibut, John dory and seabass (i.e. *E. encrasicolus*, *S. pilchardus*, *R. hippoglossoides*, *Z. faber* and *D. labrax* respectively, see Fig. 12.4).

By contrast Rutterford et al. (2015) used the same fish survey datasets for the North Sea, together with generalised additive models (GAMs), to predict trends in the future distribution of species, but came to the conclusion that fish species over the next 50 years will be strongly constrained by the availability of suitable habitat in the North Sea, especially in terms of preferred depths. The authors found no consistent pattern among species in predicted changes in distribution. On the basis of the GAM results the authors suggested that they did not expect or predict substantial further deepening (as previously observed by Dulvy et al. 2008), and that the capacity of fish to remain in cooler water by changing their depth distribution had been largely exhausted by the 1980s, that fish with preferences for cooler water are being increasingly exposed to higher temperatures, with expected physiological, life history and negative population consequences.

Beaugrand et al. (2011) described a model to map the future spatial distribution of Atlantic cod. The model, which they named the non-parametric probabilistic ecological niche model (NPPEN), suggested that cod may eventually disappear as a commercial species from some regions including the North Sea where a sustained decline has already been documented; in contrast, the abundance of cod is likely to increase in the Barents Sea. Lenoir et al. (2011) applied the same NPPEN model with multiple explanatory variables (sea surface temperature, salinity, and bathymetry) to predict the distribution of eight fish species up to the 2090s for the Northeast Atlantic. This study anticipated that by the 2090s horse mackerel and anchovy would show an increased probability of occurrence in northern waters compared with the 1960s, that pollack *Pollachius pollachius*, haddock and saithe would show a decrease in the south, and that turbot *Scophthalmus maximus* and sprat would show no overall change in probability (−0.2 to +0.2) anywhere.

French scientists from IFREMER have used a delta GAM/GLM approach to model future plaice and red mullet distribution in the eastern English Channel and southern North Sea (see Vaz and Loots 2009). Abundance of each species was related to depth, sediment type, bottom salinity and temperature. Results suggested that climate change may strongly affect the future distribution of plaice. For large plaice (>18 cm), distribution will still be centred in the southern part of the North Sea, however for young individuals, the predicted distribution is anticipated to shift north-westwards and to the Dogger Bank area in particular (as has already been observed, see van Keeken et al. 2007; Engelhard et al. 2011). Model outputs indicate that the distribution of red mullet will not change dramatically but that for young individuals (defined as <17.3 cm), the offshore habitat situated on the Dogger Bank may become increasingly favourable. Older individuals seemed little affected by the simulated change in environment, but they may benefit from higher juvenile survival and expand their area of occupation as a result.

There are some concerns about the validity of the bioclimate envelope approach for predicting the future distribution of commercially important fish species (see Jennings and Brander 2010; Heath et al. 2012). First, it may not be possible to assess temperature preferences from current distributions because the observed distributions are modified by abundance, habitat, predator and prey abundance and competition. Second, there may be barriers to dispersal (although this is typically less of an issue in the sea than on land) and species will move at different rates and encounter different local ecologies as temperature changes (Davis et al. 1998). A more detailed, physiologically-based approach has been taken by some authors, whereby the detailed dynamics of individual animals are modelled, often by linking complex biophysical models (forced with the output from Global Climate Models) to sub-routines which replicate the behaviour/characteristics of eggs, larvae, juveniles or adults. Teal et al. (2008) reported a study of plaice and sole distribution in the North Sea, in which they predicted size- and season-specific fish distributions based on the physiology of the species, temperature and food conditions in the sea. This study combined state-of-the-art dynamic energy budget (DEB) models with output from a biogeochemical ecosystem model (ERSEM) forced with observed climatic data for 1989 and 2002, with contrasting temperature and food conditions. The resulting habitat quality maps were in broad agreement with observed ontogenetic and seasonal changes in distribution as well as with long-term observed changes in distribution. The technique has recently been extended to provide future projections up to year 2050, assuming moderate climate warming (L. Teal, pers. comm. IMARES, Netherlands).

12.3.1.2 Year-Class Strength and Implications for Fisheries

Fishers and scientists have known for over 100 years that the status of fish stocks can be greatly influenced by prevailing climatic conditions (Hjort 1914; Cushing 1982). ‘Recruitment’ variability is a key measure of stock productivity, and is defined as the number of juvenile fish surviving from the annual egg production to be exploited by the fishery. Recruitment is critically dependent on the match or mismatch between the occurrence of the larvae and availability of their zooplankton food (Cushing 1990) as well as other processes that affect early life-history stages (see Petitgas et al. 2013). Empirical data on exploited populations often show strong relationships between recruitment success, fisheries catches and climatic variables. These strong relationships have been demonstrated, for example, for cod (O’Brien et al. 2000; Brander and Mohn 2004; Cook and Heath 2005), plaice (Brunel and Boucher 2007), herring (Nash and Dickey-Collas 2005), mackerel (Jansen and Gislason 2011) and seabass (Pawson 1992). Correlations have been found between fish recruitment and various climate variables, including sea surface temperature, the NAO and even offshore winds (Table 12.2).

A number of publications describing the impact of climate variability (e.g. the NAO and AMO) on small pelagic fishes such as herring, anchovy or sardine in the North Sea have been published in recent years, for example those of Alheit et al. (2012) and Gröger et al. (2010). According to the most recent assessment of the UN Intergovernmental Panel on Climate Change (IPCC), the NAO is one of the climate indices for which it is most difficult to provide accurate future projections (IPCC 2013). Recent multi-model studies (e.g. Karpechko 2010) suggest overall that the NAO is likely to become slightly more positive (on average) in the future due to increased greenhouse gas emissions. Consequently, a slight tendency towards enhanced recruitment and larval abundance of these species in the future could be expected if the relationships observed in the past continue to hold.

In the case of cod, there is a well-established relationship between recruitment and sea temperature (O’Brien et al. 2000; Beaugrand et al. 2003), but this relationship varies with regard to the different cod stocks that inhabit the North Atlantic (Planque and Frédou 1999). For stocks at the northern extremes (e.g. in the Barents Sea) or the western Atlantic (e.g. Labrador), warming leads to enhanced recruitment, while in the North Sea, close to the southern limits of the range, warmer conditions lead to weaker than average year classes (Drinkwater 2005). During the late 1960s and early 1970s, cold conditions were correlated with a sequence of positive recruitment years in North Sea cod

Table 12.2 Demonstrated correlations between recruitment success (year-class strength) and climatic variables for important fish and shellfish stocks in northwest Europe

Species	Source	Sea area	Correlation	Climate parameter
Plaice	van der Veer and Witte (1999) and Brunel and Boucher (2007)	Southern North Sea, English Channel	Negative	SST (Feb)
Herring	Nash and Dickey-Collas (2005)	North Sea	Negative	SST (winter)
Herring	Gröger et al. (2010)	North Sea	Positive	Winter NAO, AMO
Scallop	Shephard et al. (2010)	Isle of Man	Positive	SST (spring)
Cod	Brander and Mohn (2004)	North Sea, Irish Sea	Positive	Winter NAO
Cod	Planque and Frédou (1999) and O'Brien et al. (2000)	North Sea, West of Scotland, Irish Sea	Negative	SST (Feb–Jun)
Sandeel	Arnott and Ruxton (2002)	North Sea	Negative, Positive	Winter NAO, SST (spring)
Mackerel	Jansen and Gislason (2011)	North Sea	Unclear	SST (summer)
Brown shrimp	Siegel et al. (2005) and Henderson et al. (2006)	Bristol Channel, Wadden Sea	Positive, Negative	SST (Jan–Aug), Winter NAO
Sole	Henderson and Seaby (2005)	Bristol Channel	Positive	SST (spring)
Seabass	Pawson (1992)	English Channel	Positive	SST (summer)
Squid	Robin and Denis (1999)	English Channel	Positive	SST (winter)
Turbot	Riley et al. (1981)	Coastal UK	Positive	Offshore wind
Whiting	Cook and Heath (2005)	North Sea	Positive	SST
Saithe	Cook and Heath (2005)	North Sea	Positive	SST

SST Sea surface temperature; *NAO* North Atlantic Oscillation; *AMO* Atlantic Multi-decadal Oscillation

and subsequently high fisheries catches for a number of years thereafter (Heath and Brander 2001). In recent years however, despite several cold winters, cod have suffered very poor recruitment in the North Sea, although it is unclear whether this is a direct consequence of changed climatic conditions, reduced availability of planktonic prey items for larval fish or over-fishing of the parental stock (i.e. some sort of 'Allee effect') (Mieszkowska et al. 2009), or more intensive predation of cod larvae by pelagic fish stocks which have increased, such as herring and sprat (Engelhard et al. 2014a).

A clear seasonal shift to earlier appearance of fish larvae has been described for several species at Helgoland Roads in the southern North Sea (Greve et al. 2005), and this has been linked to marked changes in zooplankton composition and sea surface temperature in this region (Beaugrand et al. 2002). In particular, there has been a decline in the abundance of the copepod *Calanus finmarchicus* but an increase in the closely related but smaller species *C. helgolandicus*. *Calanus finmarchicus* is a key prey item for cod larvae in the northern North Sea, and the loss of this species has been correlated with recent failures in cod recruitment and an apparent increase in flatfish recruitment (Reid et al. 2001, 2003; Beaugrand et al. 2003). *Calanus helgolandicus* occur at the wrong time of the year to be of use to emerging cod larvae. Greve et al. (2005) suggested that in ten cases both the 'start of season' and 'end of season' (Julian date on which 15 and 85 % of all larvae were recorded respectively), were correlated with sea surface temperature. Strongly significant relationships were observed for plaice, sole and horse mackerel as well as for many non-commercial species including scaldfish, and Norway bullhead *Taurulus lilljeborgi*.

Fincham et al. (2013) examined the date of peak spawning for seven sole stocks based on market sampling data in England and the Netherlands. Four out of seven stocks were shown to have exhibited a significant long-term trend towards earlier spawning (including the east-central North Sea, southern North Sea, and eastern English Channel) at a rate of 1.5 weeks per decade since 1970. Sea surface temperature during winter affected the date of peak spawning, although the effect differed between stocks. Recruitment is critically dependent on the match or mismatch between the occurrence of the larvae and the availability of their food (Cushing 1990) and other climate-sensitive processes (Peck and Hufnagl 2012; Llopiz et al. 2014), thus a change in spawning date could have knock-on effects for larval survival and hence future fisheries.

It is important to note that extensive fishing can cause fish populations to become more vulnerable to short-term natural climate variability (e.g. Ottersen et al. 2006) by making such populations less able to 'buffer' against the effects of the occasional poor year classes. Conversely, long-term climate change may make stocks more vulnerable to fishing, by reducing the overall 'carrying capacity' of the stock, such that it might not be sustained at, or expected to recover to, levels observed in the past (Jennings and Blanchard 2004). Cook and Heath (2005) examined the relationship between sea surface temperature and recruitment in a number of North Sea fish species (cod, haddock, whiting, saithe, plaice, sole) and concluded that if the recent warming period were to continue, as suggested by climate models, stocks which express a negative relationship with temperature (including cod) might be expected to support much smaller fisheries in the future. In the case of cod, climate change has been estimated to have been eroding the maximum sustainable yield at a rate of 32,000 tonnes per decade since 1980. Calculations show that the North Sea cod stock, could still support a sustainable fishery under a warmer climate but only at very much lower levels of fishing mortality, and that current 'precautionary reference' limits or targets (such as F_{MSY}), calculated by International Council for the Exploration of the Sea (ICES) on the basis of historic time series, may be unrealistically optimistic in the future.

For Atlantic mackerel, increases in sea surface temperature are known to affect growth, recruitment and migration with subsequent impacts on permissible levels of exploitation (Jansen and Gislason 2011). Jansen et al. (2012) used information on larval fish from the Continuous Plankton Recorder (CPR) to show that abundance has declined dramatically in the North Sea since the 1970s and also that the spatial distribution of mackerel larvae seems to have changed. Whether these trends can be ascribed to changes in climatic conditions remains unclear, although development and/or mortality of mackerel eggs is known to be very sensitive to seawater temperature (Mendiola et al. 2007).

There have been many attempts to include climatic variables in single-species population models (e.g. Hollowed et al. 2009), and thereby to project how the productivity of fish stocks will be affected by climate change in the future. Particular emphasis has been placed on climatic determinants of fish recruitment, and indeed several studies have inserted temperature or other environmental terms within the 'stock-recruit' relationship in order to make medium or long-term forecasts. Clarke et al. (2003) used projections of future North Sea temperatures and estimated the likely impact of climate change on the reproductive capacity of cod, assuming that the high level of mortality inflicted by the fishing industry (in 2003) continued into the future. Outputs from the model suggested that the cod population would decline, even without a significant temperature increase. However, scenarios with higher rates of temperature increase resulted in faster rates of decline. In a re-analysis by Kell et al. (2005), the authors modelled the effect of introducing a 'cod recovery plan' (as being implemented 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 needed for the cod stock to recover was not greatly affected by the particular climate scenario chosen (and was generally around five to six years), although overall productivity was affected and spawning stock biomass (SSB) once 'recovered' was projected to be considerably less than would have been the case assuming no temperature increase (251,035 tonnes compared to 286,689 tonnes in 2015).

12.3.1.3 Ocean Acidification and Low Oxygen

Carbon dioxide (CO_2) concentrations in the atmosphere are rising as a result of human activities and are projected to increase further by the end of the century, as carbon-rich fossil fuels such as coal and oil continue to be burned (Caldeira and Wickett 2003). Uptake of CO_2 from the air is the primary driver of ocean acidification. Modelling and observational studies suggest that the absorption of CO_2 by seawater has already decreased pH levels in the global ocean by 0.1 pH units since 1750 (Orr et al. 2005), which equates to an average increase in surface ocean water acidity worldwide of about 30 % since pre-industrial times, and that the present rate of change is faster than at any time during the previous 55 million years (Pearson and Palmer 2000).

Modelled estimates of future seawater pH in the North Sea are generally consistent with global projections. However, variability and uncertainties are considerable due to riverine inputs, biologically-driven processes and geochemical interactions between the water column and sea-bottom sediments (Blackford and Gilbert 2007; Artioli et al. 2012). Under a high CO_2 emission scenario, model outputs indicate that much of the North Sea seafloor is likely to become undersaturated with regard to aragonite (a form of calcium carbonate used by some marine organisms to build their shells or skeletons) during late winter/early spring by 2100 (Artioli et al. 2012). Ocean acidification may have direct and indirect impacts on the recruitment, growth and survival of exploited species (Fabry et al. 2008; Llopiz et al. 2014) and some species may become more vulnerable to ocean acidification with increases in temperature (Hale et al. 2011). Impacts may be particularly apparent for animals with calcium carbonate shells and skeletons such as molluscs, some crustaceans, and echinoderms (Hendriks et al. 2010; Kroeker et al. 2010), but studies show large variations in responses to ocean acidification between and within taxonomic groups. Several major programmes of research are underway in Europe to determine the possible consequences of future ocean acidification. In laboratory studies, significant effects have been noted for several important commercial shellfish species, notably mussels, oysters, lobster and *Nephrops* (Gazeau et al. 2010; Agnalt et al. 2013; Styf et al. 2013).

A preliminary assessment in 2012 estimated the potential economic losses to the UK shellfish industry under ocean acidification (Pinnegar et al. 2012). Four of the ten most valuable marine fishery species in the UK are calcifying shellfish and the analyses suggested losses in the mollusc fishery (scallops, mussels, cockles, whelks etc.) could amount to GBP 55–379 million per year by 2080 depending on the CO_2 emission scenario. Thus, there is a clear economic reason to improve understanding of physiological and behavioural responses to ocean acidification, and a Europe-wide assessment of economic consequences is currently underway within the German BIOACID programme.

Fin-fish species are thought to be most vulnerable to ocean acidification during their earliest life stages, although experiments on North Sea species (such as cod and herring) have so far shown that they are relatively robust (e.g. Franke and Clemmesen 2011). Indirect food-web effects may be more important for fin-fish, than direct physiological impacts (Le Quesne and Pinnegar 2012). To date, few studies have attempted to investigate the potential bottom-up impacts of ocean acidification on marine food webs, and hence on fisheries (although see Kaplan et al. 2010; Ainsworth et al. 2011; Griffith et al. 2011). In their economic analysis, Cooley and Doney (2009) did account for “fish that prey directly on calcifiers”. These authors suggested that indirect economic consequences of ocean acidification could be substantial. Clearly, more work is needed before definitive conclusions can be drawn about the socio-economic implications of ocean acidification for the fishing industry and society as a whole.

Reduced oxygen concentrations in marine waters have been cited as a major cause for concern globally (Diaz and Rosenberg 2008), and there is evidence (Queste et al. 2012) that areas of low oxygen saturation have started to proliferate in the North Sea. Whether these changes are a result of long-term climate change remains unclear and it is also unclear whether such changes will impact on commercial fish species and their fisheries. Unlike parts of the Baltic Sea, which regularly experience complete anoxia (lack of oxygen), regions of the North Sea only experience reduced oxygen conditions (65–70 % saturation, 180–200 μMol dm^{-3}). Therefore it is uncertain whether North Sea fish stocks will suffer major mortality of eggs and larvae due to changes in oxygen levels (as is the case in the Baltic Sea), and it is perhaps more likely that they will experience more subtle, non-lethal, effects in the future. Several authors have highlighted how oxygen concentrations, low pH and elevated temperature interact and determine ‘scope for growth’ (e.g. Pörtner and Knust 2007). These findings have been used as the basis for models predicting size and distribution in North East Atlantic fishes (Cheung et al. 2013). Laboratory studies concerning low oxygen conditions have been used to predict fish distribution and habitat suitability (Cucco et al. 2012). Some types of organism are more affected than others. Larger fish and spawning individuals can be more affected by low oxygen levels owing to their higher metabolic rates (Pörtner and Farrell 2008). There are certain thresholds below which oxygen levels affect the aerobic performance of marine organisms (Pörtner 2010), although this is very dependent on the species or type of organism, respiration mode, and metabolic and physiological requirements, with highly active species being less tolerant of low oxygen conditions (Stramma et al. 2011). *Nephrops norvegicus* juveniles show sub-lethal effects at oxygen concentrations below 156 μMol dm^{-3}, but adults are more robust, although their ability to tolerate other environmental stresses (for example elevated temperature) is severely compromised (Baden et al. 1990). There are few projections of future oxygen concentrations in the North Sea, although modelling was undertaken for three locations by van der Molen et al. (2013). These authors were able to provide some insight into future conditions, assuming a SRES A1B scenario to 2100. In particular, the model suggested marked declines in oxygen concentration at all sites as a result of simulated changes in the balance between phytoplankton production and consumption, changes in vertical mixing (stratification) and change in oxygen solubility with temperature. A parallel study by Meire et al. (2013) for the ‘Oyster Grounds’ site (also using the SRES A1B scenario) suggested that bottom water oxygen concentrations in late summer could decrease by 24 μM or 11.5 % by 2100.

12.3.2 Pathogens, Pests and Predators

A key issue for North Sea fish and shellfish is the link between climate change and the prevalence of pathogens or harmful algal bloom (HAB) species. A global review suggested that marine pathogens are increasing in occurrence, and that this increase is linked to rising seawater temperature (Harvell et al. 1999) with possible consequences for commercial fisheries and aquaculture.

The presence of certain pathogens or algal toxins in seawater samples or in tissues harvested from shellfish can result in temporary closure of a fishery. Many pathogens that occur in European shellfish are very sensitive to seawater temperature and salinity, for example the bacteria *Vibrio parahaemolyticus* and *V. vulnificus* that pose a significant threat to human health (Baker-Austin et al. 2013). *Vibrio* species proliferate rapidly at temperatures above 18 °C and incidents of shellfish-associated gastrointestinal illness in Europe have been noted during heat waves (Baker-Austin et al. 2013). In the United States, *Vibrio*-related incidents cost the economy more than any other seafood-acquired pathogen and these incurred costs have increased dramatically in recent years (Ralston et al. 2011). In contrast, *Norovirus*, another major cause of shellfish-acquired gastroenteritis, occurs most frequently in winter and following periods of high precipitation and hence is associated with flash-flooding and runoff from sewers (Campos and Lees 2014). Future projections of precipitation (rain and snowfall) and river run-off for catchments surrounding the North Sea suggest that intense rainfall and hence extreme river flows will occur more often in the future, particularly during winter, and so considerable changes could be anticipated in the epidemiology and proliferation of marine pathogens—and therefore exposure risk for European citizens consuming seafood (Pinnegar et al. 2012).

Reports of increased abundance of jellyfish in the media and in scientific literature over recent decades have raised concerns over the potential role of climate change in influencing outbreaks (Atrill et al. 2007; Purcell 2012) and in possible implications for commercial fisheries and aquaculture. Data obtained from the CPR survey show an increasing occurrence of jellyfish in the central North Sea since 1958 that this may be positively related to the NAO and Atlantic inflow (Lynam et al. 2004; Atrill et al. 2007). High jellyfish numbers are potentially detrimental to fisheries both as competitors with, and predators of, larval fish (Purcell and Arai 2001). In particular, negative impacts of jellyfish on herring larvae have been noted (Lynam et al. 2005) and this is now a major focus of scientific attention.

Climate change can also influence the presence of potential predators. For example Kempf et al. (2014) demonstrated that grey gurnard *Eutriglia gurnardus*, has expanded its high density areas in the central North Sea northward over the last two decades to overlap with that of 0-group cod. Grey gurnard are thought to be important predators of juvenile cod, hence recruitment success of cod was found to be negatively correlated with the degree of spatial overlap between the two species. Similar fears have been voiced by fishers regarding the recent expansion of hake in the northern North Sea (see Sect. 12.3.1.1), since hake is also known to be a voracious predator of smaller fish.

12.3.3 Fishery Operations

Through its effects on seawater temperature as well as its influence on storm conditions climate change can affect the performance of fishing vessels or gears, as well as vessel safety and stability at sea.

Dulvy et al. (2008) explored the year-by-year distributional response of the North Sea demersal fish assemblage to climate change and found that the whole North Sea fish assemblage has deepened by ~3.6 m per decade since 1981. This has important implications since it is known that trawl gear geometry and hence 'catchability' can be greatly influenced by water depth (see Godø and Engås 1989).

In tropical tuna (the main target of Europe's distant-water fleet), strong El Niño events along the west coast of the Americas typically result in a deeper thermocline, and declines in yellowfin tuna *Thunnus albacares* catches (see Miller 2007) because fish are able to spread out in the water column beyond the reach of commercial fisheries. Poor catch rates during the intense 1982–1983 El Niño played a role in the migration of the entire US tuna fleet from the Eastern Pacific to the Western and Central Pacific. Similar processes and mechanisms, but on a smaller spatial scale, appear to influence catch rates in North Sea pelagic fisheries, such as those targeting herring. Maravelias (1997) demonstrated that temperature and depth of the thermocline, appear to be key factors that modulate both the presence and relative abundance of herring within the northern North Sea. Herring appeared to avoid the cold bottom waters of the North Sea during the summer, probably due to the relatively poor food resources there. This greatly affected 'catchability'.

At present, confidence in the wind and storm projections from global climate models (GCMs) and downscaled regional climate models (RCMs) is relatively low, with some models suggesting that northwest Europe might experience fewer storms and others suggesting an increase (Woolf and Wolf 2013). In general, models suggest that climate change could result in a north-eastward shift of storm frequency in the North Atlantic, although the change in storm intensity or frequency that this implies is not clear (Meehl et al. 2000; Ulbrich et al. 2008). The winter of 2013/14 was the stormiest in the last 66 years with regard to the southern North Sea and the wider British Isles (Matthews et al. 2014) and this is known to have coincided with major disruption to the fishing industry throughout the region. Months of high winds and high seas left many fishers unable to work, and caused millions of Euros worth of damage—as well as a lack of fish and higher prices on fish markets.

12.3.3.1 Climatic Influences on 'Catchability'

There is little evidence of significant changes in catchability of demersal trawl gears in the North Sea as a result of climate change or poor weather conditions, although Walden and Schubert (1965) examined wind and catch data, and found that wind direction and force were correlated with catch at a few locations. Similarly Harden Jones and Scholes (1980) investigated the relations between wind and the catch of a Lowestoft trawler. Their analysis showed that over the course of a year, catches of plaice were lowest with northerly winds but that the reverse was true for cod. Long-term projections for winds over the North Sea are highly uncertain, but several authors (notably Wang et al. 2011) have suggested a climate-change-related upward trend in storminess in recent years. Analyses (de Winter et al. 2013) under a range of different climate change scenarios, do not anticipate changes in annual maximum wind speed over the next 50–100 years, however they do suggest that annual extreme wind events will occur more often from western directions. This is particularly relevant for fishing boats in the German

Bight, as such a shift would imply larger extreme waves and surge levels in this region.

Poulard and Trenkel (2007) reported that the impact of wind strength on catchability depends on the habitat preferred by a given species. For a bottom trawl survey in the Bay of Biscay, catches of benthic and demersal species were significantly affected by wind condition whereas no effect was detected for pelagic species. Similarly, Wieland et al. (2011) examined bias in estimates of abundance and distribution of North Sea cod during periods of strong winds. Wind speed had significant effects on catch rates, and specifically catches were reduced during the strongest winds. Strong winds prevailing over a prolonged period lead to poor visibility in shallow coastal waters, caused mainly by resuspension of bottom sediments. North Sea trawlers and especially 'flyshooters' would usually not fish in that area under such conditions due to the expectation of poor catches whereas gillnets may perform well in this case.

Fish are known to behave differently in turbid versus clearer waters. For example, Meager and Batty (2007) examined activity of juvenile cod and found both longer prey-search times and higher activity in turbid conditions, and suggested that such behaviour might increase energetic costs and also make the cod more vulnerable to fishing gears and potential predators. Capuzzo et al. (2015) demonstrated that the southern North Sea has become significantly more turbid over the latter half of the 20th century, and that this may be related to changes in seabed communities, weather patterns, and increased coastal erosion. Gill net catches are typically higher in turbid waters after storms. Ehrich and Stransky (1999) found that catch rates of some groundfish species in the North Sea exhibited significant variability following strong and severe gales (periods of strong winds from 50 to 102 km h^{-1}). Catches of dab, solenette, plaice and sole all changed markedly between the first and second day after the storm.

12.3.3.2 Vessel Stability and Performance

An increase in the frequency or severity of storms could have negative consequences for the ability of fishing boats to access resources in the future or could have consequences for vessel stability and performance. Abernethy et al. (2010) reported that 85 % of fishers interviewed as part of a survey in southern England, elected to stay in port during bad weather due to the risk of gear loss and increased fuel consumption. Fishing remains a dangerous occupation. A research project, published in 2007 showed that the fatal accident rate for UK fishers for the decade 1996–2005 was 115 times higher than that of the general workforce (MAIB 2008). In the United States, severe weather conditions contributed to 61 % of the 148 fatal fishing vessel disasters reported between 2000 and 2009 (Lincoln and Lucas 2010). In Denmark, more than half of fatalities reported were caused by foundering/capsizing due to stability changes in rough weather (Laursen et al. 2008). In the UK, the majority of vessel losses recorded (52 %) were due to flooding/foundering, and most involved small vessels of less than 12 m in length (MAIB 2008). Most flooding/foundering losses occurred in moderate weather. However, this needs to be considered against the likelihood that there would be fewer fishing vessels at sea during extreme weather conditions (MAIB 2008).

Dramatic increases in wave height occurred in the North Sea between 1960 and 1990, but these are now viewed as one feature within a longer history of variability (Woolf and Wolf 2013). Future patterns of storminess are poorly understood, with little consensus between models and highly uncertain model outputs. Changes in storminess and associated consequences for fishing operations is an under-researched topic, with no recent assessments of vessel operating envelopes or the willingness of vessel owners/skippers to put to sea. Laevastu and Hayes (1981) suggested that modern high-sea fishing vessels usually have to stop fishing at wind speeds of 50–78 km h^{-1} (Force 7 to 8 on the Beaufort scale), whereas coastal fishing vessels in the North Sea find difficulty in operating at wind speeds of 39–49 km h^{-1} (Force 6 on the Beaufort scale). A number of modelling approaches have been applied in the North Sea to try to predict the behaviour of fishers and the distribution of fishing vessels (e.g. Hutton et al. 2004) but none have yet included storms or weather disruption in their analyses.

12.3.3.3 Assessing Economic Implications

There has been little research directed towards understanding the future implications of climate change for fishing fleets, fishers, coastal economies and society directly. This is certainly the case with regard to countries surrounding the North Sea. However, a number of studies have set out to investigate the vulnerability and adaptive capacity of the fisheries sector at a global scale (McClanahan et al. 2008; Allison et al. 2009). Vulnerability to climate change depends upon three key elements: exposure to physical effects of climate change; sensitivity of the natural resource system or dependence of the national economy upon economic returns from the fishing sector; and the extent to which adaptive capacity enables these potential impacts to be offset. Allison et al. (2009) ranked North Sea countries very low in terms of overall vulnerability, largely due to low rates of fish consumption in the surrounding countries, highly diversified economies and only moderate exposure to future climate change. Similarly, Barange et al. (2014) categorised all North Sea countries as either low (Norway) or very low in terms of nutritional and economic dependence on fisheries. However fisheries represent an important component of employment in certain North Sea regions (EU 2011), notably in Shetland where 22 % of all jobs are estimated to be in fisheries/fisheries-related industries, and Urk in the Netherlands where 35 % of jobs rely on fisheries.

Cheung et al. (2010) estimated future changes in maximum potential catch (a proxy for maximum sustainable yield) given projected shifts in the distribution of exploited species and changes in marine primary productivity. This study suggested that climate change may lead to large-scale redistribution of global maximum catch potential, with an average of 30–70 % increase in yield of high-latitude regions (north of 50°N in the northern hemisphere), but a drop of up to 40 % in the tropics. North Sea countries are anticipated to gain very slightly in maximum potential catch but not as much as Nordic countries such as Norway and Iceland. This region will witness increases in catches of some commercial species but decreases in others, and thus the gains and losses are expected to broadly balance out.

Working at a national level, Jones et al. (2015) used a similar bioclimate envelope model (see Fig. 12.4) to investigate economic implications for fisheries catch potential in the UK exclusive economic zone (EEZ) specifically. Maximum catch potential was calculated for each species in both the reference and projection periods using an algorithm that takes into account net primary production and range area. Results suggested that the total maximum catch potential will decrease within the UK EEZ by 2050, although this was heavily influenced by an assumed decline in plankton productivity. Extending these projections into a cost benefit analysis resulted in a median decrease in net present value of 10 % by 2050. Net present value over the study period further decreased when trends in fuel price were extrapolated into the future, becoming negative when capacity-enhancing subsidies were removed. This study highlights key factors influencing future profitability of fisheries and the importance of enhancing adaptive capacity in fisheries and resilience to climate change.

Uncertainty is inherent in fisheries management, so there is an expectation of change and a wealth of knowledge and experience of coping with and adapting to this uncertainty. Badjeck et al. (2010) argued that diversification is a primary means by which individuals can reduce risk and cope with future uncertainty. A recent study commissioned by the UK Department for Environment, Food and Rural Affairs included a detailed assessment of whether the fish catching sector might be expected to adapt to the opportunities and threats associated with future climate change over the next 30 years (Defra 2013). This assessment built heavily on the species projections of Jones et al. (2012, 2013—see Sect. 12.3.1.1) and looked for examples of current adaptation by the sector, focusing on species increasing in the UK EEZ (such as anchovy, squid, seabass) and also on past increases in scallops, boarfish *Capros aper*, and hake. The key adaptation actions identified included:

- Travelling further to fish for current species, if stocks move away from existing ports.
- Diversifying the livelihoods of port communities, this may include recreational fishing where popular angling species become locally more abundant (e.g. seabass).
- Increasing vessel capacity if stocks of currently fished species increase.
- Changing gear to fish for different species, if new or more profitable opportunities to fish different species are available.
- Developing routes to export markets to match the changes in catch supplied. These routes may be to locations (such as southern Europe) which currently eat the fish stocks which may move into northern waters.
- Stimulating domestic demand for a broader range of species, through joined-up retailer and media campaigns.

Many of the same adaptation options were also highlighted by McIlgorm et al. (2010) who reviewed how fishery governance may need to change in the light of future climate change, also the ACACIA report (ACACIA 2000) prepared as part of the European impact assessment for the IPCC Third Assessment which included a short chapter on fisheries. Vanderperren et al. (2009) provided a brief overview for Belgian marine fisheries. These authors noted the strong specialisation of the Belgian fleet with regard to a single fishing method (93 % beam trawlers) and target species (mainly flatfish) and that this makes the sector particularly vulnerable to changing circumstances. Possible adaptation measures as well as technological and economic consequences for the fleet were detailed (see Van den Eynde et al. 2011), and the elaboration of scenarios for secondary impacts at different points in time (2040, 2100) is ongoing.

Sumaila and Cheung (2009) attempted to estimate the necessary annual costs of adaptation to climate change in the fisheries sector worldwide. Adaptation to climate change is likely to involve an extension of existing policies to conserve fish stocks and to help communities. In Europe the estimated annual cost of adaptation was USD 0.03–0.15 billion, a small fraction of the costs (USD 1.05–1.70 billion) anticipated for East Asia and the Pacific.

12.4 International Fish Markets and Commodity Chains

Fisheries in the North Sea should not be viewed in isolation given that seafoods are traded globally and many North Sea countries are both exporters and importers of fish and shellfish commodities. It could be expected that prices of a particular commodity would reflect local patterns of availability (supply) and hence that the price of fish might even reflect regional climatic conditions (see Pinnegar et al. 2006). However this is rarely the case, given that supplies can often be secured from elsewhere and thus prices may remain low, even if locally resources become scarce. Cod stock status in the North Sea currently remains very low, possibly as a result of long-term climatic influences on recruitment, but catches are at an all-time high further north in the Barents Sea (ICES 2014b) and thus cod prices in Europe are supressed. A clear adaptation response in the face of ensuing climate change is to obtain fish from sources further north (either by trade or by shifting the location of fishing fleets where this is possible). As other countries around the word also need to secure sufficient food for growing populations, and have considerably higher buying-power (notably China, which in 2030 will account for 38 % of total fish consumption), European countries may find the ability to secure sufficient fish products from Nordic (non-EU) countries, such as Norway, Iceland and Greenland, much more difficult in the future (World Bank 2013).

Another international fisheries topic that has received considerable attention in recent years has been the link between global climate and fishmeal supplies and markets (e.g. Merino et al. 2010a, b). Aquaculture and animal feed production depend on fishmeal and fish oil as their primary source of protein, lipids, minerals and essential Omega 3/6 fatty acids. Every year 30 million tonnes of anchovita *Engraulis ringens, E. mordax* etc., sardines *Sardinops sagax, Sardina pilchardus* and other small pelagic fish are reduced into 6 million tonnes of fishmeal. More than half of this is derived from Peruvian/Chilean anchoveta although Denmark and Norway supply an additional 12 % based on North Sea sandeel, sprat, Norway pout and blue whiting as well as Arctic capelin *Mallotus villosus*. A lack of supply in Peruvian anchoveta (for example during El Niño climatic regimes) raises the price of fishmeal from elsewhere (e.g. the North Sea) and can influence the behaviour of European fishers, with indirect (e.g. predator-prey) consequence for other fish stocks.

12.5 Conclusions

North Sea fisheries may be impacted by climate change in various ways and consequences of rapid temperature rise are already being felt in terms of shifts in species distribution and variability in stock recruitment. While an expanding body of research now exists on this topic, there are still many knowledge gaps, especially with regard to understanding how fishing fleets themselves might be impacted by underlying biological changes and what this might mean for regional economies. Historically, fisheries managers and fishers have had to adapt to the vagaries of weather and climate, however the challenge presented by future climate change should not be underestimated and it is clear that fish communities and the fisheries that target them will almost certainly be very different in 50 or 100 years and that management and governance will need to adapt accordingly.

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Socio-economic Impacts—Agricultural Systems

13

Jørgen Eivind Olesen

Abstract

Europe is one of the world's largest and most productive suppliers of food and fibre. In the North Sea region, agroecosystems vary from highly productive farming systems such as the arable cropping systems of western Europe to low-input and low-output farming systems with or without livestock. Climate change impacts on agricultural production will vary across the North Sea region, both in terms of crops grown and yields obtained. Given adequate water and nutrient supply, a doubling of atmospheric CO_2 concentration could lead to yield increases of 20–40 % for most crops grown in the North Sea region. The high-input farming systems could also respond favourably to modest warming. Extreme weather events may severely disrupt crop production. Increased temperature and more frequent extreme weather events could affect animal production through changes in feed production, changes in the availability of grazing, direct heat stress, and increased risk of disease. Overall, there seems to be potential for agriculture in the North Sea region to adapt to the changing climate in such a way that productivity and profitability may both increase, particularly over the long term. The challenge will be to ensure sustainable growth in agricultural production without compromising environmental quality and natural resources.

13.1 Introduction

Agriculture is situated at the interface between ecosystems and society with the main aim of ensuring food supply. Located at this interface, agriculture is both affected by and helps drive changes in global environmental conditions, for the latter by contributing to emissions of greenhouse gases, notably methane and nitrous oxide. Management of agricultural ecosystems varies from highly productive farming systems such as the arable cropping systems of western Europe to low-input and low-output farming systems with or without livestock, some of which are also located in Europe.

Europe is one of the world's largest and most productive suppliers of food and fibre (Olesen and Bindi 2002). In 2012, it accounted for 19 % of global meat production and 17 % of global cereal production. About 78 % of the European meat production and 63 % of cereal production occurred within EU countries, with the remaining production primarily in Russia, Belarus and Ukraine. The productivity of European agriculture is generally high, especially in western Europe, and average hectare cereal yields in EU countries are about 40 % higher than the world average (Olesen et al. 2011).

The overall driving force in agriculture is the globally increasing demand for food and fibre. This is primarily caused by a growing world population with a high demand for food production and a wealthier world population with a higher proportion of meat in the diet (Godfray et al. 2010). The result is that agriculture globally exerts increasing pressure on the land and water resources of the earth, which often results in land degradation (such as soil erosion and salinization), and eutrophication. Agriculture is also associated with greenhouse gas emissions (Kirchmann and Thorvaldsson 2000).

Agricultural land use along the Atlantic coast in Europe is dominated by grassland and forage crops, because the wet conditions limit soil trafficability (i.e. capability of supporting

J.E. Olesen (✉)
Department of Agroecology—Climate and Bioenergy,
Aarhus University, Aarhus, Denmark
e-mail: jorgene.olesen@agrsci.dk

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agricultural traffic/machinery without degrading the soil) required for cultivating annual crops. In regions with less rainfall such as continental parts of Europe, arable cropping systems often dominate the agricultural landscape. In northwest Europe the arable cropping systems are dominated by cereals, in particular winter wheat and spring barley, and break crops (secondary crops grown to interrupt the repeated sowing of cereals as part of crop rotation) like oilseed rape, grain legumes, and root and tuber crops like sugar beet and potato. Over recent decades the area cultivated with high yielding crops such as winter wheat and silage and grain maize has increased. This increase in area of winter wheat has largely happened at the expense of less productive spring cereal crops.

Increases in winter wheat yield are mostly due to crop breeding and improved crop protection coupled with increased fertilisation; however, wheat yields in Europe have been stagnating over the past 10 to 20 years (Olesen et al. 2011). There also seems to have been greater variability in grain yields for wheat over the past two decades. Stagnating wheat yields in France have been attributed to lower yields under the rising temperature (Brisson et al. 2010), but changes in management may also have played a role in some countries (Finger 2010). In contrast to wheat, yields of grain maize show a continued increase in both France and Germany, such that grain maize yields now exceed those of winter wheat. The area of silage and grain maize is therefore growing in northern Europe (Elsgaard et al. 2012), and this appears to be linked to the warmer climate (Odgaard et al. 2011).

High-input farming systems in western and central Europe generally have a low sensitivity to climate change, because a given change in temperature or rainfall has a modest impact (Chloupek et al. 2004) and because farmers have resources to adapt management. However, there may be considerable difference in adaptive capacity between cropping systems and farms depending on their specialisation (Reidsma et al. 2007). These systems may therefore respond favourably to modest climate warming (Olesen and Bindi 2002). Across the North Sea region there is a large variation in climatic conditions, soils, land use and infrastructure, which greatly influences responsiveness to climatic change.

13.2 Impacts

13.2.1 Crop Responses to Climate Change

Rising greenhouse gas emissions affect agroecosystems directly (primarily by increasing photosynthesis and water use efficiency at higher CO_2 levels) and indirectly via climate change (temperature and rainfall affect several aspects of the functioning of cropping systems). Effects may also be both direct through changes in crop physiology and indirect through impacts on soil fertility, crop protection (weeds, pests or diseases) and the ability to perform field operations in a timely manner. The exact responses depend on the sensitivity of the particular agricultural system to environmental change and on the relative changes in controlling factors.

Increasing atmospheric CO_2 concentration stimulates yield of crops that have the so-called C3-photosynthesis pathway, which constitute almost all crops grown in the North Sea region, with the exception of maize and *Miscanthus* (cultivated for biofuel). A doubling of atmospheric CO_2 concentration is projected to lead to yield increases of 20–40 % in most crops (Ainsworth and Long 2005), provided adequate water and nutrient supply. The response is considerably less for C4-plants, which include tropical grasses such as maize. Higher CO_2 concentration not only increases photosynthesis, but also reduces plant water consumption. This may result in improved tolerance of plants to drought and generally drier conditions.

Higher CO_2 concentrations also affect the quality of plant biomass, because plants accumulate more sugar leading to higher carbon contents of leaves, stems and reproductive organs. This has consequences for the quality of the food and feed, which in some cases are negative. It will thus reduce the protein content of cereal grains and diminish the baking quality of wheat (Högy et al. 2013). The attraction of plants for pests and diseases will also change, which could make the plants more resistant to attack. However, weed growth will also benefit from increased CO_2, which may necessitate intensified or different control measures, for example, due to reduced efficacy of herbicides (Ziska 2001).

Temperature affects crops in different ways, partly through affecting the timing of crop phenological phases (crop development); partly through the efficiency of energy capture, conversion and storage (crop growth); and partly through crop water demands (temperature affects evapotranspiration). With warming, active growth starts earlier, plants develop faster, and the potential growing season is extended. This may have the greatest effect in colder regions (Trnka et al. 2011), and may be most beneficial for perennial crops or crops which remain in their vegetative phase, such as sugar beet and grasslands.

Higher temperature reduces crop duration of determinate species (plants that flower and mature). This concerns all cereals and seed plants such as pulses and oilseed crops. For wheat, a temperature increase of 1 °C during grain fill is estimated to reduce the length of this phase by 5 %, and yield to decline by a similar amount (Olesen et al. 2000). However, in the North Sea region such reductions can often be more than offset by changing to cultivars with longer growth duration (Olesen et al. 2012) and this may even lead

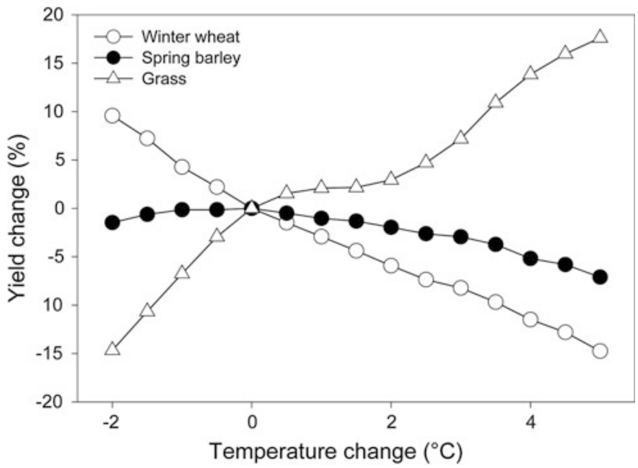

Fig. 13.1 Mean simulated change in yield of winter wheat, spring barley and ryegrass with increasing temperature for a site in Denmark. The simulations were performed with the CLIMCROP model assuming that water is not growth-limiting (Olesen et al. 2000; Olesen 2005)

to improved yields with potential for longer growing seasons at high latitudes (Montesino-San Martin et al. 2014).

These differential responses of crop yield to rising temperature in plants with different responses of crop development are illustrated in Fig. 13.1. The results were produced with a crop simulation model that integrates the biophysical interactions between soil, climate and plants on crop growth and yield over the growing season. Such models are commonly used to assess the effects of climate change on crop yield and quality (Ewert et al. 2015).

The greatest reductions in grain yield in Fig. 13.1 were simulated for winter wheat, where growth duration is reduced, because any changes in sowing date in autumn would have little effect on duration of the vegetative and reproductive phases in the following spring and summer. This response concurs well with observed response of winter wheat yields in Denmark, where the largest reductions were found to be related to high temperatures during the grain filling phase (Kristensen et al. 2011). Figure 13.1 shows a smaller response of spring barley to higher temperatures, because this crop can be sown earlier in spring thus maintaining a productive growing season. In contrast, yields were simulated to increase for a grass crop, which represents crops with a non-determinate growth pattern, where yields depend on the total duration of the growing season with suitable temperatures and rainfall.

Peltonen-Sainio et al. (2010) characterised the coincidence of yield variations with weather variables for major field crops using long-term datasets to reveal whether there are commonalities across the European agricultural regions. Long-term national and/or regional yield datasets were used from 14 European countries for spring and winter barley and wheat, winter oilseed rape, potato and sugar beet. Harmful effects of high precipitation during grain-filling in grain and seed crops and at flowering in oilseed rape were recorded. In potato, reduced precipitation at tuber formation was associated with yield penalties. Elevated temperature had harmful effects for cereals and rapeseed yields. Similar harmful effects of rainfall and high temperature on grain yield of winter wheat were found by Kristensen et al. (2011) in a study using observed winter wheat yields from Denmark.

13.2.2 Impacts of Climatic Variability and Weather Extremes

Extreme weather events, such as periods of high temperature, heavy storms, or droughts, can severely disrupt crop production. Individual extreme events do not usually have lasting effects on the agricultural system. However, if the frequency of such events increases, agriculture will need to respond, either by adapting or by ceasing its activity.

Crops often respond nonlinearly to changes in their growing conditions and have threshold responses, which greatly increases the importance of climatic variability and the frequency of extreme weather events in terms of absolute yield, yield stability and quality (Trnka et al. 2014). This may lead to drastic reductions in yield from short episodes of high temperature during sensitive crop growth phases such as the reproductive period. Temperatures above 35 °C during the flowering period can in most crops severely affect seed and fruit set and thus greatly reduce yield (Porter and Semenov 2005). High temperatures will also greatly increase evapotranspiration leading to higher risk of drought, if rainfall is insufficient to compensate for the water losses (Lobell et al. 2013). Such high temperature stresses may severely impact crop yields, even in the North Sea region (Semenov and Shewry 2011).

An increase in temperature variability will increase yield variability and also result in a reduction in mean yield. Even in the North Sea region there may be a sufficient increase in climatic variability to significantly affect crop yield (Kristensen et al. 2011), although this effect is expected to be more severe in other parts of the world. This risk is likely to be particularly large for high-input production systems (Trnka et al. 2012), where the demand for continued high soil water supply is greater than for low-input systems (having lower rates of evapotranspiration). Also, a given proportional reduction in crop yield will have a greater absolute yield effect on high- rather than low-yielding crops. Therefore increases in climatic extremes will also have greater effects in high-input rainfed systems than in less intensive and diverse systems (Schaap et al. 2011). The high-input rainfed cropping systems may thus be particularly vulnerable to climate change, although some will also benefit in terms of higher average yields from the warming and higher CO_2 concentrations.

13.2.3 Changes in Crop Productivity and Suitability

Climatic warming will in temperate regions result in earlier onset of the growing season in spring and a longer duration in autumn. A longer growing season allows the proliferation of species that have suitable conditions for growth and development and can thus increase their productivity (e.g. crop yield, number of crops per year). This may also allow for the introduction of new species previously unfavourable due to low temperatures or short growing seasons. This is relevant for the introduction of new crops, such as for grain maize or winter wheat in northern Europe (Elsgaard et al. 2012), but will also affect the spread of weeds, pests and diseases that often follow the crops grown (Roos et al. 2011).

Warming has already caused a northward expansion of the area of silage maize in northern Europe into southern parts of Scandinavia, where the system of grass and silage maize for intensive dairy production has largely replaced the traditional fodder production systems (Odgaard et al. 2011; Eckersten et al. 2014; Nkurunziza et al. 2014). Very recently grain maize has started to be grown in southern parts of Denmark, reflecting the warming trends (Elsgaard et al. 2012). Analyses of the effects of observed climate change on yield potential in Europe have shown positive effects for maize and sugar beet, which have benefited from the longer growing season for these crops (Supit et al. 2010). Yield benefits have been greatest in northern Europe. The warming may also have contributed to higher potato yields in northern regions of Europe. In contrast, warmer and more variable climatic conditions with increased occurrence of drought have reduced crop yields in parts of central Europe (Eitzinger et al. 2013).

A further lengthening of the growing season as well as a northward shift for some species are projected to result from further increases in temperature across Europe (Olesen et al. 2011). The date of last frost in spring is projected to reduce by 5–10 days by 2030 and 10–15 days by 2050 throughout most of Europe compared with the period 1961–1990 (Trnka et al. 2011). Since a longer growing season will increase productivity of many crops in northern Europe, this could lead to further intensification of cropping systems.

Projected climate change is expected to result in more favourable conditions for crop production at high latitudes than at low northern European latitudes (Table 13.1). The agroclimatic indices show a substantial lengthening (one month) of the growing season by 2050 in northern regions, but much less in southern parts of the North Sea region. Although the duration of the growing season is projected to increase throughout the North Sea region, in southern and continental parts this increase may be counteracted by drier conditions during summer resulting in reduced crop growth.

Projected impacts of climate change on crop yields depend on crop type, emission scenario and the sensitivity of the underlying climate model used to project climate changes (Olesen et al. 2007). Projections for most crops in the North Sea region show an increase in projected yield during the first half of the 21st century (Supit et al. 2012). However, later in the century yield is projected to decrease due to the effects of temperature rise and reduced summer rainfall that together exceed the benefits achieved from higher atmospheric CO_2 concentration, in particular for cereal crops. For root and tuber crops in Europe (such as sugar beet and potato) yields are projected to continue increasing (Angulo et al. 2013). However, even for potato some regions may become less suitable for production due to drier summer conditions and constraints imposed on the use of irrigation (Daccache et al. 2012).

At high latitudes or at high elevations with wet and cool climates, cropping systems with grasslands and forage production for ruminant livestock currently tend to dominate. Timothy *Phleum pratense* L. and perennial ryegrass *Lolium perenne* L. are the most important forage grasses at high latitudes, and in cold and snow-rich regions, timothy outcompetes perennial ryegrass due to better winter survival (Höglind et al. 2013). Due to the higher productivity and better feed quality of ryegrass compared to timothy, warming leading to less risk of winter kill is expected to shift the patterns in the cultivation of grassland species in Norway and Sweden northwards. Similar shifts may be expected in grazing season duration (Uleberg et al. 2014). In some cases these shifts will be constrained by rainfall, either with conditions too dry during summer or too wet during spring or autumn.

13.2.4 Environmental Impacts

Soils have many functions, of which water and nutrient supply to growing crops are essential for sustained crop production. However, soils are also important in regulating water and nutrient cycles, for carbon storage and greenhouse gas emissions. Soils are habitats for many of the organisms that contribute to the functioning of soils and agroecosystems, having both positive and negative effects on crop yield. Where soil moisture allows, increasing temperatures will enhance decomposition of soil organic matter, which tends to decrease soil organic stocks unless counterbalanced by larger inputs of organic matter in crop residues (Falloon and Betts 2010). A reduction in soil carbon enhances the

Table 13.1 Effects of projected climate change on changes in key agroclimatic indices in northern European agroecological zones by 2050 compared to the period 1961–1990 (Trnka et al. 2011)

Zone	Change in effective solar radiation (%)	Change in effective growing days (days)	Change in date of last frost (days)	Change in dry days in spring (%)	Change in dry days in summer (%)
Alpine North (Norway and north Sweden)	+8	+29	−10	+1	−2
Boreal (Finland, central Sweden, parts of Norway)	+8	+16	−11	−1	+2
Nemoral (south-central Sweden)	+8	+12	−10	+1	+11
Atlantic North (Ireland, British Isles, western Denmark, Netherlands)	−1	+5	−11	−4	+21
Continental (east Denmark, south Sweden, Germany)	−6	−6	−12	−2	+20

contribution of agriculture to global warming through higher net CO_2 emissions. In contrast, the effects of warming on nitrous oxide emissions from agricultural soils are less clear, since effects depend on the balance between the separate effects of temperature, rainfall and CO_2 as well as their seasonal changes, relative to effects of changes in crop growth patterns (Dijkstra et al. 2012).

Any reduction in soil organic matter stocks implies a decrease in fertility and biodiversity, a loss of soil structure, reduced soil water infiltration and retention capacity, and increased risk of erosion and compaction. If these changes are significant, this leads to lower productivity of crops growing on the soils. Changes in rainfall and wind patterns, in particular more intense rainfall, can lead to increased erosion from soils with poor crop cover or with little surface cover of plant residues to protect the soil. Also, increasing frequencies of freeze/thaw cycles during winter, due to reduced snow cover, in combination with stronger rainfall may greatly enhance soil erosion (Ulén et al. 2014). In addition to depleting soil fertility this erosion may also enhance nutrient runoff to sensitive aquatic ecosystems (Jeppesen et al. 2009).

Faster decomposition of soil organic matter at higher temperatures increases mineralisation of soil organic nitrogen. This in turn may increase the risk of nitrate leaching during periods of little or no crop cover with sufficient nitrogen uptake to prevent nitrate being leached in periods of precipitation surplus (Jabloun et al. 2015). This may increase the risk of nitrate leaching to surface and groundwater systems (Stuart et al. 2011; Patil et al. 2012). Current measures to reduce nitrate leaching may not be sufficient to maintain low leaching rates under projected climate change (Doltra et al. 2014) and this could increase the risk of algal blooms and the occurrence of toxic cyanobacteria in lakes (Jeppesen et al. 2011).

13.2.5 Crop Protection

Most pest and disease problems are closely linked with their host crops. Introducing new crops will therefore mean new pest and disease problems. In cool regions, higher temperatures favour the proliferation of insect pests, because many insects can then complete a greater number of reproductive cycles. Higher winter temperatures will also allow pests to overwinter in areas where they are currently limited by cold periods, causing greater and earlier infestation during the following crop season (Roos et al. 2011). Earlier insect spring activity and proliferation of some pest species will favour some of the virus diseases that spread with insects. A similar situation may occur for plant fungal diseases leading to increased need for pesticides.

Unlike pests and diseases, weeds are directly influenced by changes in atmospheric CO_2 concentration. Differential effects of CO_2 and climate change on crops and weeds will alter the weed-crop competitive interactions, sometimes to the benefit of the crop and sometimes to the weeds. Interaction with other biotic factors and with changing temperature and rainfall may also influence weed seed survival and thus weed population development.

Improved climatic suitability will lead to invasion of weeds, pests and diseases adapted to warmer climatic conditions. The speed at which such species invade depends on the rate of climatic change in terms of suitability ranges (e.g. in km per year), the dispersal rate of the species (e.g. in terms of km per year) and on measures taken to combat non-indigenous species. The dispersal rates of pests and diseases are often so high that their geographical extent is determined by the range of climatic suitability. The Colorado beetle *Leptinotarsa decemlineata* L. and the European cornborer *Ostrinia nubilalis* Hubner are examples of pests and diseases that are expected to show a considerable northward expansion in Europe under climatic warming (Olesen et al. 2011).

Studies show projected increases in the occurrence of several crop diseases with projected warming in the currently cooler parts of high-input cropping regions, such as UK (Butterworth et al. 2010; Evans et al. 2010) and Germany (Siebold and von Tiedemann 2012), whereas the risk of some diseases may reduce with warming in regions further south, such as France (Gouache et al. 2013). As well as affecting crop yield, such changes will also affect the quality of the yield, for example through the occurrence of mycotoxins which may increase in northern Europe under the projected climate change (Madgwick et al. 2011; van der Fels-Klerx et al. 2012). This would increase the need for fungicides or alternative strategies such as breeding for resistance.

13.2.6 Livestock Production

Increased temperature and more frequent extreme weather events could affect animal production through changes in feed production, changes in availability of grazing, direct heat effects on animals, and increased risk of disease.

More variable weather and more extreme weather events are projected under climate change (Jacob et al. 2014). This is likely to result in more variable quantities and quality of crops such as cereals, forage crops and protein crops, causing unstable feed prices both globally and locally. This has already occurred in recent years, with large fluctuations in grain price due to heat waves and droughts in wheat-producing regions. This has mostly affected production of monogastric livestock such as pigs and poultry. However, ruminant animals have also been affected through the production of grass and forage, either because conditions are too wet or too dry, which affects grazing. For example, in 2003 a long drought across western and central Europe severely affected not only arable crop production, but also fodder production for ruminants, to the extent that livestock production costs greatly increased (Fink et al. 2004).

Climate change will exacerbate problems with existing animal diseases, which negatively affect animal welfare and livestock production. Global warming and more frequent extreme weather events (droughts and increased rainfall) will provide more favourable climates for some viruses, their vector species, and for fungal or bacterial pathogens. New viral vector-borne diseases may not necessarily originate from nearby regions but may arrive from outside Europe. An example is bluetongue disease, where climate change has allowed the midge *Culicoides imicola* Kiefer that acts as a vector for the disease to spread—causing the virus to expand its distribution northwards in Europe (Purse et al. 2005). The risk of bluetongue and other emerging pathogens and vectors becoming established in the North Sea region will greatly increase under higher temperatures. Blood-sucking midges *Culicoides* spp. are one of the major threats to animal welfare, because they spread viruses that cause serious diseases in animals. Ticks, mosquitoes and lymnaeid snails can also transmit extremely harmful diseases to livestock. Increased annual temperature, milder winters and higher rainfall will favour the propagation of helminth parasites, resulting in disease and pronounced negative effects on the welfare of grazing cattle and sheep (Skuce et al. 2013).

13.3 Adaptation, Vulnerabilities and Opportunities

13.3.1 Adaptation at Farm and Regional Scale

Farmers are already adapting to climate change since farming is very weather dependent. Farmers constantly experiment with new cropping techniques, and the most successful ones spread quickly among the farming community where agricultural advisors and researchers are ready to take up and disseminate new results. This is evident, for example, in the northward spread of silage maize into Denmark and southern Sweden (Odgaard et al. 2011). Such adaptations are autonomous in the sense that they require no external action or planning. In a European context they are also fairly effective due to the high capacity among farmers to incorporate new technologies and management practices.

Adaptation only works when the basic resources for crop growth are still maintained and when the climate allows proper soil and crop management to take place (Table 13.2). In northern areas climate change may have positive effects on agriculture through introducing new crop species and varieties, higher crop production and expansion of areas suitable for cultivation. Negative effects may be an increase in the need for plant protection, risk of increased nutrient leaching and the degradation of soil organic matter. Further south in Europe issues around managing drier summer conditions will dominate adaptation needs.

The responsiveness of agricultural systems to climate change depends on many factors, both how current crops are being affected by climate change, but also on the options available for modifying the systems to reduce negative impacts and take advantage of new opportunities. The capacity for agriculture in the North Sea region to adapt to future changes is expected to be good, since the changes could be largely favourable for production, and because research, educational and advisory capacities are high (Table 13.2). However, there may be barriers to adaptation, not least within the current agricultural and environmental policies that may have to be adjusted to ensure effective adaptation.

Table 13.2 Resource-based policies to support adaptation of agricultural systems to climate change (adapted from Olesen and Bindi 2002)

Resource	Policy
Land	*Reforming agricultural policy to encourage flexible land use.* The great extent of cropland in northern Europe across diverse climates will provide diversity for adaptation
Water	*Reforming water management to ensure balance between maintaining the amount and quality of water resources and the ecosystems that these support, with the needs of agricultural production*. Climate change will affect the demand for irrigation and drainage, which depending on location have consequences for water resources and their ecological quality and may affect needs for revising management and governance schemes
Nutrients	*Improving nutrient use efficiencies through changes in cropping systems and development and adoption of new nutrient management technologies.* Nutrient management needs to be tailored to the changes in crop production as affected by climate change, and utilisation efficiencies must be increased, especially for nitrogen, in order to reduce climate change induced emissions to water and air
Agrochemicals	*Support for integrated pest management systems (IPMS) should be increased through a combination of education, regulation and taxation.* There will be a need to adapt existing IPMS to changing climatic regimes
Energy	*Improving the efficiency of food production and exploring new biofuels and ways to store more carbon in trees and soils.* Reliable and sustainable energy supply is essential for many adaptations to new climate and for mitigation policies
Genetic diversity	*Assembling, preserving and characterising plant and animal genes and conducting research on alternative crops and animals*. Genetic diversity and new genetic material will provide important basic material for adapting crop species to changing climatic conditions, such as by improving tolerance to adverse conditions
Research capacity	*Encouraging research on adaptation, developing new farming systems and developing alternative foods.* Greater investment in agricultural research may provide new sources of knowledge and technology for adaptation to climate change
Information systems	*Enhancing national systems that disseminate information on agricultural research and technology, and encouraging information exchange among farmers.* Fast and efficient information dissemination and exchange to and between farmers using the new technologies (e.g. internet) will increase the rate of adaptation to climatic and market changes
Culture	*Integrating environmental, agricultural and cultural policies to preserve the heritage of rural environments in a new environment*. Integration of policies will be required to maintain and preserve the heritage of rural environments which are dominated by agricultural practices influenced by climate

Some of the adaptation is beyond farm scale, and requires collective action. This is the case for breeding new cultivars and for infrastructure projects that provide water for irrigation or for improving drainage at the catchment scale. Such efforts may have long time perspectives and involve many actors and so require planning and in some cases approval from authorities. Actions for managing water at the catchment scale require a consideration not only of the needs of farmers, but also of the needs of human settlements and nature conservation, including consideration of surface and groundwater quality (Refsgaard et al. 2013).

Plant and livestock breeding is one of the most effective options for adapting to climate change, as well as switching livestock and crop species used. Among the measures required for both plant and livestock breeds is to increase tolerance to heat stress events (Semenov et al. 2014). For plants, there is also a need to enhance tolerance to a wider range of stresses, including drought, extreme heat and flooding. Soil management will need to accommodate the projected increase in frequency and intensity of erosion events associated with more intense rainfall. This may involve trade-offs between various factors that all contribute to crop yield. Therefore there is a risk that higher yield stability may come at the cost of reduced yield in favourable years. Plant breeders will need to deliver cultivars that are more resilient to weather extremes and resistant to new diseases. Plant breeding is a long-term activity, and timely delivery of such cultivars will require good and early predictions of future environmental conditions to allow the development and use of suitable germplasm.

13.3.2 Role of Vulnerability and Uncertainty in Adaptation

Projecting the effects of climate change on agricultural systems involves many uncertainties, some concern the climate change projections themselves while others concern biophysical understanding of how crops and livestock will respond to climate change. However, an even larger uncertainty concerns how well farmers and agricultural systems can and will adapt to climate change in the longer term in order to minimise losses and take advantage of new opportunities (Moore and Lobell 2014). Part of the uncertainty lies in how quickly some of the longer-term adaptations needed to overcome major changes in climate (expanding irrigation or drainage systems, new crops etc.) can be implemented, since short-term adaptations (e.g. changes in varieties or sowing time) are likely to be much less effective (Fig. 13.2). In southern Europe, farming profits are expected to decline

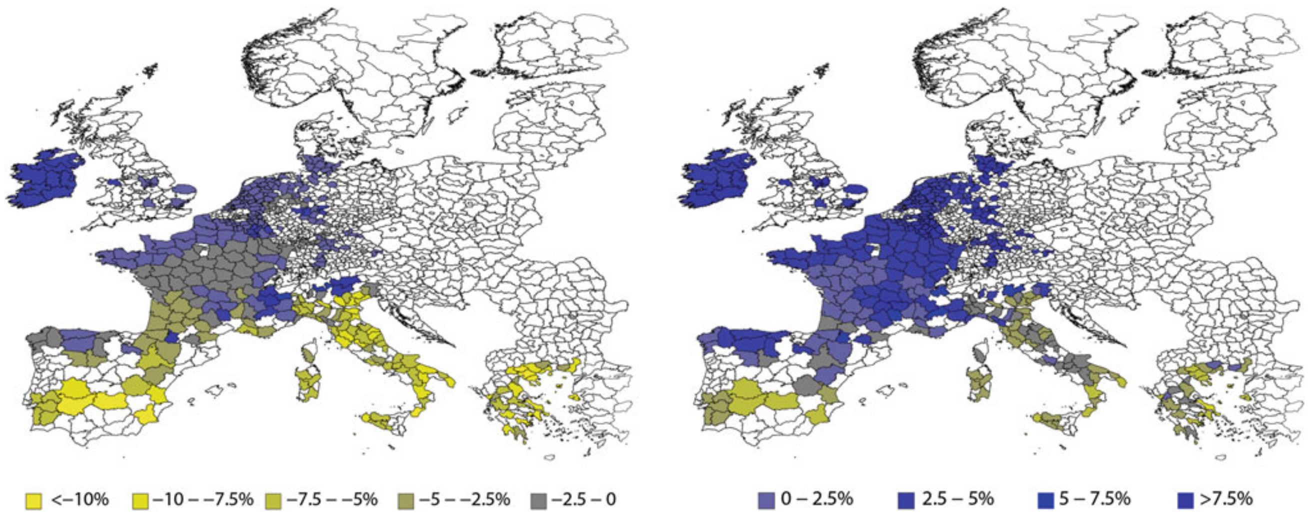

Fig. 13.2 Projected change in farm profit by 2040 under the IPCC A1B scenario for selected growing regions in Europe. Data concern wheat, maize, barley, sugar beet and oilseed. Projections made with short-run response function of crop yield to temperature and precipitation (*left*) and projections made using a long-run response function that includes farm-level adaptations (*right*) (Moore and Lobell 2014). White areas reflect regions with insufficient data

under climate change, while the North Sea region may see a rise in farming profits, particularly over the long term.

Temperature and rainfall regimes in combination with soil properties dictate the potential for agricultural production. Thus climate change, particularly in terms of dryness or wetness will affect agricultural land use, and even moderate changes may have marked effects on land use, especially for soils that are borderline with respect to which crops can be grown (Brown et al. 2011). Such areas are therefore more sensitive to environmental change than areas that are clearly favourable or unfavourable for specific agricultural land uses under both current and future climatic conditions.

Adapting to increased frequency of extreme weather events may be a significant challenge, since extreme events are by nature difficult to predict and so are also difficult to prepare for. Even with statistical evidence that shows extremes are changing in frequency such information may be interpreted differently among decision makers, resulting in over- as well as under-adaptation (Refsgaard et al. 2013).

The European agricultural sector is regulated and financially supported in several ways. Therefore, a major consideration must be how the adaptation responses will interact with regulations on environmental and nature protection, as well as on issues such as food safety and local employment. The vast amount of EU support for farming may be used strategically to support adaptations that maintain the balance between the need for high-production output of healthy and safe foods on the one hand and the need to protect the environment as well as the agricultural resource base on the other.

13.4 Ecosystem Functions and Services

Climate change impacts on agricultural production will vary across the North Sea region, both in terms of crops grown and yields obtained. Overall, there seems to be potential for adapting to the changing climate in such a way that productivity and profitability may both increase. In some parts of the region, a longer growing season would enable a switch to longer season crops such as highly productive grasses or *Miscanthus*, which with the use of biorefinery technologies could increase the output not only of food and feed for livestock, but also of the production of biofuels as a fossil fuel substitute (Smith and Olesen 2010). Because similar increases are not projected for most annual crops, this may facilitate changes in cropping systems, provided the technologies become profitable.

In grasslands, a longer growing season would allow more cuts and higher production, particularly in areas less affected by summer drought. This may facilitate greatly increased production of protein-rich crops by cultivating highly productive grass-clover pastures with little fertiliser and pesticide use. These pastures may be harvested for feed or grazed by ruminant livestock such as dairy and beef cattle and sheep. The pastures may also be a new source of sustainable protein production for monogastric farm animals (pigs and poultry) as well as for farmed fish. This would require the development and implementation of new biorefinery technologies, for which Europe with its ability to combine advanced technologies may be particularly well suited (Parajuli et al. 2015). This would strengthen the role of northwest Europe as a continued supplier of food, but also as a supplier of the technologies for sustainable intensification of production systems that target both adaptation and mitigation to climate change.

Changes in climatic suitability may lead to major changes in land use, which would affect not only the production of goods in agriculture, but also the landscape and ecosystem services (such as the quality of nature, the environment, groundwater and freshwater systems) (Harrison et al. 2013). This would challenge current land use planning, and would call for a strategic, long-term perspective on land-use policy under climate change (van Meijl et al. 2006).

In arable farming systems, higher temperatures will enhance turnover of soil organic matter and this, in combination with increased and more intense rainfall, would enhance the risk of nitrogen and phosphorus losses to the aquatic environment, thereby threatening the quality of these waters for recreational use and fish production. New and revised policy may be needed to manage the environmental impacts of agricultural production. Likewise, an increased need for pesticide use in agricultural production would be problematic in relation to current EU pesticide policies.

Policies will need to promote active resource management and the utilisation of renewable raw materials as substitutes for metal and oil-based products and fossil fuels. This is essential for sustainable resource management, as well as for mitigating climate change. Resource management of this type would need to take multiple needs into consideration, including: provision of biomass for food, feed, bioenergy and biomaterials within the bioeconomy; recycling of nutrients and resilient organic matter to the agricultural systems; maintenance of soil carbon stocks; and provision of other ecosystem goods and services, such as clean water and air and a diverse natural environment.

Cultivation of agricultural crops requires suitable and well-drained soils. The anticipated increase in winter rainfall across large parts of the North Sea region would place additional stresses on current drainage systems. This issue is expected to become increasingly important in areas where agricultural production may expand due to increased suitability. Enhancing drainage of agricultural soils cannot be implemented without ensuring that water can be effectively transported in streams and rivers. Aligning drainage needs with the need to protect parts of the landscape from flooding may cause conflict among actors, and will require new planning at the landscape and catchment level. Similar considerations must be taken into account when preparing for increased risk of summer drought.

13.5 Conclusions

Agricultural systems in northwest Europe are generally characterised by high inputs of fertilisers and pesticides and resulting high crop yields and livestock productivity. Observations over recent decades show consistent changes in crop phenology and geographical shifts towards higher latitudes of intensive crop cultivation in accordance with observed climate change. The observed effects on crop yield range from negative (dominating for cereal and seed crops) to positive (dominating for non-determinate crops such as many forage and grass crops). The combined effects of enhanced CO_2 and changes in temperature and precipitation are expected in many cases to increase productivity. Model-based and empirical studies show an increased risk of higher interannual yield variability with the projected climate change, resulting from changes in interannual temperature variability as well as from nonlinearities in the response of crops to changes in temperature and rainfall, increasing the risk of low yields. Negative effects on crop yield may be further exacerbated by extreme temperature and rainfall events. Climate change will further increase needs to reconsider measures for dealing with soil fertility, crop protection and nutrient retention in intensive cropping systems.

To contribute to global food security and help mitigate agricultural greenhouse gas emissions, there is a need to focus on sustainable intensification of agricultural production (Tilman et al. 2011). The challenges in the North Sea region will be to ensure sustainable growth in agricultural production without compromising environment and natural resources. This is likely to require the development of new production systems with a greater use of perennial crops such as grasses or increased use of cover crops in the rotations to make use of a longer growing season and to protect the soil and wider environment from erosion and nutrient leaching.

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Socio-economic Impacts—Offshore Activities/Energy

14

Kirsten Halsnæs, Martin Drews and Niels-Erik Clausen

Abstract

The energy sector has a strong presence in the North Sea and in the surrounding coastal areas. Commercial extraction of offshore oil and gas and related activities (exploration, transportation and distribution; pipelines; oil refining and processing) constitutes the single most important economic sector and renewable electricity generation—mainly from offshore wind—is increasing. Energy and offshore activities in the North Sea are critically vulnerable to climate change along the full supply chain. The major vulnerabilities for offshore installations like rigs, offshore wind energy and pipelines concern wind storms and extreme wave heights, whereas on land coastal installations and transportation may also be adversely affected by flooding. Future renewable energy potentials in the North Sea are also susceptible to climate change. Whereas the hydropower potential is expected to increase, it is highly uncertain how much the future potential of other renewable energy sources such as wind, solar, terrestrial biomass, or emerging technologies like wave, tidal or marine biomass could be positively or negatively affected. Due to the different national energy supply mixes the vulnerability to climate-related impacts will vary among North Sea countries. To ensure safe and reliable future operations comprehensive and systematic risk assessments are therefore needed which account for, for example, the high integration of power systems in the region.

14.1 Introduction

Reliability and security of the energy supply are of critical socio-economic importance and safety at sea is one of the main concerns for offshore industries in general. The offshore energy sector is particularly vulnerable to future changes in climate. This includes changes in metocean conditions (the combined wind, wave and climate conditions as found at a certain location), in relation to the full energy supply chain from resource extraction, to pipelines, refineries, conversion, and transmission (e.g. Ebinger and Vergara 2011). Maintenance and operation as well as energy demand are also likely to be influenced by climate change. This chapter reviews some of the main risks and potential for offshore and energy activities in maritime and coastal areas; with a focus on energy supply and on selected economic sub-sectors within the North Sea region that are considered particularly climate sensitive, including offshore oil rigs and wind farms.

14.2 Climate Vulnerabilities in the North Sea Region

The major climate vulnerabilities in terms of resource extraction in the North Sea region are associated with the operation and maintenance of offshore oil and gas

K. Halsnæs (✉) · M. Drews (✉)
Systems Analysis, DTU Management Engineering, Lyngby, Denmark
e-mail: khal@dtu.dk

M. Drews
e-mail: mard@dtu.dk

N.-E. Clausen
DTU Wind Energy, Roskilde, Denmark
e-mail: necl@dtu.dk

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Table 14.1 Overview of climate change risks on energy conversion

Conversion technology	Gradual climate change	Extreme weather events
Thermal power plant	Rising temperature implies decreased thermal efficiency and cooling efficiency	Damage to plant from storms Lower efficiency of cooling
Oil refinery and gas treatment	Sea-level rise and flooding	Flooding emergency Water scarcity disturbs production
Nuclear power plant	Cooling water scarcity	Damage to plant from flooding or storms
Wind power	Less frequent icing Dust from precipitation Flooding at coastal sites	Structural damage from storms Operation and maintenance
Solar energy	Lower efficiency of photovoltaic systems with higher temperature Higher efficiency of solar thermal heating systems with higher temperatures	Structural damage from storms, hail and heavy precipitation
Hydropower	Decreased potential in some areas and increased potential in others	Damage to dams

Adapted from Troccoli et al. (2014)

infrastructure, principally rigs and pipelines, due to their susceptibilities to wind storms and extreme wave heights (Vanem and Bitner-Gregersen 2012; Bitner-Gregersen et al. 2013; IEA 2013).

Climate change effects are also expected to have a significant impact on renewable energy sources (e.g. EEA 2012; Weisse et al. 2012). Some of the projected impacts include: changes in wind and wave energy potential; changes in hydropower potential (i.e. related to precipitation and temperature); changes in solar energy production (i.e. dependent on solar radiation and temperature); and variations in biomass for energy (i.e. related to the climate-related productivity of dedicated crops, and indirectly influenced by agricultural productivity and food security).

In addition to effects on resource extraction, the energy system is also influenced by vulnerabilities related to energy conversion. Table 14.1 provides an overview of major risks and shows that energy conversion is sensitive both to gradual changes in the mean and variance of climate parameters such as temperature and precipitation and to the projected intensification of extreme weather events in the North Sea region. The efficiency of many existing plants is expected to decline with higher temperatures, for example cooling will be more difficult, and damage from storms and flooding can disrupt energy supply with significant consequences for the economy and for disaster management in the case of extreme weather events. The International Energy Agency (IEA) estimates that for a 1 °C rise in temperature by 2040, 20 % of coal-fired power plants in Europe would need additional cooling capacity, whereas the electricity production capacity could be reduced by up to 19 % during summer (IEA 2013: their Table 3.2). In contrast, Thorsteinsson and Björnsson (2012) concluded that the projected increase in precipitation implied a potential increase in hydropower-based electricity production in the Nordic countries of about 10 % by 2050.

14.3 National Energy Supply Mixes

The vulnerability of energy systems around the North Sea to climate change must be seen in relation to the supply structure of individual countries. Figures 14.1 and 14.2 provide an overview of the present sources of electricity generation in the North Sea region and may be used to highlight some of the key risks.

In 2013, coal and peat accounted for about 32 % of the total electricity generation in the North Sea region, gas for

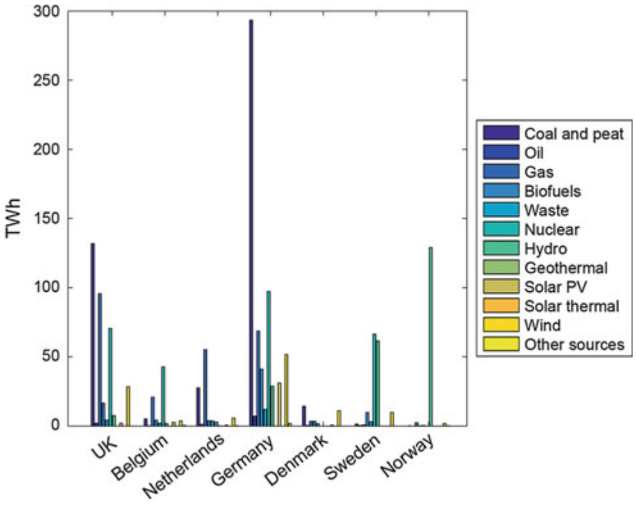

Fig. 14.1 Total electricity generation by source in 2013 (TWh) for North Sea countries (www.iea.org/statistics)

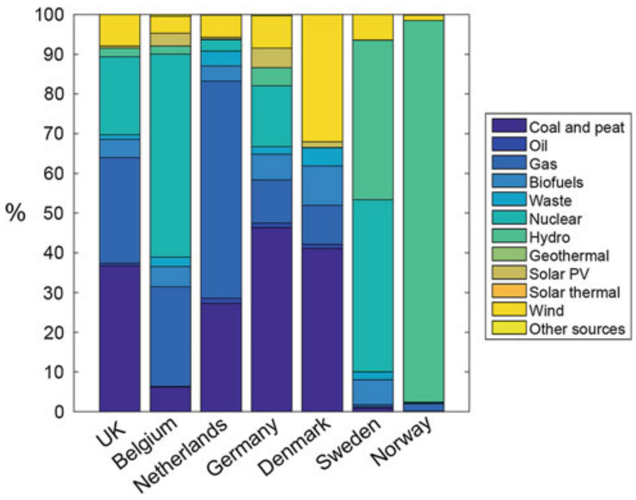

Fig. 14.2 Percentage composition of electricity generation by source in 2013 for North Sea countries (www.iea.org/statistics)

about 16 %, and nuclear for about 19 % (Fig. 4.1). In terms of renewable energy sources, hydropower accounts for about 15 % of total electricity generation and wind for 7 %. Several countries bordering the North Sea depend largely on coal and gas plants (the UK, Netherlands, Germany and Denmark), while nuclear power is important in others (Belgium and Sweden). Sweden, and especially Norway are highly dependent on hydropower. The different national energy supply mixes (Fig. 4.2) show that the projected climate-related impacts on electricity generation will vary on a country-by-country basis. The combined impacts of climate change on the energy system, whether related to gradual changes in mean climate parameters and their variations or to extreme weather events will also depend on the highly interconnected nature of the electricity markets, which is particularly strong in northern Europe and the possible correlation (e.g. in time) of climate and non-climate related stressors affecting the different fuel sources. Countries like Denmark that aim to base electricity generation on very large shares of fluctuating energy sources (e.g. wind energy), could thus become even more dependent than today on electricity trade with the Scandinavian market, such as for another climate-impacted energy source like hydropower (Halsnæs and Karlsson 2011).

Energy demand is also likely to be affected by climate change. Higher temperatures are likely to lead to decreased demand for space heating during winter, but to an increased demand for cooling in summer, especially in cities (e.g. Aebischer et al. 2007). The IEA has estimated that the energy demand for space heating could decrease by about 12 % by 2050 (IEA 2013) and that this decline could be particularly strong in northern Europe due to the current relatively high demand for space heating.

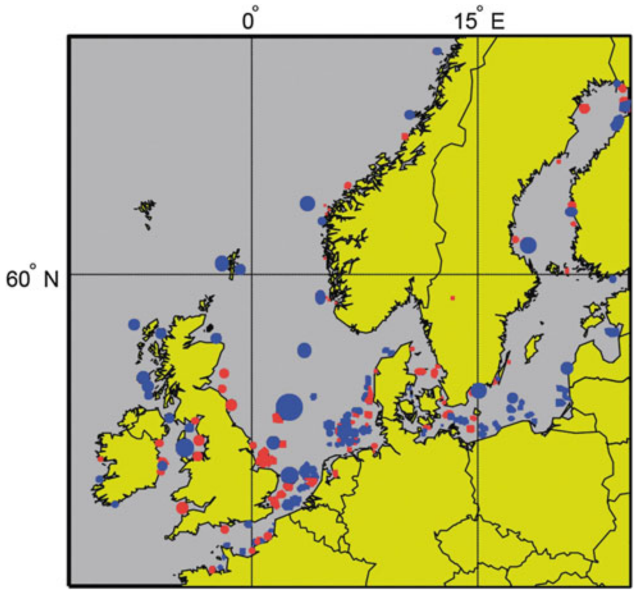

Fig. 14.3 Future offshore wind power development in Northern Europe aligned with the wind energy targets for 2020 (41 GW, *red*) and 2030 (107 GW, *blue*) from the European Wind Energy Association (2014) (Hvidtfeldt Larsen and Sønderberg Petersen 2015)

14.4 Renewable Energy Sources

Energy supply by means of renewable energy sources is expected to increase dramatically as the European Union aims to increase its share of energy consumption from renewable resources to 20 % by 2020. Options include offshore wind, hydropower, bioenergy, solar, wave energy and tidal power. They are all electricity-generating renewable technologies. Two of these technologies—offshore wind energy and hydropower—are well developed and already fully integrated into the energy system, while solar photovoltaics (PV) are in the commercial phase for land-based applications only. Likewise, the production of bioenergy/biofuels, such as from energy crops, has been extensively explored for land-based applications (see Chap. 13), whereas large-scale energy generation from marine biomass is still at an experimental stage.

Wind power is by far the most exploited renewable offshore technology in the North Sea area. Several recent initiatives, including three research and development projects funded by the European Union's Seventh Framework Programme *The Ocean of Tomorrow,*[1] explore the synergies of different renewable technologies in designing new floating offshore platforms powered by a combination of several renewable energy sources. The platforms also include aquaculture, leisure and transport options.

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[1] http://ec.europa.eu/research/bioeconomy/fish/research/ocean/index_en.htm.

14.4.1 Offshore Wind Energy

More than 80 % of all offshore wind farms are installed in four countries bordering the North Sea: the UK, Denmark, Germany and Sweden, future development plans are shown in Fig. 14.3. A recent report by the European Wind Energy Association described the current status of the European offshore wind farms (EWEA 2014; Navigant Research 2014):

- 2080 turbines are installed and grid-connected offshore, accounting for a cumulative capacity of 6.5 GW divided onto 69 wind farms in eleven European countries.
- The offshore wind farms generate 24 TWh in an average year. Including land-based wind farms this corresponds to about 204 TWh generated in an average year or about 7.3 % of Europe's total electricity consumption.
- Twelve offshore projects are currently (2014) under construction corresponding to about 3 GW, which will bring the cumulative capacity in Europe to 9.4 GW.
- The average water depth of all wind farms in operation in 2013 is about 16 m and the average distance to shore 29 km.

Offshore wind energy technology is sensitive to changes in average wind speed, extreme wind speed, sea level, atmospheric icing and the extent and duration of sea ice.

The local wind climate represented by the average wind speed is the single most important factor in determining annual electricity generation by a wind farm and thereby the economy of single wind farms and of European offshore wind farms in general. Current climate projections (see Chap. 5) suggest largely unchanged average wind speeds in the North Sea area but as these projections have large uncertainties, considerable changes in generation potential cannot be ruled out.

'Extreme wind', defined as winds with a return period of 50 years (U_{50}) is an important design parameter for offshore wind turbines and used to define the durability of turbines. In general, strong winds are more important than extreme winds for the operation of an offshore wind farm as they occur much more frequently, for example strong winds with wind speeds exceeding 17 m s^{-1} occur as often as for 3–4 days per year at 10 m height in the Fehmarn Belt between Denmark and Germany. Strong winds are commonly described as winds above the 99th percentile (Thorsteinsson and Björnsson 2012) and are important for several reasons. First, during the planning period, the developer must compare potential wind farm sites and different operation and maintenance strategies. Second, in the daily planning of maintenance, strong winds and wind-induced waves have a large influence upon the ability to deploy vessels for installation and maintenance activities and thus on decision-making regarding such operations. Very strong winds (above 25 m s^{-1}) can result in periodic shutdowns due to structural safety. While this leads to a minimal loss of energy generation overall, such events are a challenge for the transmission systems operators who may need to cope with losing a large part of the electricity generating capacity within a few hours and with loads cycling on and off the grid potentially many times within a relatively short period.

Future climate projections for the North Sea (see Chap. 5) indicate that the number of storms towards the end of the century could remain at the same level as in the present-day reference period. The extreme wind speed U_{50} on the other hand could increase by as much as 10 % above present-day extremes in some areas, with the uncertainty of the same order as the estimated increases in extreme wind speed. This is likely to influence slightly the design of the wind turbines and possibly have a (minor) influence on the price of a wind turbine (Tarp-Johansen and Clausen 2006). Changes in strong winds may have a larger impact as they influence the time schedule during construction in general and in particular for crane work during erection of the wind farm. Maintenance activities are also affected by strong winds and boat transport of service crew and spare parts may be periodically difficult or impossible (Fig. 14.4).

Atmospheric icing and sea ice are rare in the North Sea (even though the Baltic Sea partly freezes every year) due to warming from the Gulf Stream. Thus higher temperatures are expected to have only minor influence on offshore wind energy generation.

14.4.2 Hydropower

Hydropower is the most important renewable energy source in Norway, where it currently covers about 99 % of Norway's electricity demand (Chernet et al. 2013). Hydropower also plays an important role in Sweden and makes a significant contribution to energy systems in the UK, Germany and Belgium. Small-scale hydropower plants (<10 MW) generate electricity by converting power from flowing water in rivers, canals or streams, while larger-scale plants often include dams and storage reservoirs to retain water.

Hydropower systems in the North Sea region will be strongly affected by the projected climate change (Thorsteinsson and Björnsson 2012; Chernet et al. 2013). The potential for hydropower is projected to rise by up to 20 % in northern and eastern Europe towards the end of the century. This is due to increased inflow to the hydropower systems from precipitation and snow melt and contrasts with the future decrease in hydropower potential projected for southern Europe.

Fig. 14.4 Installation of wind turbine at Horns Rev II wind farm (Picture provided by DONG Energy)

Hydropower production is sensitive to changes in both total runoff and its timing, and so any increase in climatic variability, even with no change in annual runoff, is likely to affect hydropower performance. Performance also depends on several other factors that are all inherently vulnerable to climate change, including reservoir design, operation strategies, dam safety, and distributions of floods and droughts. Thorsteinsson and Björnsson (2012) showed that climate change may have critical significance for dam safety and flood risk and so is likely to influence the future design and operation of hydropower plants.

14.4.3 Solar Energy

Solar energy is playing an increasingly important role in Europe. Currently, the two main technologies for generating energy from the sun are photovoltaics and solar thermal heating and most applications are land-based. In the North Sea region the largest contributions are found in Belgium and in particular in Germany, where about 7.6 GW of newly connected photovoltaic systems were installed in 2012 alone—the most in the world.

The adverse effects of climate change on solar energy primarily concern damage due to extreme weather events such as storms and heavy precipitation. In addition, some types of photovoltaic systems are sensitive to temperature, that is, their performance declines at higher temperatures (Troccoli et al. 2014). In contrast, solar thermal heating systems generally gain from increasing temperatures. Current climate projections for northern Europe (see Chap. 5) indicate small increases in sun hours (reduced cloud cover) during summer and small decreases in sun hours (increased cloud cover) during winter, but are generally associated with large uncertainties. The performance of both solar thermal heating and photovoltaic systems would thus be expected to improve during summer and decline during winter. Given the dominant uncertainties, however, future technological developments are likely to far outweigh the impacts of climate change.

14.4.4 Wave and Tidal Energy

Wave energy is an emerging technology, which is expected to see future use in the North Sea both in the coastal zone and offshore. Several conceptual designs are being tested or are at a prototype or demonstration stage worldwide. Devices still need to prove their integrity and reliability both during normal operations as well as extreme conditions. If successful some designs, in particular shoreline and near-shoreline devices, could reach commercial status within a decade. Wave energy devices are expected to be highly susceptible to the projected changes in metocean conditions and especially to extreme weather events (see Chap. 5).

The potential of tidal energy generated from either tidal impoundment or tidal streams is very low in the North Sea except near the UK coast, where it is slightly higher (Carbon Trust 2005). Currently, a range of demonstration projects are being implemented, and two commercial-scale power plants are in operation—one in Brittany, France. To date, no studies have highlighted specifically the climate change

Table 14.2 Vulnerability of the oil and gas sector to climate change

Climate change	Oil and gas activities	Potential impacts
Higher temperatures	Extraction and transportation	Arctic sea-ice decline could lead to increased exploration and increased access for shipping
	(Oil) refining	Reductions in steam turbine effectiveness might lead to higher energy costs; higher temperatures could affect plant design and operational requirements, materials, and process efficiency
	Delivery and distribution	Low impacts (e.g. extreme temperatures have the potential to cause maintenance problems)
Heavy rain, river floods, sea-level rise	Extraction and transportation	Low impacts however onshore transportation could be affected
	(Oil) refining	Flooding of critical infrastructure may cause serious damage and shutdown of operations
	Delivery and distribution	Soil erosion may expose buried pipelines; exposed pipeline sections may suffer damage; transportation by vessel, pipeline, road and rail may suffer flood-induced disruption and damage
Storms and storm surges, extreme wave heights	Extraction and transportation	Significant damage to offshore and onshore installations and equipment will disrupt and possibly shut down operations entirely; possible environmental consequences; increased focus on safety; new design standards
	(Oil) refining	
	Delivery and distribution	Transportation by vessel, pipeline, road and rail may suffer storm or flood-induced disruption and damage
Lightning	Extraction and transportation	Oil and gas pipelines may be damaged by lightning strikes, which may lead to increased corrosion, ignition, and operational disruption
	(Oil) refining	Risk of explosions or fires due to hazardous materials
	Delivery and distribution	–

Based on Cruz and Krausmann (2013 and references therein)

impacts on tidal technologies, but it is clear that tidal turbines like wave energy devices are highly vulnerable to the projected changes in extreme wind and wave conditions in the North Sea and this could influence the operation of such installations and increase the risk of damage.

14.4.5 Marine Biomass

The production of marine biomass like microalgae for bioenergy and/or biofuel has emerged as a promising renewable energy source (e.g. Roberts and Uphamb 2012; Jard et al. 2013). Extensive research and development activities are ongoing; a demonstration case for offshore applications has also been successfully developed by the National University of Ireland, Galway (Edwards and Watson 2011). Results suggest that use of marine biomass if commercially realised could potentially be as large and comparable to existing land-based forestry and agricultural energy crops. The potential of marine biomass as a future energy source would be affected by climate-related changes in the marine ecosystem (see Chap. 8). Likewise, offshore installations would be subject to changes in the frequency and/or intensity of wind and wave extremes.

14.5 Fuel Extraction

Commercial extraction of offshore oil and gas along with related activities such as exploration, transportation and distribution; pipelines; and oil refining and processing at present constitutes the single most important economic sector in the North Sea. Five countries are involved in oil and gas extraction in the North Sea: Norway, Denmark, Germany, Netherlands, and the UK. While oil and gas reserves in the North Sea and thus revenues are expected to decline over the course of the century, industry continues to push the boundaries of oil and gas exploration technology. Even with the expansion in renewable energy sources it is highly likely that the oil and gas sector will continue to be critically important in the North Sea.

A warming climate with stronger and more frequent extreme weather events will pose serious challenges to the oil and gas sector (Bitner-Gregersen et al. 2013; Cruz and Krausmann 2013). Structural failure of offshore structures may result in a loss of lives, severe environmental damage, and large economic consequences. Climate change impacts are likely to affect the entire value-chain of the sector, particularly activities in low-lying areas or areas exposed to extreme weather events. Table 14.2 summarises some of the main vulnerabilities related to oil and gas extraction in the North Sea.

Several researchers, including Cruz and Krausmann (2013) and Bitner-Gregersen et al. (2013), have argued that comprehensive and systematic risk assessment frameworks are needed to manage emerging risks to the offshore oil and gas sector from climate change. This is to ensure that present and future design standards for offshore and onshore infrastructure, maintenance and operations reflect the actual physical threats posed by climate change while remaining acceptable from an economic, societal and environmental perspective. Adaptation options could in some cases require significant investment to upgrade facilities, protect critical infrastructure and build redundancy and robustness into systems.

14.6 Conclusion

Energy systems and offshore activities in the North Sea region of which offshore wind, oil and gas dominate are virtually certain to be affected by climate change. While most studies show that hydropower potential is expected to increase, climate projections are highly uncertain regarding how much the future potential of other renewable energy sources such as wind, solar, terrestrial biomass, or emerging technologies like wave, tidal or marine biomass could be positively or negatively affected. Offshore and onshore activities in the North Sea region are very vulnerable to extreme weather events like extreme wave heights, storms and storm surges. To ensure safe and reliable operations and to mitigate the possible loss of lives and economic assets it is necessary to take action to prevent the potentially negative effects of climate change and to develop comprehensive and systematic risk assessment frameworks, which incorporate climate projections and environmental data.

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Socio-economic Impacts—Urban Climate

15

K. Heinke Schlünzen and Sylvia I. Bohnenstengel

Abstract

About 80 % of the population within the North Sea countries currently lives in an urban area and this percentage is projected to continue to rise. Urban areas are not only impacted by changes in regional climate but are themselves responsible for causing local modifications in regional climate resulting in the so-called ‘urban climate’. The urban climate in North Sea cities has several common features: higher temperatures relative to the surrounding regions (especially at night), greater temperature variability, deeper but less stable boundary layers at night, lower average wind speeds but stronger gusts, reduced evapotranspiration, and greater air pollution (local exceedances of limit values for nitrogen oxides, nitrogen dioxide and particulate matter, with ship emissions a relevant contributor in harbour cities). Indications of climate change are now apparent and include hinterland flooding, more intense precipitation, and drier and warmer summers. Cities contribute to greenhouse gas emissions and measures are needed to reduce these. Cities also need to adapt to climate change. Despite broad similarities between urban areas, in terms of mitigation and adaptation to climate change there are large location-specific differences with regard to city planning needs. Hamburg and London are used as examples. Adaptation measures include better insulation of buildings to reduce energy use and anthropogenic heat emissions, higher dykes to protect against increased water levels, and rain water drainage to avoid hinterland flooding. Scenarios are outlined for urban development with greened roofs, higher albedo values and lower sealing of surfaces.

15.1 Introduction

Worldwide every second person lives in a town; in the North Sea region the percentage is even higher. About 80 % of the population within the North Sea countries currently lives in an urban area and this percentage is projected to continue to rise (Fig. 15.1). Nine out of ten citizens are predicted to be living in an urban area by the middle of this century. This level of urbanisation is higher than in Europe as a whole or worldwide, but is similar to that of the United States. The megacity of London (~14 million people) is located on the periphery of the southern North Sea, as are several metropolitan areas with at least 1 million inhabitants (Rotterdam, Hamburg, Amsterdam, Antwerp). Because so many people live in urban areas it is important to understand the interrelations between regional and urban climate and how both will develop over time.

The urban climate is affected by the regional climate and specific local characteristics such as closeness to the ocean or nearby mountains. Most urban areas in the North Sea region (e.g. Amsterdam, Antwerp, Hamburg, London, Rotterdam) experience a warm temperate climate, which is fully

K.H. Schlünzen (✉)
Institute of Meteorology, CEN, University of Hamburg, Hamburg, Germany
e-mail: heinke.schluenzen@uni-hamburg.de

S.I. Bohnenstengel
Department of Meteorology, University of Reading, Reading, UK
e-mail: s.i.l.d.bohnenstengel@reading.ac.uk

Present Address:
S.I. Bohnenstengel
MetOffice@Reading, University of Reading, Reading, UK
e-mail: sylvia.bohnenstengel@metoffice.gov.uk

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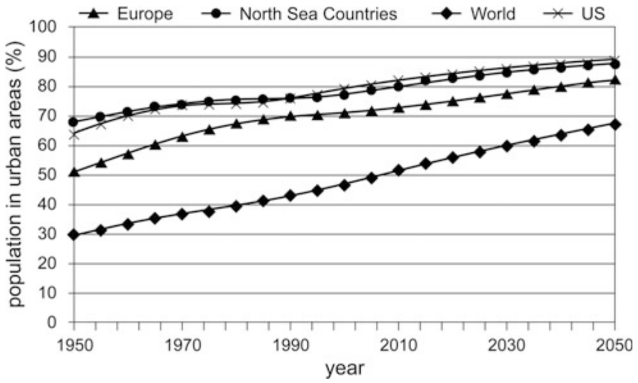


Fig. 15.1 Development of urbanisation in countries bordering the North Sea and other regions of the world (based on UN 2014)

humid with a warm summer (Class Cfb following the Köppen-Geiger climate classification as given by Kottek et al. 2006). Only in the northernmost part of the North Sea region is snow a regular winter feature, which means cities such as Oslo or Bergen are on the margin of the Dfb Köppen-Geiger climate class. More details of the North Sea climate can be found in Chaps. 1 and 2.

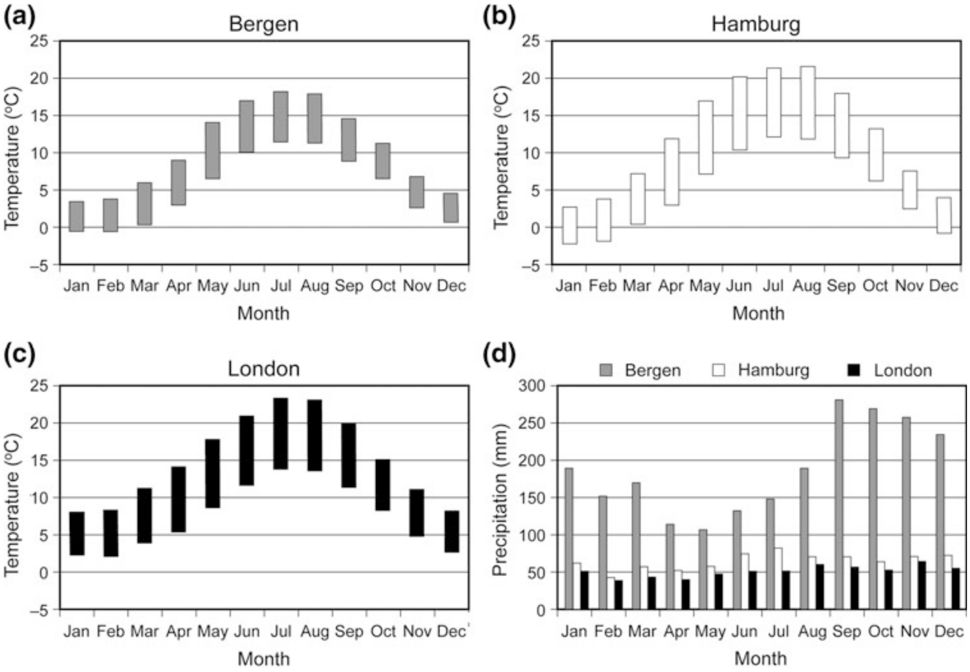
The proximity of the large metropolitan areas to the North Sea implies they are generally located in low altitude areas; some parts are even partly situated below sea level (see Annex 5, Fig. A5.1). This is especially true for the urban areas of the Netherlands (Amsterdam, Rotterdam, The Hague and Utrecht), but also for Antwerp, London or Hamburg. Although for the latter at least some parts of the metropolitan area are 10 m or more above sea level. As a result, adaptation to climate change in a coastal urban area means it is important to consider potential changes in sea level, river level, storm surge and connected groundwater level (Schlünzen and Linde 2014). However, while for city planners the rise in sea level (Chaps. 3 and 6) and river level are extremely important, they have little impact on urban climate and so fall outside the scope of this chapter (see Chap. 18 for discussion on this topic). Soil water is relevant, however, since its availability could affect evapotranspiraration and thus temperature and humidity in an urban area (Sect. 15.4.2).

15.2 Urban Climate in the North Sea Region

Any changes in the natural conditions of an area will modify the regional climate such that it is locally altered, resulting in a so-called 'urban climate' in the case of urban areas. Local modifications to regional climate in urban areas largely depend on the urban fabric (e.g. building height, percentage of sealed surfaces, building materials, atmospheric emissions), and for North Sea cities result in several common features:

- *Higher temperatures.* These result from changes in the surface energy budget due to urban fabric having greater heat storage than vegetation in rural areas. In urban areas, heat is stored during the day and then emitted during the evening and at night, supplemented by anthropogenic heat emissions; this increase in air temperature is termed the 'urban heat island' effect (UHI, Sect. 15.4.2). The UHI shows both a diurnal and an annual cycle. The intensity of the night-time warming is even more intense at the surfaces (surface urban heat island).
- *Greater temperature variability.* This results from shading and reflection of short-wave radiation by buildings, radiative trapping, heat storage by buildings, and increased energy use and emission of waste energy (Sect. 15.4.2).
- *Deeper boundary layers and more frequent unstably stratified boundary layers at night.* This is due to the UHI effect and could affect turbulent mixing of pollutants (Chemel and Sokhi 2012) which could in turn increase ozone (O_3) concentrations near the surface at night and reduce nitrogen dioxide (NO_2) concentrations (Zhang and Rao 1999; Sect. 15.4.2).
- *Lower average wind speed and greater gustiness.* The presence of buildings in urban areas causes lower average wind speeds, but local maxima can occur especially within street canyons facing the coastline or river bank. The buildings also trigger an overall increase in gustiness; wind comfort is thus much lower in coastal urban areas of the North Sea region than in inland urban areas (Sect. 15.4.3).
- *Reduced evapotranspiration.* Owing to less vegetation, less water storage capacity and often lower groundwater levels in urban areas, evapotranspiration is smaller. For North Sea cities, even the areas with high groundwater levels have reduced evapotranspiration, if the surfaces are sealed (Sect. 15.4.2).
- *Changed precipitation fields.* The urban fabric and UHI effect lead to convergences and more updrafts in the flow field, often resulting in more downwind precipitation (Shepherd et al. 2002) if anthropogenic pollutant emissions are neglected. In an urban area with high pollutant emissions (e.g. sulphur dioxide, SO_2) the urban area might reduce precipitation; however, aerosol impacts are still uncertain (Pielke et al. 2007). Whether downwind precipitation is higher or lower depends among other things on aerosol composition, meteorological situation, and urban surroundings (Han et al. 2014). Urban precipitation impacts are visible through changes in downwind precipitation (Sect. 15.4.3).
- *More air pollution.* Owing to higher emissions from a range of anthropogenic sources (traffic, households, industry) there are higher levels of primary pollutants. Also, most of the cities mentioned above are harbour cities, with Rotterdam, Hamburg and Antwerp the largest

Fig. 15.2 Monthly average minimum and maximum temperatures for Bergen, Hamburg and London, and monthly average precipitation for the three cities. *Data sources* Bergen (http://wetter.welt.de/klimadaten.asp, accessed 16 February 2014), Hamburg (temperature http://wetter.welt.de/klimadaten.asp accessed 16 February 2014; precipitation averaging period 1981–2010, www.dwd.de accessed 3 April 2015), London (averaging period 1981–2010, www.metoffice.gov.uk accessed 3 April 2015)



in Europe. For these cities, emissions from ships add to the air pollution load (Sect. 15.4.1).

The effects of urban areas are referred to collectively in this chapter as the ‘urban footprint’.

The following sections examine urban climate in the past (Sect. 15.3) and present (Sect. 15.4), as impacted by climate change (Sect. 15.5) and adaptation measures (Sect. 15.6), using two cities as examples: the megacity of London with an extensive metropolitan area (14.3 million inhabitants[1]) but no international harbour and the comparatively small metropolitan area of Hamburg (2.7 million inhabitants[2]) with one of the largest harbours in Europe. The two cities are about 700 km apart, with Hamburg having a slightly more continental climate, visible in lower winter temperatures, a greater minimum to maximum temperature range and a more pronounced summer precipitation maximum (Fig. 15.2). The busy North Sea harbour cities of Rotterdam and Antwerp have a climate similar to that of London or Hamburg, which implies the external climate drivers interacting with urban-induced changes are similar. In contrast, one of the northernmost North Sea cities, Bergen (Norway), has a lower temperature range in each month and throughout the year, and thus little problem with excessive summer temperatures. However, due to the nearby mountain ranges Bergen experiences much higher precipitation (roughly three-fold higher) and this must be considered in urban planning.

London and Hamburg have experienced urban climate problems, especially regarding heavy air pollution (Sect. 15.3). Only in the past few decades, especially since the very warm summer of 2003, have other parameters characterising the urban climate come into focus (Sects. 15.4–15.6). With a similar climate in both cities, the challenges mainly concern their differences in size and thus urban footprint on regional climate.

15.3 Historical Problems in Urban Climate

Historically, air pollution drove studies on urban climate. A severe pollution event was followed by action to understand and improve air quality (Table 15.1). Elevated sources were found to create widespread pollutant plumes as well as high pollutant concentrations, in urban areas as well as in rural areas. Standards for air quality were initiated by the European Communities Programme for Action on Environment from 1973. This led to the first directive (Council Directive 80/779/EEC, see EC 1980) on levels of SO_2 among EU member states. More EU-wide directives on limit values for pollutant concentrations followed (e.g. Council Directive 96/62/EC, and its later updates given in EC 2008). This initiated national and local strategies to reduce pollutant concentrations. For instance, in London the Clean Air Act of 1993 was followed by the Greater London Authority Act in 1999. With a focus on London, GLA (2002) gives a detailed overview of air pollution control and air quality strategies

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[1] www.citypopulation.de/world/Agglomerations.html accessed 11 December 2015.

[2] www.citypopulation.de/world/Agglomerations.html.

Table 15.1 Occurrences related to air pollution

Date	Event
1952	About 4000 people died within five days during a winter smog episode in London (GLA 2002)
1957	Field experiments were performed in the UK to study the dispersion of pollutants (Hay and Pasquill 1957)
1957	Commission on clear air was founded in Germany
1967	First air quality measurement sites established in Germany (financed by the German Research Foundation, DFG); later becoming an operational network
~1970	Dispersion field experiments took place in several countries to better understand dispersion (heavy gases, elevated stack emissions)

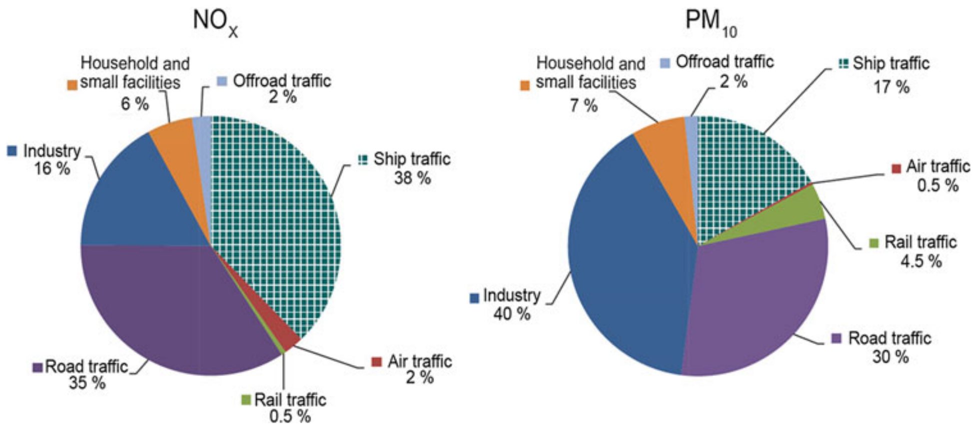

Fig. 15.3 Sector contributions to total emissions of nitrogen oxides (NO_X) and particulate matter (of 10 μm or less in diameter; PM_{10}) in Hamburg (based on data from Böhm and Wahler 2012)

over the last 150 years starting from the control of air pollutants by industry to reduce smoke, to ambient air quality standards.

Heat is an additional health threat. The 2003 heat wave caused around 70,000 excess deaths in Europe, with about 20–38 % attributed to air pollution (Jalkanen 2011). There was an overall 17 % increase in death rates for England and Wales with the excess mortality most pronounced in London, with a 33 % increase in the over 75-year old age group (Kovats et al. 2006). Since regional heat waves and the strongest UHIs are both observed in summer during stationary anti-cyclonic conditions with calm winds, the UHI is even more relevant during heat waves. After summer 2003 it was clear that the additional temperature enhancement in urban areas can lead to unbearable and health-threatening temperatures during a heat wave, even in cities of the North Sea region. This led to the start of several research projects and experimental campaigns to better understand the current urban climate and to develop urban footprint reduction and adaptation measures.

15.4 Current Urban Climate

15.4.1 Air Quality

The contribution of high-stack emissions to the total emissions of primary pollutants and high concentrations recorded in urban areas today is small compared to those of the past (see Sect. 15.3). For example, in 2005 only 25 % of the total nitrogen oxide (NO_X) emissions in Germany were from high stacks. Local traffic and—for harbour cities—ship traffic are now the main sources of several primary pollutants). For Hamburg, 78 % of NO_X emissions and 53 % of PM_{10} (particulate matter of 10 μm or less in diameter) emissions result from traffic, with ship emissions contributing 38 % of the total NO_X emissions (Fig. 15.3). Traffic emissions (except air traffic) are ground-based and so directly increase concentrations within the urban area. Therefore, measurements mainly show exceedances of the NO_2 annual average limit value of 40 μg m^{-3} at traffic-impacted sites, where air masses are confined and so less mixed than in less built-up areas. This is true for Hamburg (Böhm and Wahler 2012) and London (Fuller and Mittal 2012).

However, Fuller and Mittal (2012) found that the limit values are even exceeded at urban background stations in locations such as inner London, close to Heathrow or near the M4 motorway, probably due to the huge commuter belt around London. This is not the case for Hamburg and even in the harbour the NO_2 values are currently below the annual average limit values of 40 μg m^{-3}, but above the values measured at urban background stations (Böhm and Wahler 2012). With the development of new residential areas on the banks of the River Elbe, air masses will be more confined and ship emissions might lead to higher air concentrations that could affect the health of the residents. As a consequence, plans for reducing air pollution concentrations now include ship emissions (Böhm and Wahler 2012).

For NO_X concentrations in London, Fuller and Mittal (2012) found a seasonal cycle with higher concentrations in winter and an overall decline since 1998. The decrease is greatest close to roadsides. Carslaw et al. (2011) reported an increase in the ratio of NO_2/NO_X over the last decade at roadsides and the increase has been more marked in London than at other UK sites. The increase is probably due to higher NO_2 emissions for vehicles conforming to newer emission standards (e.g. through oxidation catalysts and particle filters in light-duty diesel vehicles) (Carslaw et al. 2011). The changes are similar for Hamburg and in Europe as a whole, and so a similar change can be assumed across the whole of the North Sea region.

Annual average PM_{10} concentrations show more or less a decrease for Hamburg between 2001 and 2011, although values are still up to 80 % of the EU annual average limit value of 40 µg m^{-3} (Böhm and Wahler 2012). The interactive map developed by the European Environment Agency[3] gives an annual mean for PM_{10} of the same order (31–40 µg m^{-3}) for London in 2012. This is the highest value in the UK, but comparable to Leiden (Netherlands), Bremen (Germany) and Antwerp (Belgium). According to Fuller and Mittal (2012), monthly mean PM_{10} concentrations vary between 25 and 38 µg m^{-3} depending on location in London (roadside, background, city centre, fringes). They found that several monitoring stations at roadsides in London exceed the 50 µg m^{-3} daily mean limit value on more than 35 days in 2011. However, according to Jones et al. (2012) a large decrease in particle number has occurred in London since 2007 possibly due to the introduction of ultra-low sulphur diesel. Sources of PM_{10} in London depend on the weather pattern and comprise local sources and advection from within the UK and Europe. First results by the ClearfLo campaign measuring the composition of particulate matter in 2011 and 2012 in London at an urban background site suggest that organic aerosol is the most abundant (35 % of the total) followed by secondary inorganic aerosols such as nitrate (18 %), sulphate (11 %) and ammonium (9 %), and smaller contributions from marine aerosol components such as chloride (7 %) and sodium (4 %), and combustion emissions such as elemental carbon (Bohnenstengel et al. 2015). Early analysis indicates that local London emissions have a bigger impact in winter when the lower boundary layer enables a build-up of primary pollutants. See www.londonair.org for a summary of air quality measurements in London from several stations and information on exceedances.

North Sea urban regions have undertaken active measures to reduce pollutant exceedances: The Air Quality Strategy for London (GLA 2010) details some of the measures taken in London to further reduce PM_{10} concentrations. These include low emission zones, cleaner vehicle transport, cycle superhighways, best practice guidance for construction and demolition, and biomass boilers. Measures have also been taken in Hamburg and a reduction in exceedances is expected due to future emission reductions from traffic (including bus-lanes, car-sharing, and land-based energy supply for ships; Böhm and Wahler 2012). However, wood is increasingly used for heating (owing to its CO_2-neutral emissions); without regulatory measures PM_{10} emissions from households and thereby PM load might increase again, especially in winter.

15.4.2 Temperature and Humidity

The UHI is the most well-known feature of urban climate, and describes the temperature difference between urban and rural areas (Oke 1982). It is most pronounced during calm nights with clear skies (e.g. Schlünzen et al. 2010; Richter et al. 2013). This is important because higher night-time temperatures can cause discomfort and increase mortality rates during prolonged hot summer periods, as found for example for London (Armstrong et al. 2011).

In these situations the UHI at night for North Sea cities can be up to 7 K (London: Watkins et al. 2002), 10.5 K (Hamburg: Hoffmann et al. 2012) or 7 K (Rotterdam: Heusinkveld et al. 2014). However, the monthly average values for night-time temperature enhancements are lower. For Hamburg, analyses show monthly average minimum temperature differences between the urban and surrounding rural area of 1 (suburbs) to 2.7 K (inner city) for April through October (Schlünzen et al. 2010). Similar monthly average night-time temperature enhancements were found by Heusinkveld et al. (2014) for Rotterdam (June, July, August: median 0.7–2.26 K depending on location) and Jones and Lister (2009) for London (enhancement of minimum temperatures of 1.6 K for St James Park based on four 30-year averages 1901–1930, 1931–1960, 1951–1980, 1981–2006, and 2.8 K for the central London weather station for 1981–2006). Unpublished long-term simulations with the UK Met Office Unified model at 1-km horizontal resolution show the spatial pattern of positive temperature anomalies in the order of 2–3 K around 1 UTC (Universal Time Coordinated) (Fig. 15.4) and 1–2 K around 4 UTC, averaged for June to August 2006. Using the same model, Bohnenstengel et al. (2011) showed the temperature enhancement to remain constant throughout the night for the London city centre from the evening transition to the morning transition for a case study in May 2008 with moderate winds speeds.

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[3] www.eea.europa.eu/themes/air/interactive/pm10.

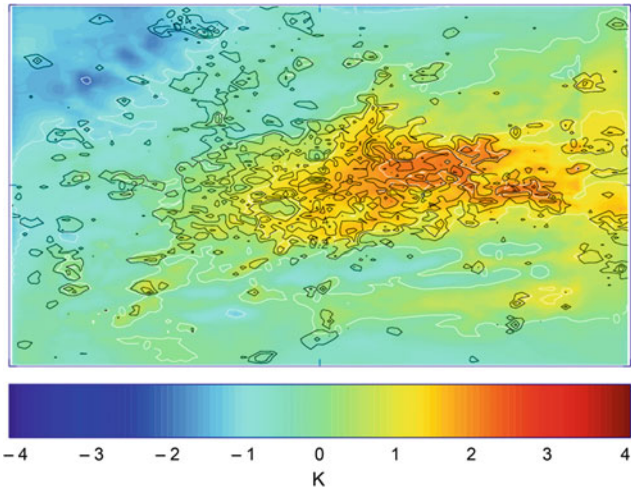

Fig. 15.4 Urban temperature enhancement for London at 1UTC averaged over the period 1 June to 15 August 2006. Values are derived from long-term model simulations with the UK Met Office Unified Model employing the MORUSES urban parameterisation (model setup described by Bohnenstengel et al. 2011). *Black lines* indicate sub-grid scale urban land-use fraction per grid box ranging from 0 (no urban land use) to 1 (grid box entirely covered by urban land use) and *colours* represent the urban temperature anomaly in *K*. A grid box is roughly 1 km^2

As in other regions of the world, urban land-use is the biggest driver of UHI in the North Sea cities (Schlünzen et al. 2010; Bohnenstengel et al. 2011; Hoffmann 2012; Heusinkveld et al. 2014). The effect of greening reduces the enhanced temperatures on a clear night with low wind speeds by 2–3 K (model results by Bohnenstengel et al. 2011 and Grawe et al. 2012, both for London). Similar effects were found for Hamburg and Rotterdam based on measured data, where the heat island is smaller in green areas than in areas with sealed surfaces (Schlünzen et al. 2010; Heusinkveld et al. 2014). Detailed model studies show the significant effect of building height and urban fabric on perceived temperatures (Schoetter et al. 2013). Perceived temperature is a measure of thermal comfort and is based on a heat budget model for the human body; it takes into account temperature, short- and long-wave radiation and wind speed effects on the human body (Kim et al. 2009; Staiger et al. 2011).

Air mass history and the evolution of the urban boundary layer with distance from the rural/urban transition also affect urban air temperature. On a night with moderate wind speeds, air temperature can be around 2 K lower over the upwind fringes of a city such as London than over the city centre and areas downwind of the city centre (Bohnenstengel et al. 2011).

Coastal form and meteorological situation (Crosman and Horel 2010) affect the inland penetration of sea breeze fronts and the front moves further inland the later the afternoon (Simpson et al. 1977). Thus, depending on distance from the coast, sea breezes and marine air intrusions can reduce the intensity of the UHI in the evening or at night for a couple of hours in North Sea cities in spring and early summer. This is especially the case during high pressure situations with calm winds (e.g. Chemel and Sokhi 2012). However, for an inland city like Hamburg (about 100 km inland of the North Sea, 80 km from the Baltic Sea) the impact of sea breezes is rare, since sea breeze fronts typically travel inland by up to 40 km only (Schlünzen 1990), rarely further.

Lane (2014) determined a mean temperature enhancement of 1.9 K for summer (JJA) and 1.6 K for winter (DJF) based on hourly temperature measurements from a roof top site 18 m above ground level in central London and a spatial average of 10 rural stations mostly to the east and west of London. As for other cities, the enhancement of the maximum temperatures is quite small compared to the rural surroundings and most pronounced in winter months (determined for Hamburg; Schlünzen et al. 2010), when anthropogenic heat emissions play a larger role. Schlünzen et al. (2010) found a range of 0.2 (suburb) to 0.7 K (inner city) for Hamburg's monthly average winter maximum temperature enhancements. The maximum temperature enhancement for London is of a similar order at 0.6 K (St James Park; 1901–2006) and 0.9 K (London weather centre; 1981–2006) according to Jones and Lister (2009). They stated that maximum temperature enhancements in St James Park differ marginally between seasons, while minimum temperature enhancements are slightly higher in spring and summer. They found no evidence for climate-related enhanced warming trends in central London compared to the trends found for rural stations around London.

As summarised by Mavrogianni et al. (2011), the excess heat in urban areas affects energy use, comfort and health. Their simulations show that the number of hours with indoor temperatures exceeding 28 °C increases towards the city centre of London for a building without air conditioning. However, building form and urban land-use also play a role in comfort temperatures in London and need to be taken into account when designing strategies that reduce overheating. Iamarino et al. (2011) showed for a resolution of 200 m × 200 m that anthropogenic heat fluxes for the Greater London area are of the order of 10 Wm^{-2}, while the city centre is associated with anthropogenic emissions of the order of 200 Wm^{-2} and, according to Hamilton et al. (2009) and Bohnenstengel et al. (2014), of 400 Wm^{-2} at peak times. Petrik et al. (in prep) determined the anthropogenic heat at 250 m resolution for Hamburg, finding values of 10 Wm^{-2} in suburbs and up to 100 Wm^{-2} at some industrial sites and in harbour areas. These lower values agree well with the findings of Allen et al. (2011) who determined anthropogenic heat fluxes globally on a 2.5 arc minute grid. For North Sea cites, they found higher values for London,

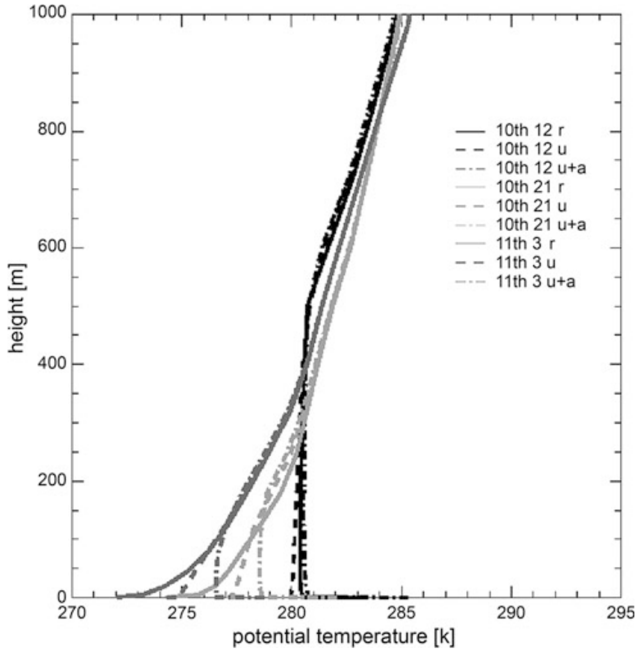

Fig. 15.5 Vertical potential temperature profiles over the London city centre for 9–12 December 2009. *Dark grey lines* depict profiles at noon, *light grey lines* depict profiles at 21UTC and *black lines* depict profiles at 3UTC. *Solid lines* depict the rural simulation, *dashed lines* the urban simulations and *dash-dotted lines* urban simulations with anthropogenic heat fluxes included (Bohnenstengel et al. 2014)

Brussels, Rotterdam and Amsterdam (> 30 Wm^{-2} annual average) and lower values for smaller cities and the Ruhr area, Hamburg or Bremen. Based on their 250-m resolution model studies with the mesoscale model METRAS, Petrik et al. (in prep) found the highest impacts on temperature at night, when the anthropogenic heat is mixed into a shallow boundary layer. Thus, night temperatures are more affected than day temperatures resulting in a summer average night-time temperature increase of up to 0.5 K in those parts of Hamburg with the highest waste heat emissions.

Bohnenstengel et al. (2014) examined the impact of anthropogenic heat emissions on London's UHI using 1-km resolution simulations with the UK Met Office Unified Model for a winter case study with calm winds over the period 9–12 December 2009. They compared three simulations covering London: a 'rural' control run, where London was replaced by grass, and two simulations including the urban surface energy balance—one with and one without high-resolution time-varying anthropogenic heat emissions. During calm and clear winter nights, anthropogenic emissions were found to increase the UHI by up to 1 K. In fact, anthropogenic emissions can tip the balance and maintain a well-mixed boundary layer (Fig. 15.5). This is based on a case study for winter, when the urban boundary layer was shallow and anthropogenic heat emissions affected a very small volume of air. In such cases, anthropogenic heat could affect the mixing properties of the urban boundary layer and thereby pollutant concentrations (Sect. 15.4.1). In spring or summer, when the daytime urban boundary layers are much deeper, the impact of anthropogenic emissions on temperatures (and thus vertical mixing) is within the measurement uncertainty.

Most North Sea cities have a considerable fraction of water surfaces within the urban area. For example, more than 3 % of Hamburg has water surfaces (channels, ponds, small lakes, rivers; Teichert 2013). In summer, the suburbs close to the inner-city water bodies experience advective cooling during the day and warming at night, since the water bodies dampen the diurnal cycle. This results in UHI-like effects at night due to the advection of warm air from the adjacent water bodies (Schlünzen et al. 2010). The water- and urban-fabric-induced reduced night-time cooling are additive and also affect the occurrence of plant species (Bechtel and Schmidt 2011). For large water bodies, such as the River Elbe downstream of Hamburg's harbour the water bodies might cause a river breeze that affects temperatures a few 1000 m off the river, as Teichert (2013) found for a calm meteorological situation in summer simulated with METRAS. It should be noted that daytime cooling by water bodies only occurs if the water temperature is lower than that of the land surfaces. Water temperatures are affected by water use: among others, water is abstracted for drinking water, industrial production or power plant cooling; and discharged in part as waste water, clean but often at higher temperatures than the abstracted water. This can increase river temperature throughout the year, especially if the river is tidal and the same water is used several times. For example, the River Weser regulations aim to prevent river water temperatures of more than 28 °C (www.fgg-weser.de). A river used to discharge the warm waste water might act as an all-year central heating system, especially at night. This can be advantageous in winter, similar to the warm North Atlantic current that acts as a central heating system for all North Sea cities.

To summarise, for industrial cities such as Hamburg or London, waste heat emissions can add to the rise in night-time temperature caused by the urban fabric. In addition, water bodies within built-up areas hinder cooling at night especially in summer when cooling is most needed, for instance during heat waves. Rivers help to cool a city in summer, if their temperature is kept low enough and waste water-related warming is also kept low. Coastal water bodies may cool cities in spring and summer, as observed in Rotterdam or Bergen compared to a city setting more inland and without sea breeze impacts. However, it should be noted that all water bodies reduce urban cooling in autumn and winter and so could help save energy during the cold season. Since urban fabric, heat emissions and water bodies are all very locally structured, a pattern of high temperatures is also

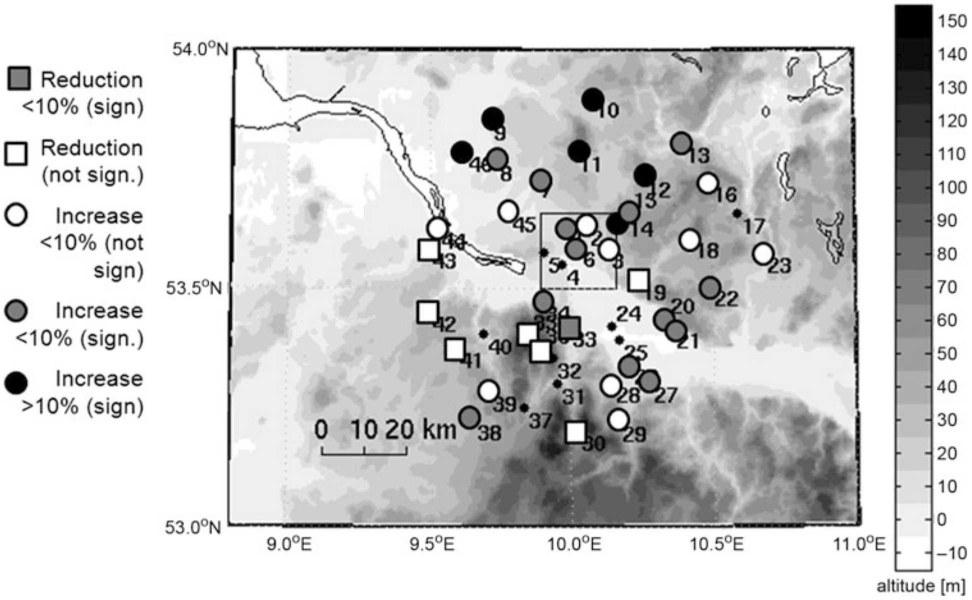

Fig. 15.6 Average percentage increase in precipitation per event, if a site is downwind of the city centre (marked by a *square*) (based on results by Schlünzen et al. 2010). *Black* and *grey filled circles* depict significant increases, the *grey filled rectangle* depicts a significant decrease, and *white filled rectangles* and *circles* depict no significant change

locally structured, with higher night-time temperatures in harbour and industrialised sealed areas, if these are not directly next to a cool river or ocean.

15.4.3 Precipitation

The urban precipitation impact can lead to precipitation enhancement downwind of an urban area. Measured data show this to be the case for Hamburg (Schlünzen et al. 2010), with increases of 5–10 % per precipitation event and found for many (but not all) downwind sites (Fig. 15.6). Assuming only one wind direction throughout the entire year (an extreme and unrealistic assumption), the difference could be $80\ \mathrm{mm\ y^{-1}}$, which is still less than half of the 200 mm climatological difference with its decrease from the north towards the south-east (Hoffmann and Schlünzen 2010). Thus, despite urban impacts the regional effects might actually be of greater significance.

Schlünzen et al. (2010) also studied long-term changes in precipitation. They found a greater increase in precipitation upwind of Hamburg than downwind of the urban area (trend 1947–2007), which might suggest an overall decline in urban impact. However, these results are speculative, since detailed model studies with METRAS by Schoetter (2013) showed the urban impact of Hamburg is only observable under some meteorological conditions, which agrees with findings by Han et al. (2014). The effects are very local (as can also be inferred from Fig. 15.6) and dependent on the actual meteorological situation. Overall, the impact of Hamburg's urban fabric is not significant for the summer. However, the urban impact might differ in winter or for other urban areas in the North Sea region. Han et al. (2014) pointed out that orography plays an additional role. This was also found for Hamburg, where the highest elevations are only 100–200 m and the urban buildings are low. METRAS model simulations without orography show that orographic effects drive a statistically robust change in the precipitation pattern (Schoetter 2013).

15.5 Scenarios for Future Developments

Adaptation to climate change is of utmost importance for cities to maintain the wellbeing of their inhabitants. Several studies have investigated climate change impacts on urban climate, with some very detailed studies undertaken in Hamburg and London. The ARCC network[4] provides an overview of UK-focussed projects involved with adaptation to 'technological, social and environmental change, including climate change, in the built environment and infrastructure sectors'. Of these the ARCADIA project gives an overview of adaptation and resilience in cities, presenting city-scale climate change scenarios consistent with the UKCP09 scenarios. The Lucid project[5] brought together meteorologists and building engineers to assess the impact of local climate on energy use, comfort and health, while the SCORCHIO project[6] used climate projections to determine adaptation measures focussing on Manchester. Similar multidisciplinary research studies on climate change adaptation were performed for several German cities under the framework of the KLIMZUG program[7] (Climate change in

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[4] www.arcc-network.org.uk.
[5] www.homepages.ucl.ac.uk/∼ucftiha/index.html.
[6] www.sed.manchester.ac.uk/research/cure/research/scorchio.
[7] www.klimzug.de.

regions): The North Sea region was investigated in northwest 2050[8] (area Bremen/Oldenburg with a focus on the development of roadmaps of climate adaption for three economic sectors: food industry, energy production and distribution, and port management and logistics) and KLIMZUG-Nord[9] (metropolitan area of Hamburg, with a focus on the development of an adaptation master plan that continues until 2050 using the thematic focal points Elbe estuary management, integrated spatial development, nature conservation and governance).

15.5.1 Climate Change Impacts on Urban Climate

Urban areas are a major source of carbon dioxide (CO_2) and anthropogenic heat. While the former drives changes in global climate, the latter has a potentially strong impact on city-scale climate. McCarthy et al. (2011) used an urban land surface scheme (Best et al. 2006) with the Hadley Centre Global Climate Model (HadAM3) and compared the impacts of doubling CO_2 emissions against effects due to urbanisation and anthropogenic heat release in urban areas. They found that urban and rural areas react differently to climate change. While their climate change scenarios (transient SRES A1B scenarios, urbanisation and anthropogenic heat release in urban areas) increased the number of hot days in both areas to the same extent, they found that London has a bigger increase in the number of hot nights (>18.2 °C) than rural areas. The reasons for this difference are local forcing such as anthropogenic heat release and urbanisation leading to the UHI. In fact, local changes such as urbanisation and anthropogenic heat release also increased the frequency of hot days, as did doubling CO_2 emissions. It should be noted that as the UHI is not caused by local CO_2 emissions, it cannot be reduced by lowering them. Oleson (2012) confirmed the results of McCarthy et al. (2011) concerning more frequent hot nights in urban areas compared to rural areas for Europe. Thus, heat risk for the urban population will increase more than for their rural counterparts due to local urban forcing.

Hamdi et al. (2014) studied present (1981–1990) and future climate (2071–2100) for Brussels. On average, the observed nocturnal UHI is of the order of 1.32 K, which agrees well with the simulated average of 1.31 K. Under an A1B scenario, night-time UHIs vary between 0 and 7 K with the frequency of UHIs above 3 K decreasing due to soil dryness in summer. For the city centre the number of heat days will rise by 62.

For Hamburg, Hoffmann et al. (2012) and Grawe et al. (2013) found small changes in the pattern and amplitude of the UHI for climate change scenarios, if the urban fabric remains unchanged. If threshold values are used (such as 18.2 °C for night-time temperatures), these are more frequently exceeded under the future climate due to the higher overall temperatures. The number of exceedances is also higher within urban areas compared to rural areas, because the additional temperature enhancement of urban areas also contributes. However, non-linear effects that contribute to a greater temperature enhancement in urban areas compared to rural areas were not apparent by mid-century under the A1B climate change scenario.

Large precipitation amounts challenge urban infrastructure and could cause streets and houses to flood, or even the total breakdown of some urban infrastructure. Summer precipitation from convective cloud systems may lead to local flooding as was observed in Rostock (Germany) when nearly twice the average monthly rainfall fell within a day (22/23 July 2011; Miegel et al. 2014). A projected increase in winter precipitation of 12–38 % in the climatological mean towards the end of this century (Rechid et al. 2014) poses additional challenges to city planners. Especially in winter, when the already low evapotranspiration in urban areas is even lower and statured soils cannot take up any excess water, this so-called 'hinterland flooding' needs to be addressed in adaptation measures for cities (KLIMZUG-NORD 2014).

15.5.2 City Development Impacts on Urban Climate

As already described (Sect. 15.4), urban areas affect the regional climate through their urban footprint. This relationship provides an opportunity to reduce the regional climate change impact on urban areas—or to enhance it if the wrong mitigation and adaptation measures are applied. Several recent research projects have investigated the impact of planned changes in urban structure on the urban footprint.

The nationally-funded research projects KLIMZUG-NORD (final results in KLIMZUG-NORD 2014) and Cli-SAP (Schlünzen et al. 2009) investigated different aspects of Hamburg's development on the urban summer climate. In all development scenarios, Hamburg's growth is confined mostly to the current regional area and is restricted vertically. In fact, Hamburg has a ban on high-rise buildings. This means that surface cover changes are relatively small, follow a compact city approach and include aspects of adaptation to the changing climate. More greening (especially of roofs) and higher albedo values on roofs and other sealed surfaces that cannot be greened (e.g. roads) were assumed. Other assumptions include some rebuilding of

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[8] www.nordwest2050.de.

[9] www.klimzug-nord.de.

single houses into duplex or terraced houses, replacing terraced houses by blocks, and adding another story to multi-story buildings. All these changes were assumed to be accompanied by a larger greening fraction and more reflective (higher albedo) material. Several simulations were performed with the mesoscale model METRAS to reproduce (at 250-m resolution) a climatological-average summer situation. According to the adaptation measures selected, the average summer temperature could be reduced by 0.2 K with the greatest decreases in those areas where the sealing is very high (KLIMZUG-NORD 2014). Anthropogenic heat emission was prescribed unchanged in these model studies. However, energy use will be more efficient in the future due to retrofitting of houses with better insulation. However, the impacts of better insulation on the surface energy budget are still unclear. Nevertheless, anthropogenic heat emissions will be lower and this will lead to a reduction in the UHI throughout the year.

Impacts on heavy precipitation events were examined for the same scenarios of urban development. As already mentioned (Sect. 15.4.3), the urban fabric has little impact on precipitation, at least for Hamburg, and this was confirmed by the model simulations. Nevertheless, more sealed surfaces pose a challenge for city planners, as these surfaces cannot take up the water and the water must to be drained to avoid hinterland flooding (see Sect. 15.5.1).

Changes in the wind field are expected to be local and possibly very large close to building structures (Schlünzen and Linde 2014). The effects of new buildings on the wind climate of a growing suburb of Hamburg (situated on the large island of Wilhelmsburg) were investigated using the obstacle-resolving model MITRAS (Schlünzen et al. 2003) at a resolution of 5 m. Impacts over a distance of 1000 m from the new buildings were found not just close to the surface but also at higher levels thus affecting ventilation of the buildings in the upper floors (Schlünzen and Linde 2014). Some streets or even balconies on upper stories could become less usable, owing to excessively high wind speeds around the new buildings, while formerly well flushed places could become very calm; this can increase heat stress on sunny days. Furthermore, pollutant dispersion can change due to changes in the wind and temperature fields and this can lead to high concentrations in different sites to before and could change the human exposure pattern.

Studies indicate that changes in temperature and precipitation resulting from urban development scenarios that aim at mitigation and adaptation measures can only slightly reduce the projected climate-driven rise in temperature and change in precipitation patterns. However, although small these local reductions might become more relevant during hot periods by keeping urban temperatures at night at values that reduce health risk. To ensure the cooling effect of urban greening, the watering needs of the vegetation must be ensured (such as by storing water during the wet periods). If the urban vegetation dries out its cooling effect is lost.

15.6 Adaptation and Urban Footprint Reduction Measures

Many North Sea cities are close to the coast or to a river and so must prepare for storm tides. This can be achieved using dykes, as for example in the Netherlands or along the river Elbe for Hamburg, or the Thames Barrier for London. Such measures are expensive, but vital to protect valuable infrastructure and save lives. Hinterland flooding has become an increasing challenge in recent years and similar preparedness needs to be developed here as for storm tides. While upriver dykes help prevent river flooding, and are constantly being improved and strengthened, coastal cities appear to lack focus in terms of rain events that can be equally challenging. Measures are needed to remove rain water following heavy precipitation events. Methods already exist, for example a city like Bergen handles at least twice the precipitation amounts observed in the southern North Sea region every month (Fig. 15.2d). Hamburg has introduced a separate rain water drainage system in recent years and introduced financial penalties, if rain water is not locally drained by home owners. To cope with intense precipitation events (Schlünzen et al. 2010) and increased amounts of winter precipitation, it is essential that urban areas can store water. Storing precipitation in winter would help to cope with future drier summers. Cities will need larger amounts of water in future for two reasons: warmer air can take up more water and so evapotranspiration will be higher, and increased urban greening to help reduce high urban night-time temperatures needs enough water to prevent the vegetation drying out.

Any increase in sealed surfaces should be kept to a minimum (they are sometimes introduced for flood protection, such as new dykes or walls with bitumen or stone cover), since they increase the amount of heat-storing surfaces and thus night-time temperatures. The current replacement of green spaces and gardens in urban and suburban areas by buildings and sealed surfaces should also be limited as this will also cause an increase in urban night-time temperatures. Plus, there is a tendency for urban spread into surrounding rural areas which extends the UHI in space. Hamburg has already begun implementing measures to keep UHI effects within reasonable limits, possibly even causing a reduction. In contrast, London can only grow vertically in the city centre, leading to more heat storage capacity, presumably greater anthropogenic heat release and warmer nights. Any increase in the spatial extent of London, and thus an increase in sealed surface, would also increase the spread of the UHI. Higher temperatures in urban areas would lead to several stress factors. Heat in itself is a recognised health factor. Planners in all North Sea cities should ensure that existing green areas are kept and that new ones are added. In addition, all waste heat emissions (to the atmosphere and to water bodies) should be reduced especially in summer to reduce night-time heat exposure within urban areas. Projections by Iamarino et al. (2011) suggested an increase of 16 % in anthropogenic heat emission due to a larger working population in the city of London by 2025 compared to 2005. Without measures to reduce the urban footprint, this would lead to even higher temperatures within the city of London. This shows a clear synergy between adaptation, mitigation and urban footprint reduction measures: less energy-consuming computers, factories, and vehicles, not only reduce CO_2 emissions (or equivalent) and thus global temperature increase in the long term, but also directly and quickly reduce the amount of waste heat emitted into the urban area and thus night-time temperatures. The same is true for well-insulated buildings: using less energy for heating in winter and cooling in summer means lower CO_2 emission (for energy production). Lower CO_2 emissions implies less global warming, while better insulation reduces UHI at night.

The projected increase in global temperatures could lead to higher biogenic volatile organic compound (VOC) emissions from vegetation, which could in turn increase O_3 levels if NO_X emissions are not considerably reduced (e.g. Meyer and Schlünzen 2011). To avoid additional VOC emissions, new urban vegetation needs to be selected with low VOC emission potential (Kuttler 2013: 281).

Drier summers would mean more particles eroded from dry surfaces and an increase in the already high particle load in urban areas. This supports the argument for increasing the amount of vegetated surface in urban areas and for providing these areas with water during dry periods. An immediate measure used in London to reduce the atmospheric particle load has been to spray adhesives onto roads in some of the most polluted areas, although this does not reduce the source of the particulate matter.

15.7 Conclusions

Urban areas are not only impacted by changes in regional climate, but themselves contribute to climate change through their large greenhouse gas emissions. Urban areas also modify the regional climate through their urban footprint. This is mainly visible in terms of concentration levels above EU limit values for NO_X (daily average value), NO_2 (annual average value) and particulate matter (PM_{10} daily average values). Higher temperatures, especially at night, result from changes in the surface energy budget due to the urban fabric and additional emission of anthropogenic heat. The temperature difference can be in the range of a few degrees in the monthly average. It may be up to ~7 K under favourable conditions (clear skies, high radiative impact, low large-scale pressure gradients).

Despite broad similarities between many urban areas, there are also large location-specific differences with regard to city planning needs (such as poorly insulated Victorian housing stock in the UK wasting large amounts of energy). While some cities are growing, others show little change with respect to the number of inhabitants and some are even shrinking. Whatever the future, it will involve change. Changes in climate will become increasingly apparent, especially towards the end of the century, with the first indications of what is to come already apparent (hinterland flooding, more intense precipitation, and drier and warmer summers). Because even in a 'non-changing' city, inhabitants will renovate buildings and young people will adopt new infrastructures and new technologies that will one day be standard for all, there is an opportunity for cities to change for simultaneously adapting to and mitigating climate change such that the worst impacts of climate change can be avoided by mitigation measures, and the unavoidable impacts of climate change can be met by adaptation measures, while the urban footprint becomes ever smaller.

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Socio-economic Impacts—Air Quality

16

Stig Bjørløw Dalsøren and Jan Eiof Jonson

Abstract

In the North Sea region, poor air quality has serious implications for human health and the related societal costs are considerable. The state of air pollution is often used as a proxy for air quality. This chapter focuses on the two atmospheric pollutants of most significance to human health in Europe—particulate matter and ground-level ozone. These are also important ‘climate forcers’. In the North Sea area, the effects on air quality of emission changes since preindustrial times are stronger than the effects of climate change. According to model simulations, this is also the case for future air quality in the North Sea region, but substantial variation in model results implies considerable uncertainty. Short-term events such as heat waves can have substantial impacts on air quality and some regional climate models suggest that heat waves may become more frequent in the coming decades. If the reductions in air pollutant emissions expected through increasingly stringent policy measures are not achieved, any increase in the severity or frequency of heat waves may have severe consequences for air quality. Climate and air quality interact in several ways and mitigation optimised for a climate or air quality target in isolation could have synergistic or antagonistic effects.

16.1 Introduction

The state of air pollution is often expressed as air quality. The concentrations of gaseous pollutants and particulate matter are then used as a measure of air quality. However, it is often not meaningful to discuss air quality without addressing the multiple impacts of air pollution. Major air pollutants may be clustered according to their properties and impacts, and this is shown in Fig. 16.1. After being emitted into the atmosphere pollutants undergo chemical oxidation and form new compounds with different properties and impacts. Pollutants then remain in the atmosphere until they are removed through cloud and precipitation processes or by direct deposition to the earth’s surface. Differences in chemical reactivity and removal rates result in atmospheric lifetimes ranging from seconds to months. Air quality and related impacts are therefore influenced by local meteorological features, regional (transboundary) processes, and intercontinental transport. The pathway from emissions to impacts is complex. The focus in this chapter is limited to impacts on human health, climate, and climate-air quality interactions and mainly excludes impacts on ecosystems (acidification, eutrophication, carbon sequestration, crops, and vegetation) and materials. Impacts of climate change on ecosystems are covered in Chaps. 8, 9, 10, and 11.

Air quality and climate interact in several ways. Air pollutants can affect climate both directly and indirectly through their influence on the radiative balance of the atmosphere. Primary particulate matter (primary PM, Fig. 16.1) affects climate directly, while pollutants such as carbon monoxide (CO), non-methane volatile organic compounds (nmVOC), polycyclic aromatic hydrocarbons (PAH), nitrogen oxides (NO_X), sulphur dioxide (SO_2) and ammonia (NH_3) although

S.B. Dalsøren (✉)
CICERO Center for International Climate and Environmental Research-Oslo, Oslo, Norway
e-mail: s.b.dalsoren@cicero.uio.no

J.E. Jonson
Norwegian Meteorological Institute, Oslo, Norway
e-mail: j.e.jonson@met.no

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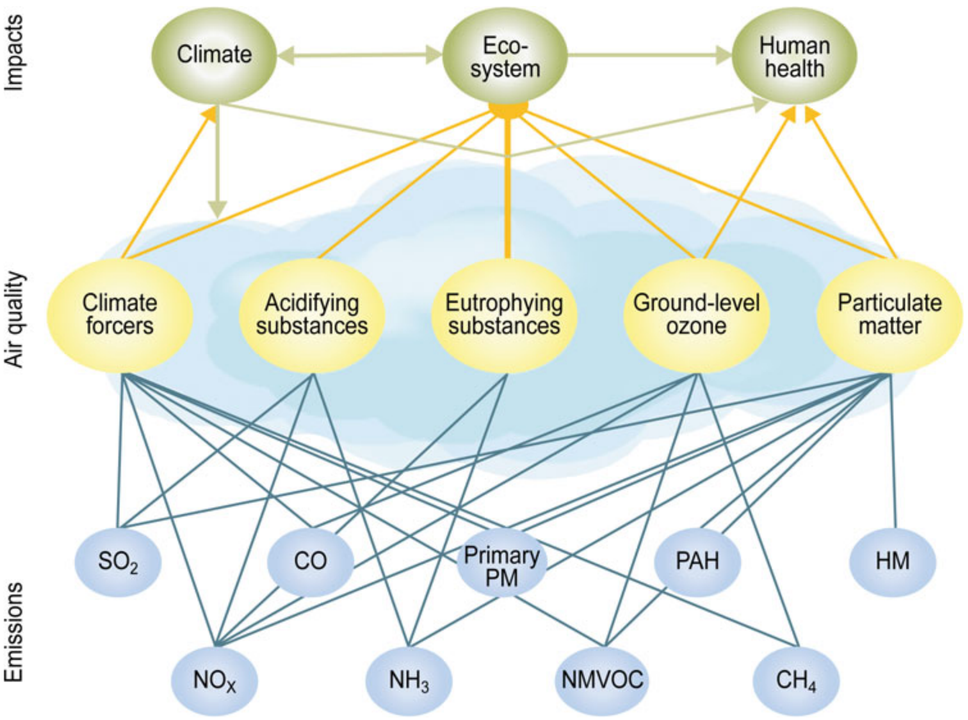
Fig. 16.1 Major air pollutants, clustered according to impacts on climate, ecosystems and human health (EEA 2012). From *left* to *right* the pollutants shown are as follows: sulphur dioxide (SO_2), nitrogen oxides (NO_X), carbon monoxide (CO), ammonia (NH_3), particulate matter (PM), non-methane volatile organic compounds (NMVOC), polycyclic aromatic hydrocarbons (PAH), methane (CH_4), heavy metals (HM)



having a negligible direct radiative (‘greenhouse’) effect, have an important indirect climate effect by acting as precursors for components that are both harmful pollutants and act as ‘climate forcers’ (e.g. ozone and particulate matter). On the other hand, air quality is also sensitive to climate change itself, since climate change drives changes in the physical and chemical properties of the earth and atmosphere. Climate policies also imply energy efficiency and technical measures that change emissions of air pollutants. Equally, air quality mitigation measures will impact on greenhouse gas emissions.

The main chemical components addressed in this chapter are PM and ground level ozone (O_3). These are generally recognised as the two pollutants that most significantly affect human health in Europe. The impacts of long-term and peak exposure to these pollutants range in severity from impairing the respiratory system to premature death. Particulate matter in the atmosphere originates from direct emissions (e.g. black and organic carbon, sea salt, dust, pollen) or is derived from chemical reactions involving precursor gases such as SO_2, NO_X, NH_3, PAH and nmVOC. The particles of greatest human health concern are 10 µm in diameter or less (PM_{10}). Of particular concern are those 2.5 µm or less ($PM_{2.5}$) since these could pass from the lungs into the bloodstream. The size and sign of the particulate climate effect (i.e. the particulate-driven temperature change) varies according to particle size, composition, shape, and altitude, and the albedo of the underlying surface. Particles can also change precipitation patterns and surface albedo.

Ozone is a secondary pollutant and greenhouse gas formed by complex chemical reactions involving NO_X, nmVOC, CO and methane (CH_4). In addition to its impact on human health, high O_3 levels may damage plants, affect agriculture and forest growth, and impact on CO_2 uptake. Compared to O_3 and PM, CH_4 is a relatively long-lived and thus well-mixed greenhouse gas and one link with regional air quality is that short-lived air pollutants such as NO_X, nmVOC, and CO may influence its chemical removal in the atmosphere. Changes in CH_4 concentration in turn affect the atmospheric oxidation capacity and thereby the speed of chemical cycles and removal of pollutants. The rise in global CH_4 levels over recent decades has contributed to rising background O_3 concentrations in the northern hemisphere.

16.2 Current Status

Poor air quality in Europe is a serious human health issue and the related external costs (costs imposed by a producer or a consumer on another producer or consumer, outside of any market transaction between them) are considerable. In 2010, annual premature mortalities were over 400,000 in the EU area and the total external costs of the health impacts were estimated at EUR 330–940 billion (EU 2013). Similar estimates are reported in other studies (Watkiss et al. 2005; Anenberg et al. 2010; Amann et al. 2011; Brandt et al. 2013a; Fang et al. 2013; Silva et al. 2013). Particulate matter is the principal pollutant in terms of human health impacts.

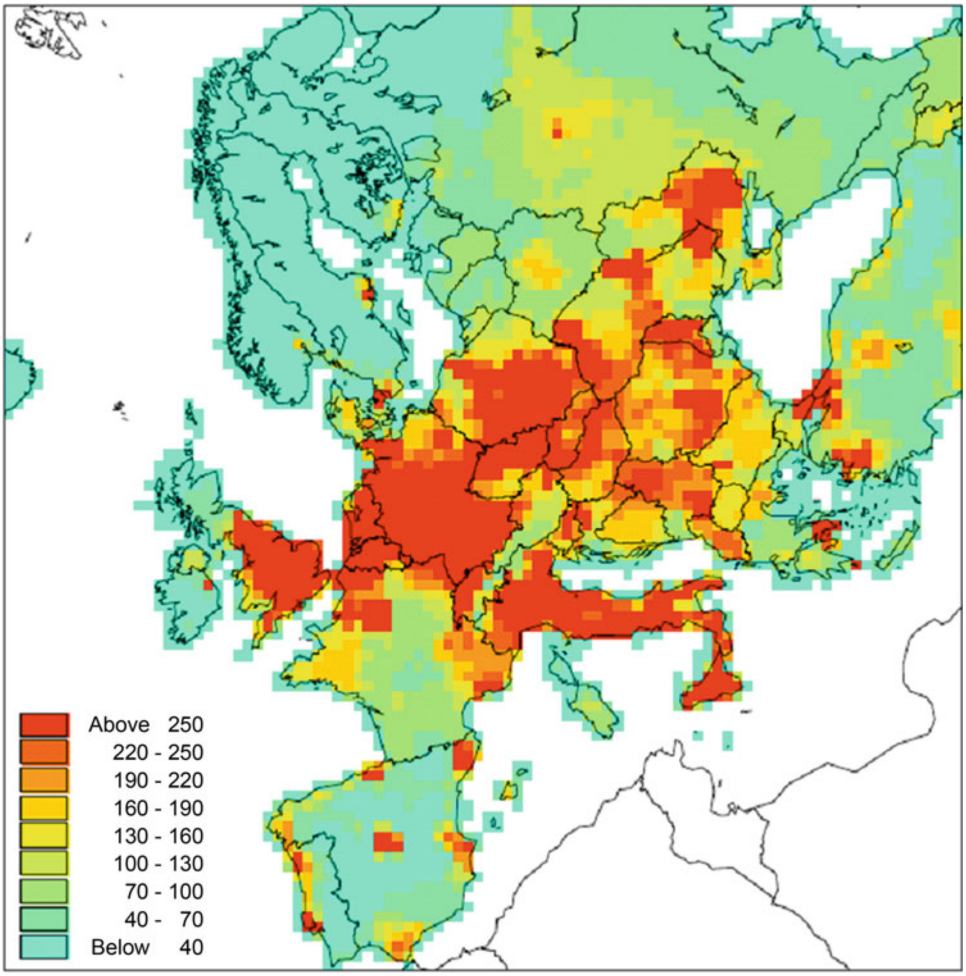


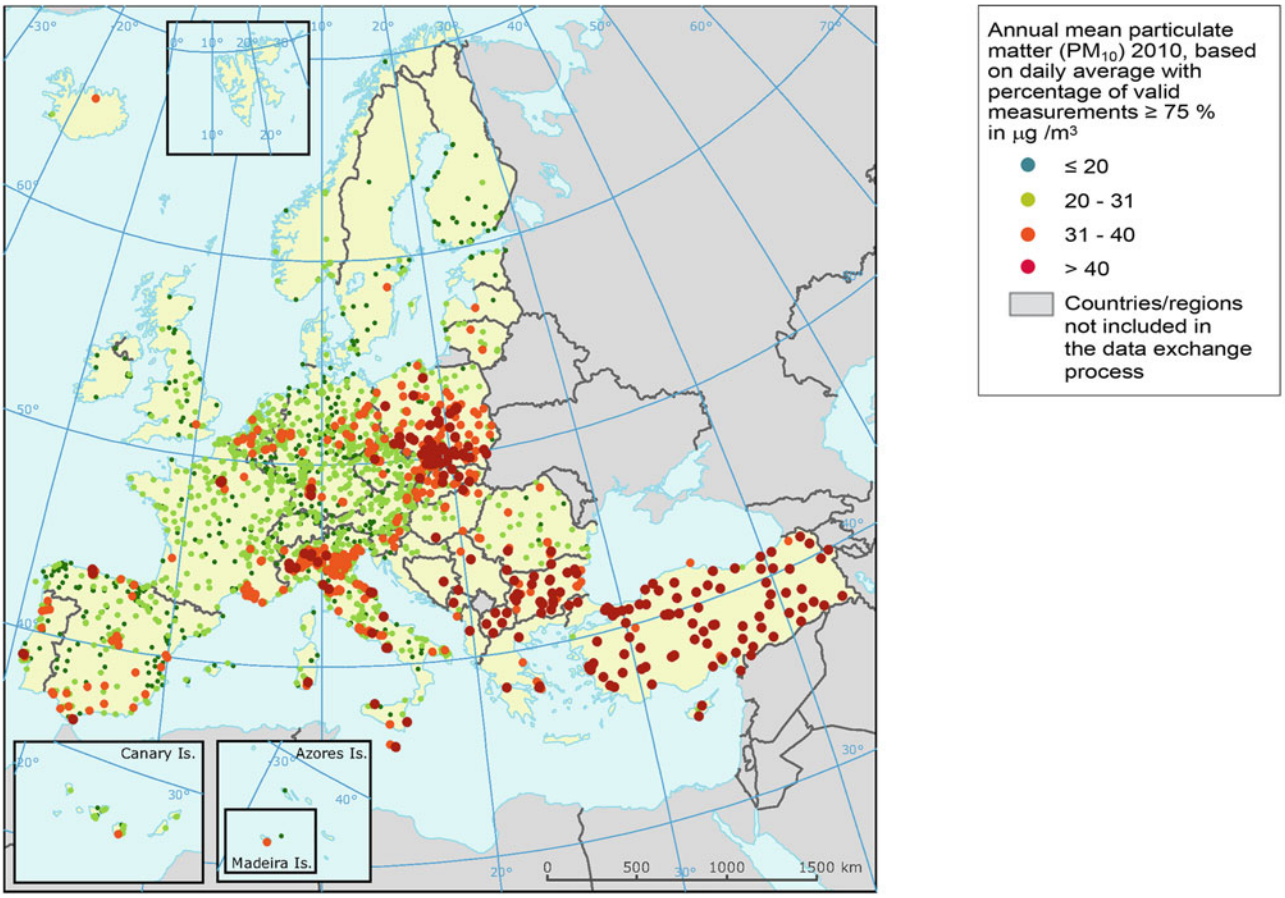
Fig. 16.2 Estimated number of premature deaths due to air pollution per 2500 km^2 grid cell in 2000 (Brandt et al. 2013a). The number of premature deaths is dependent both on pollution level and population density

Figure 16.2 shows an example of a model estimate of the geographical distribution of premature deaths in Europe in 2000 due to PM and O_3 (Brandt et al. 2013a). The number of premature deaths in highly populated regions of the North Sea countries is relatively high. Brandt et al. (2013a) estimated the number of premature deaths in Europe to have declined from 680,000 in 2000 to 570,000 in 2011. This decline reflects measures resulting in lower pollution levels in some regions of Europe such as the North Sea area (see Sect. 16.3).

16.2.1 Current Air Quality

In the European Union, $PM_{2.5}$ resulting from human activity is estimated to have reduced average life expectancy in 2000 by 8.6 months (EEA 2012). Figure 16.3 shows the annual mean measured concentration of surface PM_{10} across Europe in 2010. It should be noted that winter 2010 was colder than normal in the North Sea region (Blunden et al. 2011), resulting in higher PM concentrations than expected from a simple extrapolation of the long-term trend (Tsyro et al. 2012). It is clear that some stations in countries adjacent to the North Sea exceeded the EU daily limit value (orange and red dots). Exceedance at one or more stations occurred in 23 EU Member States in 2010. Of the urban EU population, 21 % was exposed to values above the daily limit value (EEA 2012). The World Health Organization (WHO) has a stricter guideline based on the fact that no threshold is found below which no adverse health effects of PM occur. The WHO guideline value was exceeded in most of the monitoring stations in continental Europe (red, orange and green dots). A similar picture emerges for $PM_{2.5}$ but there are fewer measurement sites.

The EU target value for O_3 of $120\ \mu g\ m^{-3}$ (daily maximum of 8-hour running mean values not to be exceeded on more than 25 days per year, averaged over three consecutive years) was exceeded at a large number of stations across Europe in 2010 (dark orange and red dots in Fig. 16.4). However, there are few exceedances of the target value in North Sea countries and none along the North Sea coast. Although winter 2010 was particularly cold in this region, summer was normal or slightly warmer than normal (Blunden et al. 2011). Even so, O_3 levels were low compared to



Note: The red dots indicate stations reporting exceedances of the 2005 annual limit value (40 µg/m³), as set out in the Air Quality Directive (EU, 2008c).

The orange dots indicate stations reporting exceedances of a statistically derived level (31 ug/m³) corresponding to the 24-hour limit value, as set out in the Air Quality Directive (EU, 2008c),

The pale green dots indicate stations reporting exceedances of the WHO air quality guideline for PM_{10} of less than 20 µg/m³ but not in exceedance of limit values as set out in the Air Quality Directive (EU, 2008c)

The dark green dots indicate stations reporting concentrations below the WHO air quality guideline for PM_{10} and implicitly below the limit values as set out in the Air Quality Directive (EU, 2008c).

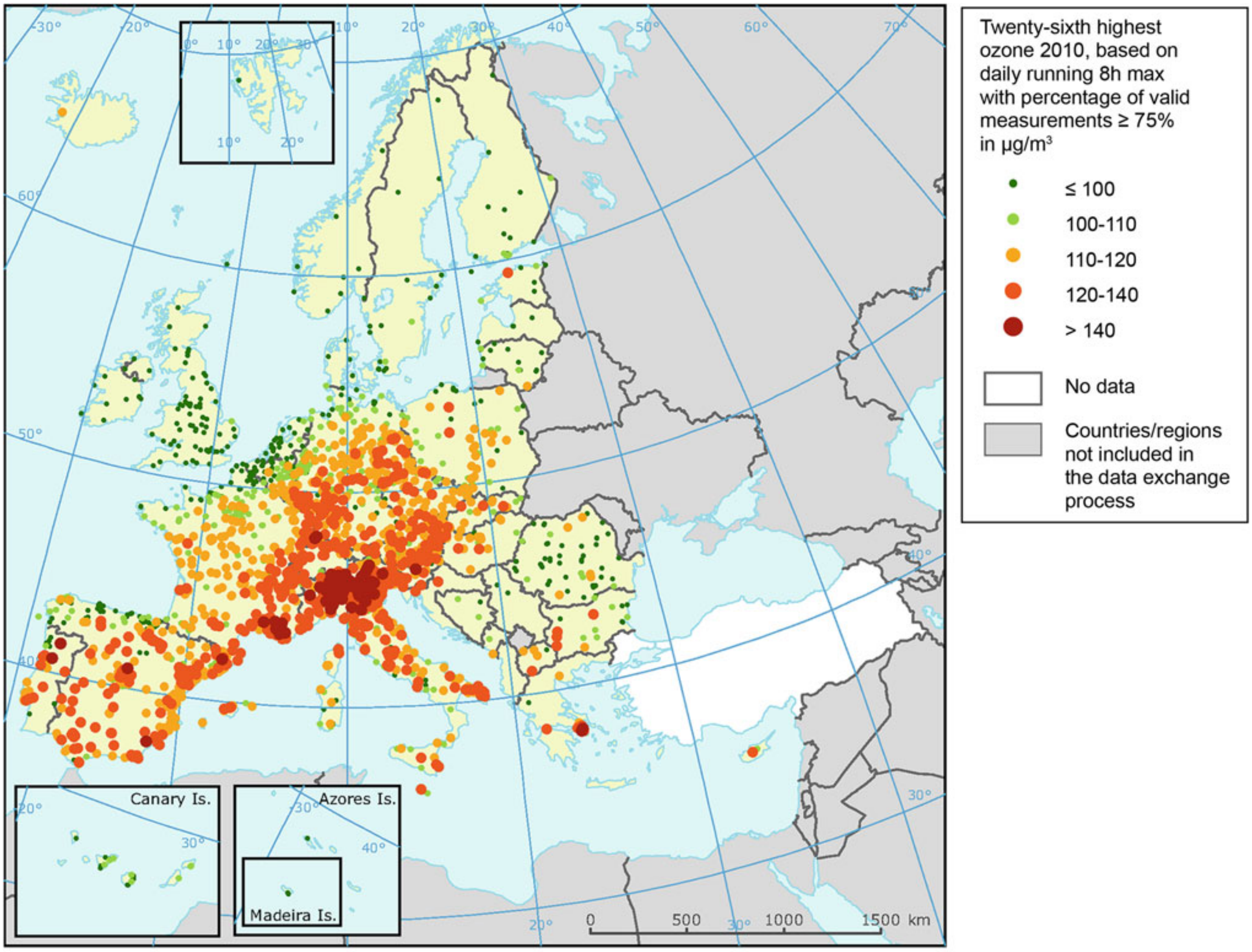
Source: AirBase v, 6.

Fig. 16.3 Annual mean surface concentration of PM_{10} across Europe in 2010 (EEA 2012)

the long-term average (Fagerli et al. 2012). Ozone formation is dependent on sunlight and concentrations increase from north to south across Europe. Ozone is also non-linearly dependent on NO_X and VOC concentrations, and is produced and destroyed in a balance between VOC and NO_X, fuelled by solar radiation. In areas with very high nitrogen oxide (NO) emissions, O_3 will be depleted by the reaction with NO (NO_X titration). As the emission plume moves away from the source region, O_3 may be regenerated. Ozone concentrations are therefore generally higher in rural areas some distance from the main NO_X emission sources. The long-term objective for the protection of human health of 120 µg m^{-3} (daily maximum of 8-hour running mean values), is exceeded at several stations in all North Sea countries (EEA 2011, 2014). For the ambitious WHO guideline (100 µg m^{-3} 8-hour mean) only two of the 510 rural stations, 3 % of urban background stations and 7 % of traffic stations would not exceed this level (EEA 2012). The EU information threshold (180 µg m^{-3} 1-hour mean) is occasionally exceeded in Belgium, the Netherlands and Denmark but is rarely exceeded in other North Sea countries (EEA 2011, 2014).

16.2.2 Contribution from Emission Sectors and Regions

On a country-by-country basis, the ratio between the contribution to air pollution and deposition from domestic versus non-domestic (transboundary) sources varies



Note: The map shows the proximity of recorded O_3 concentrations to the target value. At sites marked with dark orange and red dots, the twenty-sixth highest daily O_3 concentration exceeded the 120 μg/m³ threshold and the number of allowed exceedances by the target value.

Source: AirBase v. 6.

Fig. 16.4 Twenty-sixth highest daily maximum 8-hour average surface ozone (O_3) concentration recorded at each monitoring station in 2010 (EEA 2012)

substantially, depending on pollutant, local source strength, proximity to major non-domestic sources, and the geographical size of the individual countries (see recent reports by the European Monitoring and Evaluation Programme; EMEP[1]).

For $PM_{2.5}$, contributions to the overall national pollution level are dominated by transport from non-domestic countries (exceptions are Great Britain and Norway, which are heavily influenced by air masses originating over the Atlantic). As an example, the contributions to surface $PM_{2.5}$ and PM_{coarse} ($PM_{coarse} = PM_{10} - PM_{2.5}$) are shown in Fig. 16.5 for the Netherlands (Gauss et al. 2012). The main contributions are clearly from neighbouring countries. The contribution from volcanoes is due to the major volcanic eruption in Iceland in 2010.

The picture is more complicated for O_3 and O_3-derived parameters such as SOMO35.[2] Countries around the North Sea are some of the highest NO_X emitters in Europe. High NO_X emissions in combination with limited solar insolation during winter at these latitudes results in inefficient photochemical O_3 production and substantial NO_X titration. As a result, the present levels of NO_X emissions will, at least as an annual average, decrease the O_3 burden in the North Sea

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[1] http://emep.int/mscw/index_mscw.html.

[2] SOMO35, defined as the annual daily sum of 8-hour running average O_3 concentrations over 35 ppb, is a measure of accumulated annual O_3 concentrations and used as an indicator of health hazards, see EMEP (2013) for details.

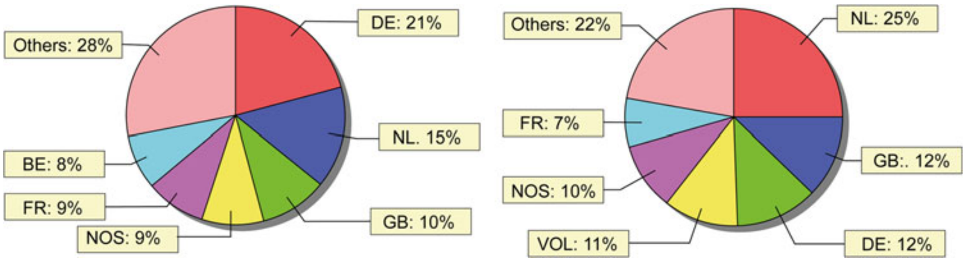

Fig. 16.5 Percentage contribution from individual countries to surface $PM_{2.5}$ (*left*) and PM_{coarse} (*right*) in the Netherlands. *BE* Belgium, *FR* France, *NOS* North Sea, *DE* Germany, *NL* The Netherlands, *GB* Great Britain, *VOL* volcanoes (Gauss et al. 2012)

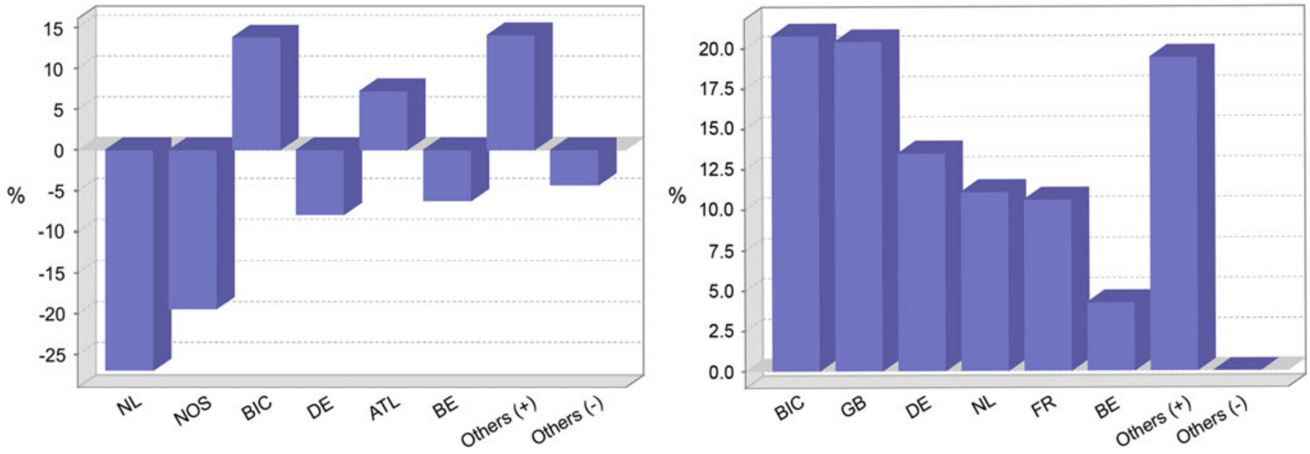

Fig. 16.6 Percentage contribution from individual countries to SOMO35 from NO_X emissions (*left*) and SOMO35 from nmVOC emissions (*right*) in the Netherlands. *NL* Netherlands, *NOS* North Sea, *DE* Germany, *GB* Great Britain, *FR* France, *ATL* remaining Atlantic within model domain, *BE* Belgium. BIC is boundary and initial concentrations (Gauss et al. 2012)

region. On the other hand, regional VOC and CO emissions result in increased O_3 levels. This is illustrated for The Netherlands in Fig. 16.6 (see EMEP country reports for further examples[3]).

The negative contribution from NO_X from several countries is caused by titration. The contribution from BIC (boundary and initial concentration) is calculated by perturbing lateral boundary (and initial) concentrations separately for NO_X and nmVOC in the EMEP model.

The contributions from different domestic emission sectors to model-calculated $PM_{2.5}$ concentrations in European countries are shown in Fig. 16.7. The countries are sorted according to the model-calculated contribution from Sector 1 (combustion in energy and transformation industries). The countries in the North Sea region are all to the right in the figure, with relatively small contributions from industry (Sectors 1–3; see figure caption for definitions).

These countries are characterised by a relatively large share of the emissions from agriculture and transportation (road and shipping). In the North Sea countries, shipping represents a significant share of the transport-related impacts. Studying the external costs from all international ship traffic in relation to the other sources, Brandt et al. (2013a) estimated that ship traffic accounted for 7 % of the total health effects in Europe due to air pollution in 2000. The corresponding value for Denmark, which is surrounded by heavy ship traffic, is 18 %. In Denmark the relative contribution from international ship traffic is comparable to the contributions from road traffic or the domestic use of wood stoves (Brandt et al. 2013b).

The North Sea region is also affected by transport of air pollutants from other continents. Figure 16.8 shows the model-calculated effects on surface O_3 from intercontinental transport due to 20 % reductions in anthropogenic emissions in North America, East Asia and South Asia. As an average for the European continent the calculated contribution to surface O_3 from other continents is about half of the total European contribution (HTAP 2010). The intercontinental contributions show large seasonal (see Fig. 16.8) and geographic variability. Brandt et al. (2012) calculated the effects

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[3] http://emep.int/mscw/index_mscw.html.

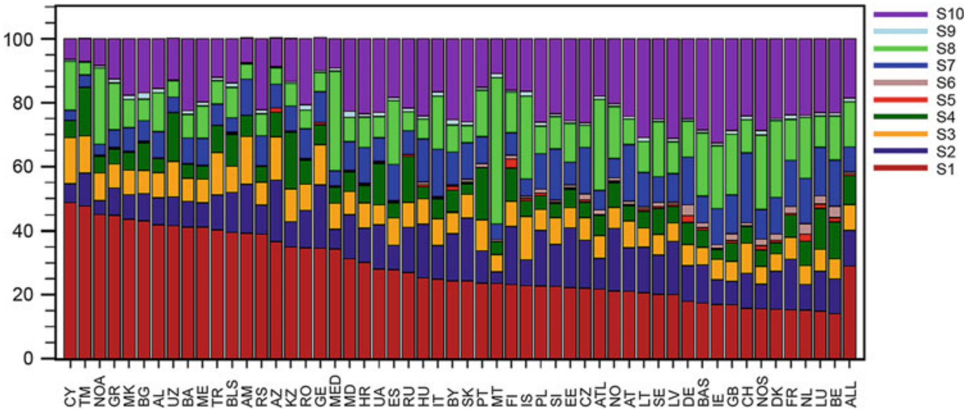

Fig. 16.7 Percentage contribution from individual sectors to $PM_{2.5}$ concentration in European countries: *S1* combustion in energy and transformation industries, *S2* non-industrial combustion plants, *S3* combustion in manufacturing industry, *S4* production processes, *S5* extraction and distribution of fossil fuels and geothermal energy, *S6* solvent and other product use, *S7* road transport, *S8* other mobile sources and machinery (including shipping), *S9* waste treatment and disposal, *S10* agriculture

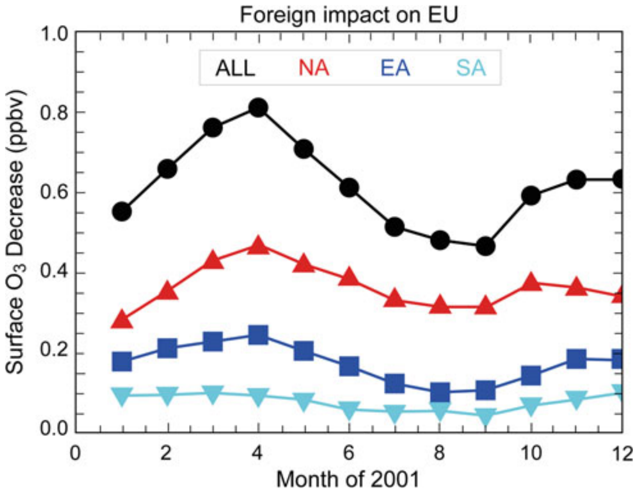

Fig. 16.8 Changes in European surface O_3 levels from 20 % reductions of anthropogenic emissions in North America (NA), East Asia (EA) and South Asia (SA). ALL is the combined effects of the contribution from the three foreign regions (adapted from HTAP 2010, see original report for more details)

of North American emissions on Europe using a tagging method. Their results are at the lower end of the HTAP estimates. The HTAP and Brandt et al. (2012) calculations are for different meteorological years. Located close to the western continental rim, the intercontinental contribution to the North Sea region is higher than the European average as shown by Jonson et al. (2006).

Particulate matter has a short residence time in the atmosphere, and as a result the intercontinental contribution to Europe is in general low. Calculating the ratio of the effect of other (than Europe) source regions to the effect of all source regions (including Europe), indicates that about 5 % of the PM surface concentrations in Europe can be attributed to intercontinental transport (HTAP 2010). However, the temporal variability is large, and the contribution can be significant for specific episodes.

16.3 Recent Change

16.3.1 Emissions

For most air pollutants emission totals reached a maximum in the late 1980s or early 1990s. Since then emissions of air-polluting substances have decreased substantially in most European countries. For parties to the Gothenburg Protocol[4] emission ceilings are set for 2010 for four pollutants: sulphur, NO_X, VOCs and NH_3. For EU Member States these emission ceilings are largely integrated within EU legislation. This is illustrated in Fig. 16.9, showing the evolution of emissions from countries within the EMEP domain (i.e. Europe, large parts of the North Atlantic and the polar basin and parts of North Africa; see www.EMEP.int for definition) from 1990 to 2010. Emissions of PM have only been reported since 2000. There are large differences in trends between individual countries, with some countries even increasing their emissions for one or more species. Parties to the Gothenburg Protocol whose emissions have a more severe impact, and whose emissions are relatively cheap to reduce are obliged to make the largest cuts in emissions. The countries around the North Sea are among those that have had to make the greatest cuts in emissions. Uncertainty in the emission trends is significant. The large drop in PM emissions from 2001 to 2002 may reflect incomplete reporting prior to 2002.

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[4] www.unece.org/env/lrtap/multi_h1.html.

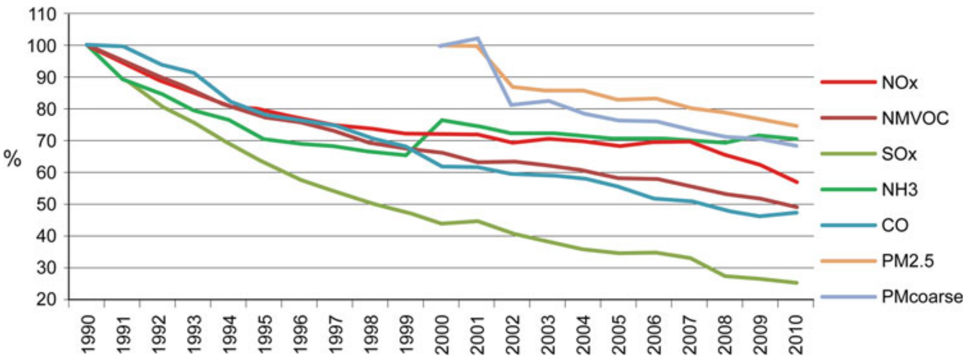

Fig. 16.9 Emission trends 1990–2010 (2000–2010 for $PM_{2.5}$ and PM_{coarse}) (Fagerli et al. 2012)

The North Sea region is strongly influenced by emissions from shipping. Traditionally, emissions from shipping have been largely unregulated. However, recent policy decisions through the International Maritime Organization (IMO MARPOL Annex VI SO_X Emission Control Area SECA requirements) and the EU (Sulphur Directive) affect ship emissions of both SO_X and PM in the region. The former restricts the marine fuel sulphur content in SECAs to 1.0 % as of 1 July 2010 and 0.1 % from 2015 whereas the latter requires ships to use 0.1 % sulphur fuel in harbour areas from 1 January 2010. Prior to 2010 the maximum allowed sulphur content in SECAs was 1.5 % as opposed to the global fleet average of about 2.4 %. Emissions of SO_X, NO_X, VOC, CO and PM from international shipping, from 1990 to present, are listed in appendix B in EMEP (2013).

16.3.2 Air Pollution

There are no PM_{10} or $PM_{2.5}$ measurements extending over decades. It is only for the past decade that enough data exist to derive trends. The monitoring network for $PM_{2.5}$ is sparser than for PM_{10} giving larger uncertainties for the reported $PM_{2.5}$ change. Over the period 2000–2009, Tørseth et al. (2012) found a decrease in PM_{10} and $PM_{2.5}$ concentration at about half of the European rural sites in the EMEP network. Average reductions in the annual means were 18 % (PM_{10}) and 27 % ($PM_{2.5}$). None of the stations in the network showed an increasing trend. Similar results were found by Barmpadimos et al. (2012) using selected EMEP stations corrected for meteorological variability. The trends roughly correspond to reported reductions in emissions of primary PM and precursors for secondary PM (Fig. 16.9). Figure 16.10 shows the change in PM_{10} for the past decade as reported by the European Environment Agency (EEA 2012). These data also include stations in urban surroundings and near roads with heavy traffic. Most of the stations registering a trend showed a decrease, with only 2 % of stations recording an increase. For countries adjacent to the North Sea, moderate decreases are found at most stations although some show no significant trend. There is also a reduction in the number of exceedances of the EU PM_{10} daily limit value for most North Sea countries (EEA 2012).

Devasthale et al. (2006) used satellite measurements complemented by station data to investigate trends in air polluting particles and focused on the English Channel and the top three polluting harbours in Europe. For the period 1997–2002 they found increasing particle concentrations over harbours and coastal areas and decreasing concentrations over land areas. The different evolution is attributed to decreased emissions from land-based sources and increased emissions from shipping. Jonson et al. (2015) and Brandt et al. (2013a) modelled the effects of Baltic Sea and North Sea ship emissions in 2009 and 2011 (before and after the reductions in the sulphur content of marine fuels from 1.5 to 1 % from 1 July 2010). The calculations indicate clear improvements in PM concentration. These are however slightly offset by increasing NO_X emissions, affecting nitrate particle formation. This is particularly the case in and around major North Sea ports owing to partial economic recovery after the financial crisis.

Ozone is strongly coupled to meteorological variability both in terms of regional photochemical production and loss, and the contribution from intercontinental transport. Trends are therefore difficult to detect and long time series are needed. In some regions, lack of long-term data makes trend analysis impossible. Reductions in the highest O_3 values are found (Fig. 16.11) in England, Benelux and Germany (EEA 2009, 2012; Tørseth et al. 2012) for the period 1990–2010, but mainly the 1990s. The frequency of high values has also decreased, especially in the Netherlands, England and Ireland (Tørseth et al. 2012).

Studies report that despite a relatively large decline in anthropogenic emissions in Europe (Fig. 16.9) a corresponding reduction in O_3 concentration is not observed (Jonson et al. 2006; EEA 2009, 2012; Tørseth et al. 2012; Wilson et al. 2012). Models also generally struggle to reproduce some of the observed trends (Solberg et al. 2005; Jonson et al. 2006; Colette et al. 2011; Wilson et al. 2012; Parrish et al. 2014). Likely reasons include increased

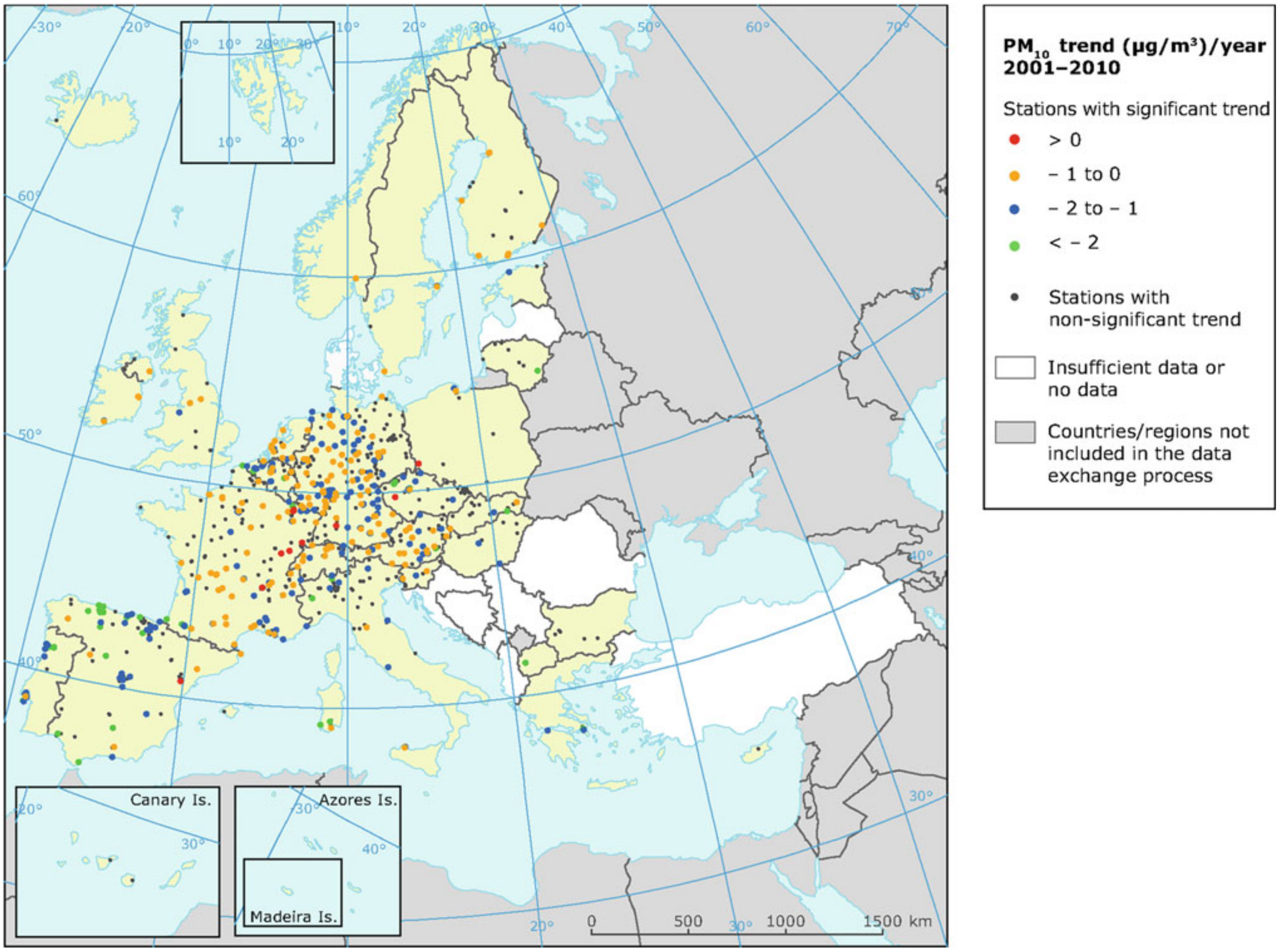

Fig. 16.10 Average annual change in surface PM_{10} concentration for the period 2001–2010 (EEA 2012). Only stations with a statistically significant trend are shown

background (hemispheric) O_3 level—observational evidence suggests that the increase in background O_3 roughly doubled from 1950 to 2000 and then levelled off (Logan et al. 2012; Derwent et al. 2013; Oltmans et al. 2013; Parrish et al. 2013). Other possibilities are limitations in the understanding of photochemistry, coarse model resolution, uncertainties related to anthropogenic emission estimates, variation in poorly constrained natural emissions, and the small number of measurement sites with long-term data sets.

16.3.3 Contribution from Climate Change

Climate change influences air pollution levels through a number of factors (see HTAP 2010), including changes in temperature, solar radiation, humidity, precipitation, atmospheric transport and biogenic emissions. Using a model to compare current conditions (1990–2009) against a baseline period (1961–1990) Orru et al. (2013) found the largest climate-driven increase in O_3-related mortality and hospitalisations to have occurred in Ireland, the UK, the Netherlands and Belgium where increases of up to 5 % are estimated. A decrease is estimated for the northernmost European countries. Hedegaard et al. (2012) compared the 1990s with the 1890s and found climate-driven decreases in surface O_3 in the North Sea region. However, the decrease is not statistically significant over the region as a whole.

Using an ensemble of global models, Silva et al. (2013) found the average number of premature annual deaths attributable to past (1850–2000) climate change in Europe to be 954 for O_3 (respiratory) and 11,900 for $PM_{2.5}$. But the magnitude and even the sign of the values varies between models. In a global study with one model, Fang et al. (2013) found a climate-driven contribution to cardiopulmonary and lung cancer mortality associated with industrial $PM_{2.5}$ since 1860 of up to 14 % over Europe. Ozone was responsible for a small contribution. The calculation does not include the climate-driven effect on emissions of biogenic hydrocarbons.

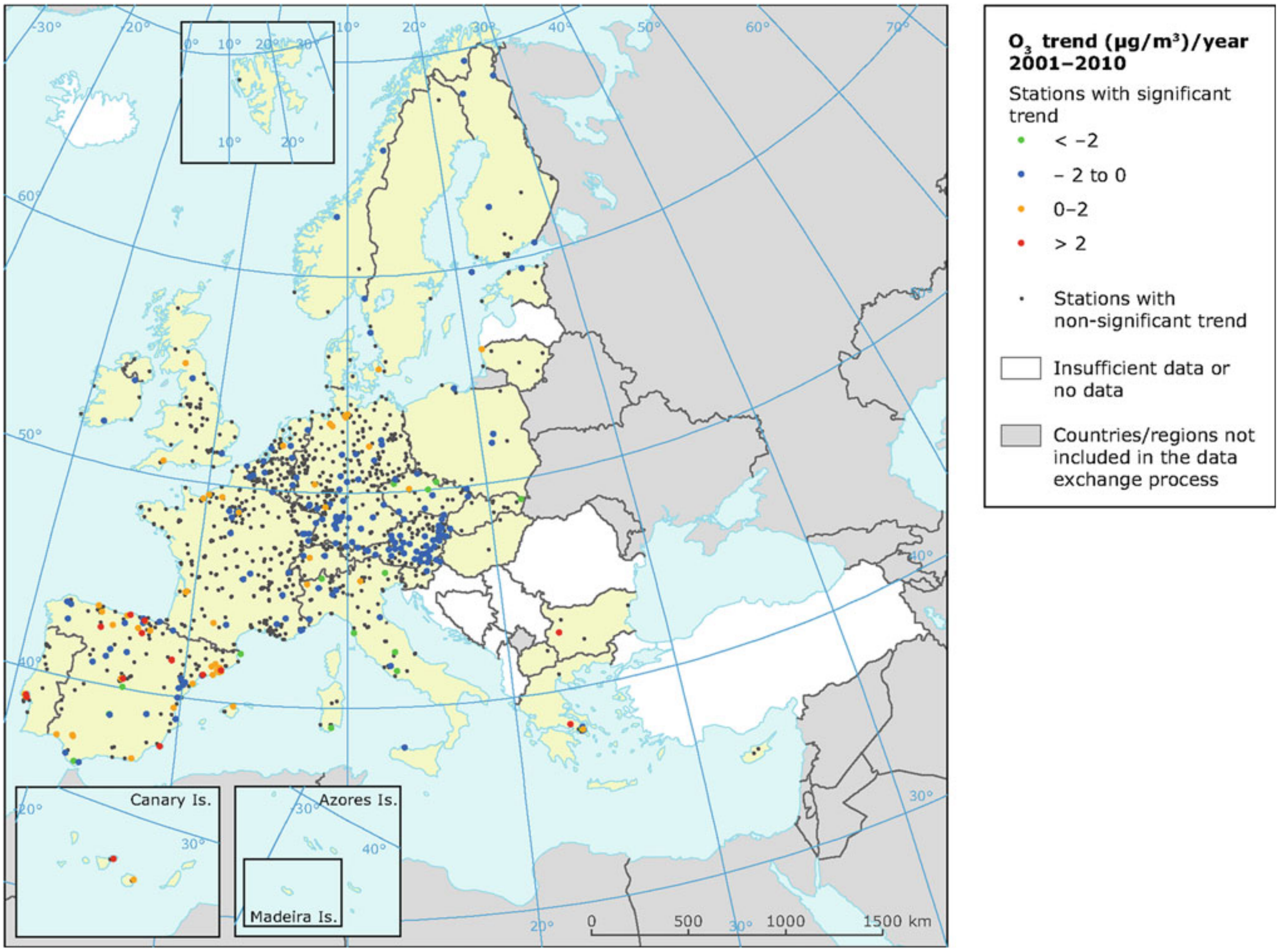

Fig. 16.11 Change in annual mean maximum daily 8-hour ozone (O_3) concentration in the period 2001–2010 (EEA 2012). Only stations (urban/suburban/rural) with a statistically significant trend are shown

Recent heat waves have been linked to climate change (e.g. Stott et al. 2004). Whether these anomalies are exceptional or a signal of changes in climate is still under debate. Summer 2003 was one of the hottest in the history of Western Europe, with surface temperature exceeding the average surface temperature reported for 1901–1995 by 2.4 °C. In fact, this summer was likely to have been warmer than any other back to 1500.

Fischer et al. (2004) estimated that almost half of the excess deaths in the Netherlands during the 2003 heat wave were due to increased air pollution (O_3 and PM_{10}). Stedman (2004) estimated that the same air pollutants were responsible for 21–38 % of excess deaths in the UK. Doherty et al. (2009) found the overall number of deaths attributable to O_3 in England and Wales to be slightly greater than that attributable to heat for the 2003, 2005 and 2006 summers. Several studies have described the high pollution levels observed in 2003 (Vautard et al. 2005; Solberg et al. 2008; Tressol et al. 2008).

The high temperatures during the 2003 heat wave influenced summer O_3 because of its link with high solar radiation, stagnation of the air masses and thermal decomposition of peroxyacetyl nitrate (PAN). Availability of solar radiation favours photolysis yielding radical formation with subsequent involvement in O_3 production. Stagnation of air masses allows the accumulation of pollutants in the planetary boundary layer (PBL) and in the residual layer during the night. Increased temperatures and solar radiation favoured biogenic emissions of isoprene with a potential for enhanced O_3 chemistry in the PBL. High temperature and a spring to summer precipitation deficit reduced dry deposition of O_3. The high temperatures and exceptional drought led to extensive forest fires on the Iberian Peninsula which contributed to the peak in ground level O_3 observed in western central Europe in August (Solberg et al. 2008; Tressol et al. 2008).

16.4 Future Impacts

Future air quality will be affected both by changes in air pollutant emissions and by changes in climate. A large span in emission scenarios and degree of detail in climate simulations are used in different studies. As a result, the studies referred to in the following sections are not directly comparable.

16.4.1 Emission Scenarios

Emissions of air pollutants have significantly reduced in recent decades (see Fig. 16.9). Even though economic activity in Europe is expected to increase, air pollutant emissions from all land-based sectors and regions in Europe are still expected to decline following current legislation. For example, emissions from the transport sector are expected to decrease owing to the penetration of vehicles with stricter emissions standards (Euro 5 and Euro 6), and the expected transition to renewable energy in Europe should drive a decline in emissions from the energy sector. After five years of negotiation, a revised Gothenburg Protocol was finalised in May 2012. The revised protocol specifies emission reduction commitments from base 2005 to 2020. It has also been extended to cover $PM_{2.5}$. Most states decided only to accept emission reduction obligations for 2020 that are even less ambitious than—or at best largely in line with—business-as-usual, that is, reductions expected to be achieved anyway solely by implementing existing legislation.

Overall, EU Member States' commitments to the revised protocol mean that from 2005 to 2020 they shall jointly cut their emissions by 59 % (SO_2), 42 % (NO_X), 6 % (NH_3), 28 % (VOCs) and 22 % ($PM_{2.5}$). According to the IMO MARPOL regulations the maximum sulphur content allowed in marine fuels will be reduced to 0.1 % from 2015 in SECAs (Sulphur Emission Control Areas). Both the North Sea and the Baltic Sea are accepted as SECAs. Further measures may also be implemented for NO_X in these seas. This may impose a shift from extensive use of heavy fuel oil to marine distillates, or a switch to liquefied natural gas (LNG), or using heavy fuel oil in combination with scrubber technology.

In sea areas outside SECAs, sulphur emissions have continued to rise and these emissions also affect the North Sea area. From 2020, the sulphur content in marine fuels outside SECAs should be reduced to 0.5 % globally, but depending on the outcome of a review to be concluded in 2018 as to the availability of the required fuel oil, this date could be deferred to 2025. However, the EU Sulphur Directive obliges ship owners to use 0.5 % fuel in

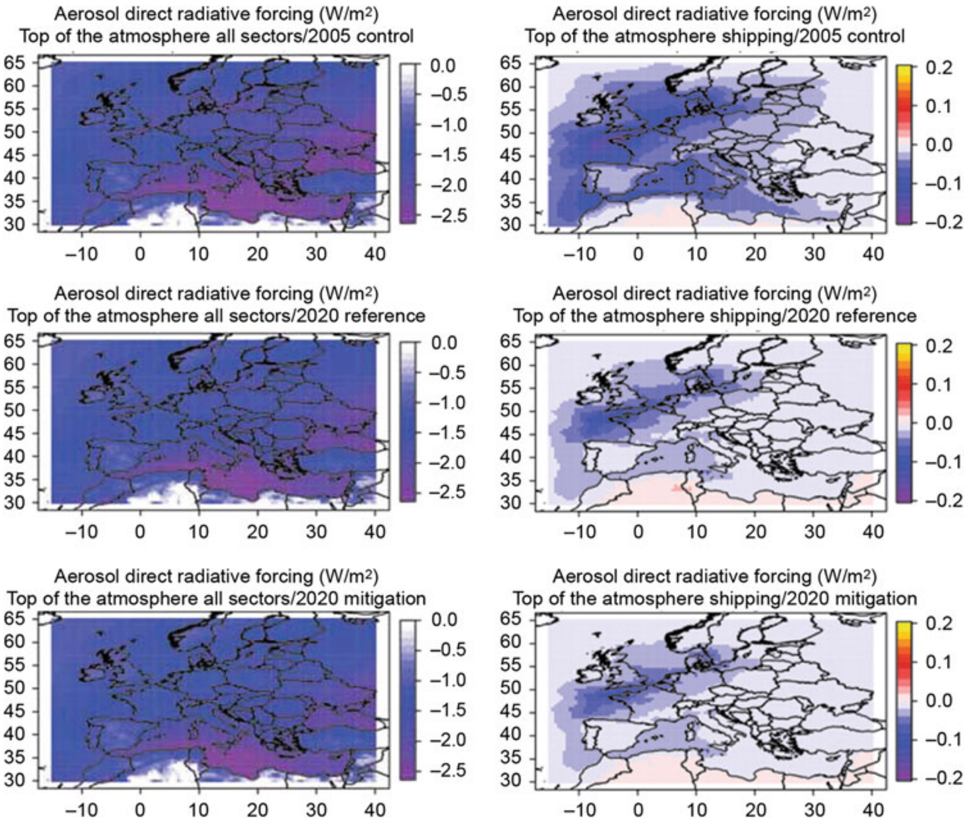

Fig. 16.12 Aerosol-induced direct radiative forcing at the top of the atmosphere in 2005 and for two projections: reference (2020) and mitigation (2020) (*left column*); Contribution attributed to shipping activities (*right column*). The reference scenario includes all current implemented and planned air quality policies. The so-called mitigation scenario in addition includes further climate policies leading to a stabilisation of global warming to not more than 2 °C in 2100. Both scenarios include mitigation measures for shipping that correspond to MARPOL regulations for NO_X and SO_2 (EEA 2013)

non-SECA EU sea areas from 1 January 2020 regardless of the outcome of the IMO review.

Efforts to improve air quality will undoubtedly influence climate. An interesting example is shown in Fig. 16.12. Large direct and indirect aerosol effects lead to a current global net cooling impact from the shipping sector. The aerosol direct and indirect (not shown) effects are likely to be substantially reduced over the North Sea in 2020. Refraining from air pollutant mitigation to favour a (potential) net cooling effect of the shipping sector is however risky from a health and environmental perspective and given large reported uncertainties, especially for the size of the climate impact of shipping aerosols.

To date, there are no NO_X Emission Control Areas (NECAs) in Europe. Hammingh et al. (2012) evaluated the potential impact of establishing a North Sea NECA. This would require new ships to emit 75 % less NO_X, from 2016 onward. A NECA in the North Sea would reduce total premature deaths due to air pollution in the North Sea countries by nearly 1 %, by 2030. This value would approximately double when all ships met the stringent nitrogen standards, a situation expected after 2040. Health benefits would exceed the costs to international shipping on the North Sea by a factor of two.

16.4.2 Impacts on Air Quality

16.4.2.1 Impacts from Emission Changes

Air quality in the North Sea region should improve as a result of expected reductions in emissions. The reductions in emissions should cause a decrease in PM levels. Based on a parameterisation of the HTAP source receptor calculations for the main source regions in the northern hemisphere, Wild et al. (2012) calculated future O_3 trends following the Intergovernmental Panel on Climate Change RCP (representative concentration pathway) emission scenarios. The calculations demonstrated that substantial annual mean surface O_3 reductions can be expected for most RCP scenarios by 2050 over most regions, including Europe. However, as discussed in Sect. 16.2.2 parts of the North Sea region are characterised by extensive NO_X titration of O_3. Unlike most other regions in Europe, reductions in NO_X emissions here are likely to result in increased levels of surface O_3, at least in the short term (Fig. 16.13). Colette et al. (2012) concluded that air pollution mitigation measures (present in both scenarios in Fig. 16.13) are the main factors leading to the net improvement over much of Europe, but an additional co-benefit of at least 40 % (depending on the indicator) is due to the climate policy. However the climate policy has little impact in the North Sea region (Fig. 16.13).

The total health-related external costs in Europe due to the total air pollution levels from all emission sources in the northern hemisphere are calculated to be EUR 803 billion year^{-1} for 2000 decreasing to EUR 537 billion year^{-1} in 2020 (Brandt et al. 2013a). The decrease is due to the general emission reductions in Europe provided that the revised Gothenburg Protocol is implemented and given the regulation of international ship traffic by introducing SECAs in the North Sea and Baltic Sea. For Denmark the external costs are estimated to be EUR 4.54 billion year^{-1} for 2000, decreasing to EUR 2.53 billion year^{-1} in 2020.

Using a baseline emission scenario, Amann et al. (2011) calculated that loss in statistical life expectancy attributed to exposure to $PM_{2.5}$ would decline between 2005 and 2020 from 7.4 to 4.4 months in the EU-27. There are significant improvements for the North Sea region (Fig. 16.14). The improvement in mortality due to ground level O_3 is about 35 % in EU Member States (Fig. 16.15) (Amann et al. 2011), with significant improvements in all North Sea countries. With commercially available emission control technologies, European emissions could be further reduced from baseline by 60 % (SO_2), 30 % (NO_X), 65 % (primary $PM_{2.5}$), and about 35 % (NH_3 and VOC). The measures would cut the loss in statistical life expectancy by 50 % (or another 2.5 months) compared to the baseline case in 2020.

However, the improvements come at a cost. Full implementation of the additional measures would increase costs for air pollution control in Europe in 2020 from EUR_{2005} 110 billion year^{-1} to EUR_{2005} 192 billion year^{-1}, i.e. from

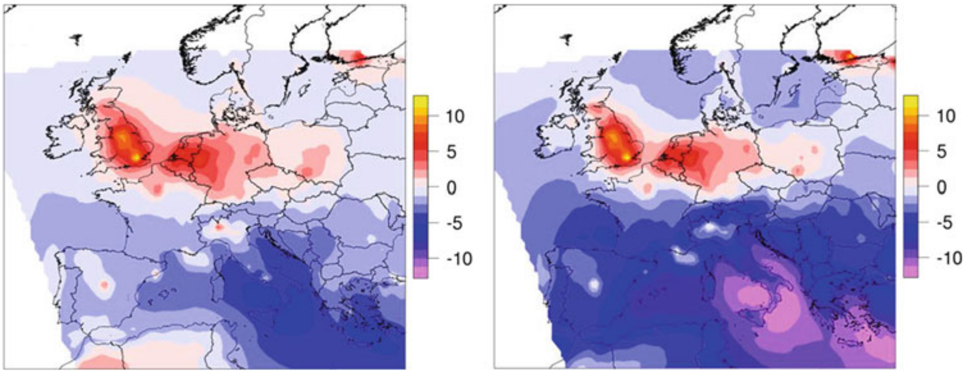

Fig. 16.13 Difference in surface O_3 between 2030 and 2005 for two scenarios: a reference case (*left*) and a sustainable climate policy case (*right*) (Colette et al. 2012)

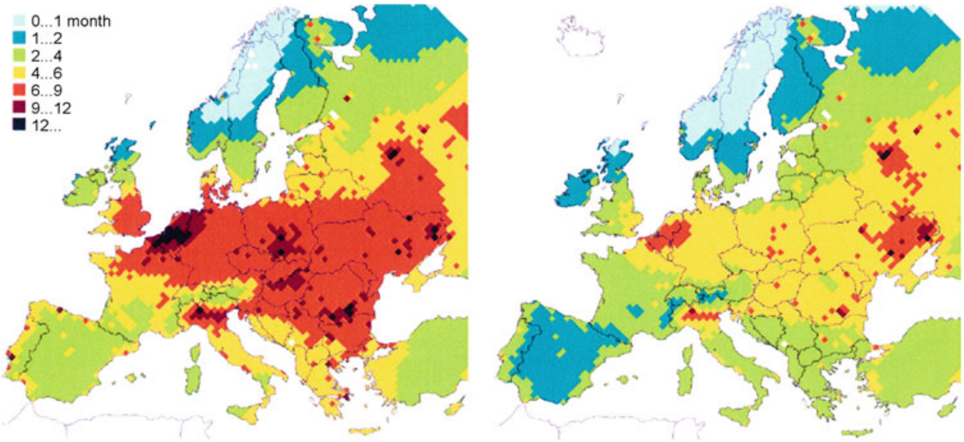

Fig. 16.14 Loss in statistical life expectancy attributable to exposure to $PM_{2.5}$ from anthropogenic sources. 2005 (*left*) and baseline projection for 2020 (*right*) (Amann et al. 2011)

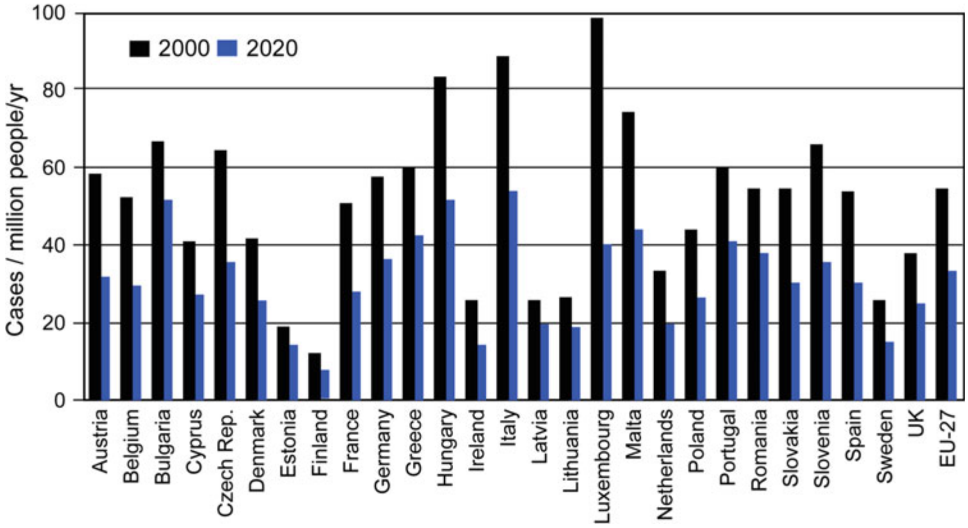

Fig. 16.15 Mortality rates attributable to exposure to ground-level O_3 (Amann et al. 2010)

0.66 % to 1.15 % of the GDP envisaged for 2020. At the same time, some of the measures achieve little environmental improvement. Experience shows that a cost-effectiveness analysis can identify portfolios that realise most of the potential improvements at a fraction of the costs of the total portfolio.

16.4.2.2 Impacts from Climate Change

Climate impacts on air pollution are summarised by HTAP (2010). Future changes in climate are expected to increase local and regional O_3 production and reduce O_3 in downwind receptor regions. Factors contributing to O_3 increases near emission regions include increased O_3 production due to higher water vapour leading to more abundant hydrogen oxide radicals (HO_X) which leads to increased O_3 production at high NO_X concentrations. Increased global average temperature increases photochemistry rates and decreases net formation of reservoir species for NO_X, leaving more NO_X available over source regions. This promotes local O_3 production. In a warmer climate natural emissions of VOC and NO_X (biogenic, lightning) are expected to increase. Such increases will depend on uncertain changes in soil moisture, cloud cover, sunlight, and biogenic responses to a more CO_2-rich atmosphere.

Although there are many factors affecting PM levels, changes in cloud amount and precipitation are the major parameters as wet removal is a major sink for PM. Despite several pathways by which climate change may influence air quality, most model simulations show air pollutant emissions to be the main factor driving change in future air quality, rather than climate or long-range transport (Andersson and Engardt 2010; HTAP 2010; Katragkou et al. 2011; Langner et al. 2012a, b; Coleman et al. 2013; Colette et al. 2013). Hedegaard et al. (2013) found emission changes to be the main driver for PM changes but that climate change is equally important for O_3 in many North Sea countries.

Orru et al. (2013) compared O_3-related mortality and hospitalisation due to climate change for a baseline period (1961–1990) and the future (2021–2050). Increases in O_3-related cases are projected to be greatest in Belgium, France, Spain and Portugal (10–14 %), whereas in most Nordic and Baltic countries there is a projected decrease in O_3-related mortality of the same magnitude. Overall there is an increase of up to 13.7 % in O_3-related mortality in Europe, which corresponds to 0.2 % in all-cause total mortality and respiratory hospitalisations.

The sensitivity of simulated surface O_3 concentration to changes in climate between 2000–2009 and 2040–2049 differs by a factor of two between the models used in a study by Langner et al. (2012a), but the general pattern of change with an increase in southern Europe is similar across different models. Changes in isoprene emissions from deciduous forests vary substantially across models explaining some of the different climate response. In northern Europe, the ensemble mean for mean and daily maximum O_3 concentration both decrease whereas there are no reductions for the higher percentiles indicating that climate impacts on O_3 could be especially important in connection with extreme summer events such as experienced in summer 2003 (see Sect. 16.2.2). Some regional climate modelling studies suggest that conditions such as those of summer 2003 could become more frequent in coming decades (Beniston 2004; Schär et al. 2004).

Colette et al. (2013) and Hedegaard et al. (2013) found that climate change in the North Sea region would constitute a slight benefit for $PM_{2.5}$ concentrations. Other studies show both small increases and decreases of PM within the region (Nyiri et al. 2010; Manders et al. 2012). The spread of precipitation projections in regional climate models constitutes a major challenge in reducing the uncertainty of the climate impact on PM (Manders et al. 2012). Nevertheless, some conclusions can be drawn from the different climate model projections for the North Sea region (Jacob et al. 2014). Winter precipitation is expected to increase over the coming century, while summer precipitation is expected to decrease over much of the region. Heavy precipitation events are expected to occur more often in all seasons.

16.5 Conclusions

Climate and air quality interact in several ways. Emitted air pollutants could directly impact climate or could act as precursors for components acting both as harmful pollutants and climate forcers. On the other hand, air quality is sensitive to climate change since it perturbs the physical and chemical properties of the environment. Climate policies imply energy efficiency and technical measures that change emissions of air pollutants. Reciprocally, air quality mitigation measures affect greenhouse gas emissions. Mitigation optimised for a climate or air quality target in isolation could have synergistic or antagonistic effects.

In the North Sea area, the effects on air quality of emission changes since pre-industrial times are stronger than the effects of climate change over this period. Despite several pathways by which climate change may influence air quality, model simulations show air pollutant emissions to be the main factor driving change in future air quality in the North Sea region, rather than climate. The variation in climate simulations in different studies results in significant uncertainty in the impacts of climate change on air quality. This is particularly the case for PM where the spread of precipitation projections in regional climate models constitutes a major challenge in narrowing the uncertainty.

Climate impacts on air quality are substantial in connection with heat waves, such as that of summer 2003. Some regional climate models suggest that heat waves could become more frequent in the coming decades. If the anticipated reductions in emissions of air pollutants are not achieved, extreme weather events of this type may cause severe problems in the future.

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17

Socio-economic Impacts—Recreation

Edgar Kreilkamp, Nele Marisa von Bergner and Claudia Mauser

Abstract

Tourism is one of the most highly climate-sensitive economic sectors. Most of its main sub-sectors, including sun-and-beach tourism and nature-based tourism, play a major role in the North Sea region and are especially weather–und climate-dependent. On top of that, most tourist activities in the North Sea region occur in the coastal zones which are highly vulnerable to the impacts of climate change. Climate acts as both a 'push' and 'pull' factor in tourism. Climate-driven changes in tourism demand are hard to determine because the tourist decision-making process is also influenced by factors other than climate. Nevertheless, summer tourism in the North Sea region is expected to benefit from rising temperatures (air and water), decreasing precipitation and longer seasons. Destinations can reduce the negative impacts of climate change on tourism by adapting to the changes. The tourist industry also contributes to climate change. Not only is the tourist industry affected by climate change, it also contributes to climate change itself. Therefore, mitigating the climate effects of tourism is largely the responsibility of politicians, the tourism industry and tourism supply. Despite some negative impacts, the overall consequences of climate change for tourism in the North Sea region are expected to be positive.

17.1 Introduction

The United Nations World Tourism Organization states that tourism is one of the most highly climate-sensitive (and even in some cases climate-dependent) economic sectors. Climate change is therefore a major challenge for global tourism (UNWTO 2009; von Bergner and Lohmann 2014). The main sub-sectors include sun-and-beach tourism, sports tourism, adventure tourism, nature-based tourism, cultural tourism, urban tourism, health and wellness tourism, cruises, theme parks, visiting friends and relatives, and meetings and conferences (Scott and Lemieux 2010). Most of these are weather- and climate-dependent and play a major role in the North Sea region.

17.2 Literature Review

The complex relationship between climate change and tourism has been part of the academic debate since the 1980s (Fig. 17.1). The first papers concerning climate change and tourism were published in 1986 (Harrison et al. 1986; Wall et al. 1986). Since then, the number of publications in this field has increased steadily (Fig. 17.2) up to 83 publications in 2011. From a review of literature between 1986 and 2012, Becken (2013) concluded that half of the studies concerned climate impacts on tourism, 34 % dealt with mitigation, and the remaining 16 % were policy papers or integrative papers.

E. Kreilkamp (✉)
Institute of Corporate Development, Leuphana University of Lüneburg, Lüneburg, Germany
e-mail: edgar.kreilkamp@uni.leuphana.de

N.M. von Bergner
Institute for Tourism and Leisure ITF, HTW Chur, Chur, Switzerland
e-mail: nelemarisa.vonbergner@htwchur.ch

C. Mauser
IFOK GmbH, Bensheim, Germany
e-mail: claudiamauser@gmx.de

M. Quante and F. Colijn (eds.), *North Sea Region Climate Change Assessment*,
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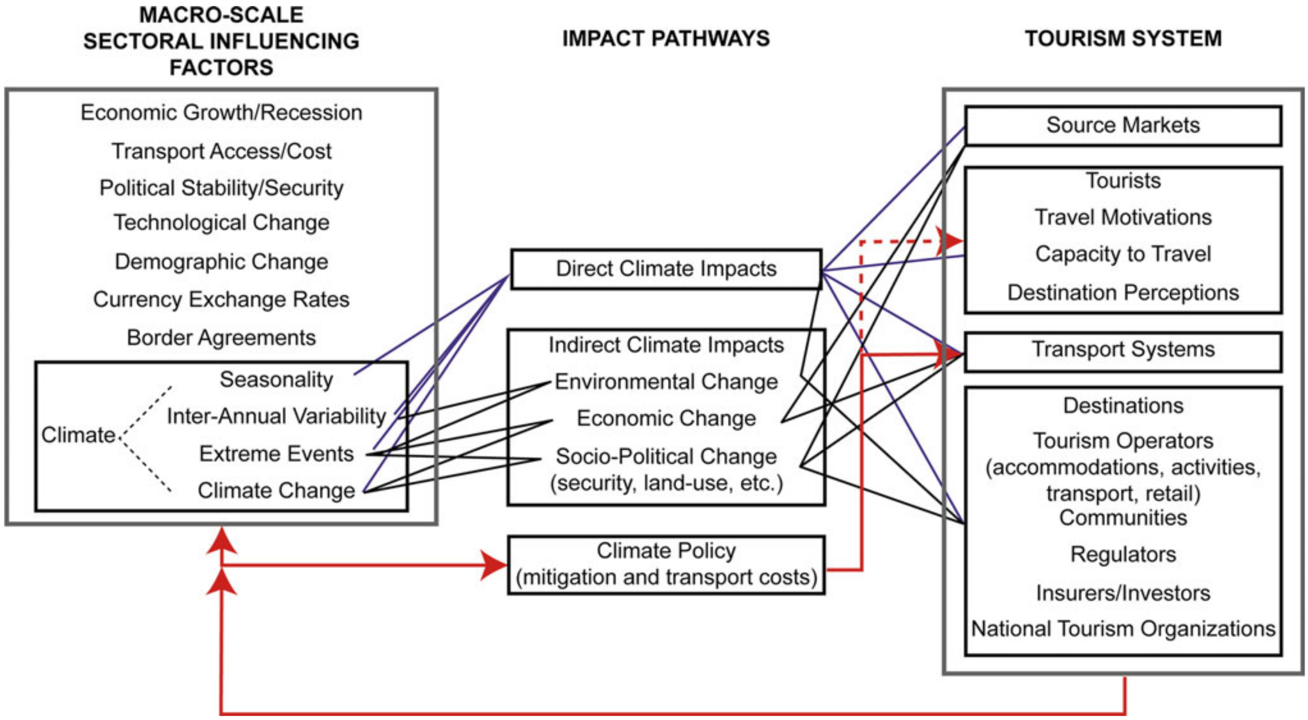

Fig. 17.1 Relationship between climate change and tourism (Scott and Lemieux 2010)

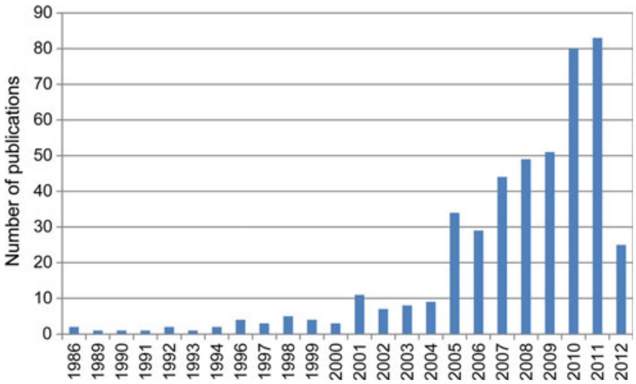

Fig. 17.2 Number of peer-reviewed publications concerning climate change and tourism produced per year between 1986 and 2012 (Becken 2013)

Although climate is not the only determinant of destination choice (Crouch 1995; Witt and Witt 1995; Rosselló et al. 2005; Gössling and Hall 2006; Bigano et al. 2006a), attractiveness is largely determined by thermal environmental assets (Smith 1993; Agnew and Palutikof 2000; Amelung and Viner 2006; for a detailed literature overview on how climate/weather and tourism interact, see Becken 2010). Destinations with better climate resources have a competitive advantage (Perch-Nielsen et al. 2010), especially those for sun-and-sea or winter sports holidays. In tourism, climate acts as both a 'push' and 'pull' factor. A push factor is one where the choice of travel destination is often related to the weather and climate conditions at the point of origin and not just at the holiday region. For example, Hill (2009) found that very rainy weather throughout much of the early summer in the United Kingdom resulted in an increase in foreign holiday bookings abroad compared to the previous year. But climate may also act as a pull factor. In Norway, 84 % of tour operators go to 'sun destinations' (Jorgensen and Solvoll 1996). This is not a recent phenomenon. Even in 1999, an annual survey of German traveller behaviour and tourism-related attitudes showed that 43 % of Germans mentioned weather as the most important factor when choosing a holiday destination (Lohmann and Kaim 1999). Nevertheless, preferences or perceptions of climate differ according to several factors, such as age, cultural and climate contexts, as well as leisure activities or the media, and are therefore hard to predict (Lise and Tol 2002; overview of literature by Gössling et al. 2012, Scott et al. 2012a).

One means of quantifying these preferences is through a 'climate index'; the aim being to provide a measure of the integrated effects of the atmospheric environment on a particular location. This would be useful both for tourists and for the tourism industry to evaluate the potential of tourism in a given area in terms of its perceived climate (de Freitas et al. 2008). The index approach can also be used to analyse the impact of climate change on the climatic attractiveness of tourist destinations (Hamilton 2005). One of the most used indices is that of Mieczkowski (1985), who developed the

Table 17.1 Priority levels for climate aspects (Morgan et al. 2000)

Climate aspect	Relative priority scores (out of 100 for aspects 1–4)
Windiness	26
Absence of rain	29
Sunshine	27
Temperature sensation	18
Bathing water temperature (22–26 °C)	(28)

Tourism Climate Index (TCI). This integrates several climate features into a single index and includes ratings for thermal comfort, physical features (e.g. rain) and aesthetic features (e.g. sunshine duration). Although Mieczkowski's index has been criticised by de Freitas (2003) owing to its subjectivity, it is still being used or adapted by others (Scott and McBoyle 2001; Scott et al. 2004; Amelung and Viner 2006; Amelung et al. 2007; Nicholls and Amelung 2008). Morgan et al. (2000) modified the index to fit beach users in the UK, using five aspects of climate (Table 17.1).

Matzarakis (2007) used the index to develop a Climate Tourism Information Scheme (CTIS) that includes parameters such as cold stress, heat stress and snow fall (i.e. skiing potential). This approach was also used for regional simulations of future conditions along the German North Sea coast (based on two regional climate models—REMO and CLM) that takes into account local-scale differences between the mainland coast and islands (Endler and Matzarakis 2010).

This chapter reviews information on climate change and its impact on recreation and tourism in the North Sea region. Because this is concentrated along the coast, the focus of this chapter is on the impacts of climate change on coastal tourism.

17.3 Impacts of Climate Change

Coastal tourism is the largest component of the tourism industry worldwide (IPCC 2014a). At the same time, coastal zones are especially vulnerable to the impacts of climate change. Even so, until 2012 few studies had addressed the topic of coastal tourism and climate change (Becken 2013). Despite some studies for the Caribbean or Mediterranean Sea and a few other beach or island regions (Nicholls and Hoozemans 1996; Lohmann 2002; Giupponi and Shechter 2003; Nicholls and Klein 2003; Perry 2005, 2006; Amelung and Viner 2006; Hein 2007; Giannakopoulos et al. 2009; Lemelin et al. 2010; Perch-Nielsen 2010; Becken et al. 2011; Jones and Phillips 2011; Scott et al. 2012c) there has been very little published on climate change impacts on tourism in the North Sea region. Those studies that do exist are all discussed in this chapter. Figure 17.2 shows the recent increase in publications on the impact of climate change on coastal tourism. Some of these studies address the response of tourists and tour operators to beach erosion and the tourist's concern about aesthetic appearance (Moreno and Becken 2009; Buzinde et al. 2010), while others examine the vulnerability of coastal tourism infrastructure to sea-level rise (Phillips and Jones 2006; Bigano et al. 2008; Schleupner 2008).

Negative effects of climate change include rising sea levels and extreme weather. Extreme storms and waves together with sea-level rise will increase the extent and frequency of flooding, storm surges and coastal erosion. Not only will this affect natural areas used by tourists, but also cultural assets and tourism infrastructure, especially transportation and accommodation (Phillips and Jones 2006; Amelung and Viner 2007; Scott et al. 2008). From a study of beach tourism in East Anglia, Coombers et al. (2009) showed that although sea-level rise would reduce the width of the beach and cause a possible reduction in visitor numbers, this effect could be outweighed by increased visitation due to better temperatures. However, overall, the economic costs of negative climate change impacts on coastal tourism could become extremely high (IPCC 2014a).

Positive effects of climate change on tourism have also been predicted. The North Sea coastal region has a maritime climate, which means mild winters and relatively warm summers. Climate projections suggest fewer cold stress events in winter, and less significant changes in heat stress events in summer compared to other regions such as the Mediterranean. The higher average temperatures projected by climate models imply a positive effect on the well-being of tourists in the North Sea region. For example, higher temperatures in summer may result in a longer (bathing) season (Pinnegar et al. 2006; Nicholls and Amelung 2008). Changes in precipitation patterns are expected to result in dryer summers and wetter winters. A decrease in summer precipitation may attract more tourists to the North Sea coastal areas. More rain and extreme weather events in winter could reduce the number of visitors in the low season.

Sea-level rise will become a major threat in the North Sea region (see Chap. 6), especially for low-altitude islands with limited tidal range, and coastal areas are particularly vulnerable to extreme weather events (Moreno and Becken 2009). Storm-surge height and the frequency of extreme wave events are expected to increase over large areas—especially in winter (IPCC 2014a). The IPCC cites an increase in future flood losses along the North Sea coast (IPCC 2014b), which may also affect the tourism industry. Even though tourist destinations recover relatively quickly from such disasters, damage to infrastructure and buildings will result in additional costs. Adaptation to climate change will also have economic impacts: Hamilton (2006) showed that protection measures such as longer dikes have a negative impact on accommodation prices along the German sea coast.

Braun et al. (1999) investigated combined scenarios of temperature and precipitation change with sea-level rise and beach loss and their effect on the number of tourists travelling to the Baltic and North Sea coasts of Germany. They concluded that the likelihood of choosing the north German coast for a holiday was slightly higher with increased temperatures. However, for scenarios with potentially negative impacts on the German coasts, such as beach erosion, the likelihood of visiting was substantially lower, even if with adaptations such as greater setback of tourism infrastructure or more diversified outdoor activities. Lohmann (2002) concluded that the effects of climate change in the North Sea area, such as sea-level rise, were likely to destroy infrastructure and that frequent extreme weather events may discourage visitors.

Infrastructure at ports and marinas is a major asset at many destinations. Sea-level rise, coastal erosion and storms might compromise its functionality. There is still a lack of detailed academic research on this topic for the North Sea region.

For the German North Sea coastline, sea-level rise is expected to extend the tides (i.e. lengthen flood duration on mudflats) hampering tidal flat walks for tourists (Regierungskommission Klimaschutz 2012).

Higher average temperatures in the North Sea region will also cause tourism-driven changes in biodiversity. If more tourists visit the North Sea in, before and after the summer season, this might increase pressure on local biodiversity, in particular vegetation cover and habitat for nesting birds (Coombers et al. 2008). Effects on nature-based tourism and activities, like animal watching, still require closer academic study. Travellers to the Baltic Sea coast judged algal blooms negatively, especially for swimming (Nilsson and Gössling 2012). There is also concern that foam algae might pollute the beaches (Regierungskommission Klimaschutz 2012). Further studies are needed to examine the (potentially toxic) effects of new plant species moving into the North Sea region and an increase in harmful algal blooms could impact on bathing water quality and the tourism industry in general over the longer term (Gössling et al. 2012). Broader socio-economic impacts of climate change on destinations, such as those concerning health, security or insurance implications should also be considered. Heat waves in summer might adversely affect health resorts, but it may be that such conditions are still preferable to those of other inland destinations and will therefore have an advantage in the future. Knowledge gaps still remain on health issues, especially the future distribution of vector-borne disease along the North Sea coast.

Overall, tourism in the North Sea area in summer is expected to profit from rising temperatures (air and water), decreasing precipitation and a longer season. But climate-driven changes in tourism demand are hard to determine because the tourist decision-making process is influenced by many other factors in addition to climate (IPCC 2014a). In addition to the direct impacts of climate change on tourism and its infrastructure, the more complex and indirect effects of climate change are also important because climate change affects all economic sectors, politics and society as a whole (Kreilkamp 2011).

17.4 Changing Patterns in Tourism Flow

Climate change may also alter tourism patterns in Europe radically by inducing changes in destination choice and seasonal demand structure (Ciscar et al. 2011: 2680). The scientific literature contains many references to tourists, their preferences and their behaviour, including changes in tourist flows and seasonality (Braun et al. 1999; Maddison 2001; Lise and Tol 2002; Wietze and Tol 2002; Lohmann 2003; Hamilton et al. 2005; Gössling and Hall 2006; Bigano et al. 2006b, 2008; Hamilton and Tol 2007; Moreno and Amelung 2009; Buzinde et al. 2010; Hall 2010; Perch-Nielsen et al. 2010; Denstadli et al. 2011; Rosselló-Nadal et al. 2011; Gössling et al. 2012). One of the major questions these studies raise is whether mass tourism of the type seen today at the Mediterranean Sea coast will shift to destinations in northern Europe, such as the North Sea region. Climate change could also result in a seasonal change in visits.

The climate for tourist activities in the North Sea is expected to improve significantly in summer but less so in autumn and spring for northern continental Europe, Finland, southern Scandinavia, and southern England, especially after 2070 (Amelung et al. 2007; Nicholls and Amelung 2008; Amelung and Moreno 2012). At the same time, the attractiveness of the Mediterranean Sea region is expected to decline as comfort distribution changes from a ‘summer peak’ to a ‘bimodal distribution’, with less attractive summers and more attractive springs and autumns (Amelung and Viner 2006; Amelung et al. 2007; Moreno and Amelung 2009; Hein 2009; Perch-Nielsen et al. 2010; Moriondo et al. 2011), see also Table 17.2.

However, studies conclude that by 2030 (or even 2060) the Mediterranean Sea region will not have become too hot for beach tourism (Moreno and Amelung 2009; Rutty and Scott 2010), because surveys show that it is mostly rain that drives beach tourists away (de Freitas et al. 2008; Moreno 2010). Domestic tourism and international visits from southern Europe to locations in northern Europe may increase at the expense of southern locations (Hamilton and Tol 2007; Willms 2007; Hein 2009; Amelung and Moreno 2012; Bujosa and Rosselló 2012). The Intergovernmental Panel on Climate Change stated with medium confidence that tourism activity may increase in northern and

Table 17.2 Qualitative assessment of the impact of climate change (IPCC SRES A1F scenario) on sustainable tourism development in the Balearic Islands in the 21st century (Amelung and Viner 2006)

	Spring	Summer	Autumn	Winter	Net effect
Revenue	↑↑	↓↓↓	↓↓	↑↑	↓↓
Occupancy	↑↑	↓↓	↔/↓	↑↑	↑
Employment	↑↑	↓↓↓	↓↓	↑↑	↓↓
Migration	↑	↓↓↓	↓↓	↔	↓↓
Water use	↑↑	↓↓↓	↓↓	↑↑	↓
Impact on biodiversity	↑↑↑	↓↓↓	↓↓	↑	↓

↑ Increase; ↓ decrease; ↔ little or no change

continental Europe, developing travelling patterns closer to home (IPCC 2014b). Nevertheless, no significant changes in the tourism sector are expected before 2050.

A spatial and temporal redistribution of tourism through climate change could lead to shifts, such as Europeans extending their tourism activities over a longer period, taking trips to the Mediterranean Sea region in spring and autumn, and to northern Europe in summer (Ciscar et al. 2011). However, a key assumption is that the tourism system has full flexibility in responding to climate change (Ciscar et al. 2011: 2681). Studies are also needed to address any new environmental challenges appearing along the North Sea coast, for example if more infrastructure and buildings are needed for the already well visited summer period.

However, there are limitations to those forecasts. Preferred beach temperatures differ among travellers from different countries (Scott et al. 2008; Rutty and Scott 2010). According to Maddison (2001), British tourists are attracted to climates around an average of 30.7 °C, which they are unlikely to find in northern Europe even with climate change. Rutty and Scott (2013) interviewed beach tourists on Caribbean islands and found that travellers from the UK preferred temperatures of 27–30 °C while Germans preferred 30 °C. It was shown that preferred beach temperatures differ among travellers from different countries (Scott et al. 2008; Rutty and Scott 2010). Rutty and Scott (2010) also found that the impact of media news about heat waves on travel decisions varied according to the level of commitment to the trip (planning a holiday or a trip already booked). Hall (2012) listed the major weaknesses of current models in predicting travel flow as follows: validity and structure of statistical databases; temperature assumed to be the most important weather parameter; role of information in decision-making unclear; role of non-climatic parameters unclear (e.g. social unrest, political instability, risk perceptions, destination perception); assumed linearity of change in behaviour unrealistic; and future costs of transport and availability of tourism infrastructure uncertain.

The assumption that rising temperatures will be positive for northern European tourist destinations does not consider the impact of other, potentially negative environmental changes in the region (e.g. Hall 2008). Also, there are tourists that still want to travel to regions where they expect resources other than the weather. For example, Moreno (2010) found that almost three-quarters of visitors from Belgium and the Netherlands questioned would still travel to the Mediterranean Sea region even if their self-defined preferred climatic conditions existed in northern Europe. For some people, certain destinations appeal for reasons largely unaffected by climate change, including uniqueness, travel time, standard and cost of accommodation, perceived safety and security, existing facilities, services, access, and host hospitality (Hall 2005). It becomes clear that climate change is just one out of many factors affecting their attractiveness.

17.5 Mitigation and Adaptation Policies

Destinations can seek to lessen the impact of climate change on tourism by adapting to the changes (Gössling et al. 2012). Several studies address both adaptation and mitigation (see Scott and Becken 2010; Scott et al. 2012b; Becken 2013 and Gössling et al. 2013).

As tourists are flexible in their destination choice and because tourism operators can easily change their portfolio, adaptation measures are of special importance for tourism suppliers on site. The choice of adaptation measures (for example when securing infrastructure, rebuilding accommodation, and changing transport) will depend on the type and magnitude of the climate impacts. They may also affect destination attractiveness. For example, raising seawalls on the North Sea coast could result in a less appealing landscape (Regierungskommission Klimaschutz 2012). More research is needed to understand the role of coastal zone management and tourism activities in climate change adaptation, especially in the North Sea region.

In deciding on long-lasting adaptation measures and investigations, the tourism sector faces two fundamental issues: uncertainty in climate scenarios (Turton et al. 2010) and short investment cycles (Bicknell and McManus 2006).

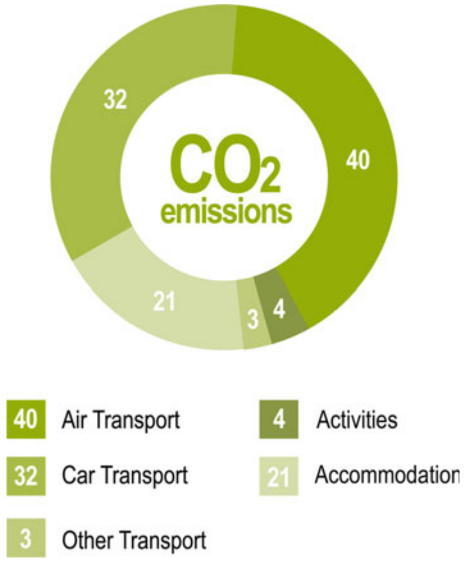

Fig. 17.3 Percentage contribution of tourism sub-sectors to carbon dioxide emissions (UNWTO/UNEP 2008)

Nevertheless, more frequent extreme weather events over the past few years have raised awareness of the need for climate change adaptation and disaster reduction (d'Mello et al. 2009; Becken and Hughey 2013).

Tourism is, in parts, an energy-intensive industry and so itself contributes to climate change. According to UNWTO/UNEP (2008), global tourism accounts for 5 % of global carbon dioxide emissions (Fig. 17.3). A business-as-usual scenario projects emissions from global tourism to grow by 161 % between 2005 and 2035. Emissions from air transport and accommodation are expected to triple. Two alternative emission scenarios show that mitigation solutions using technology only are hard to achieve. Even combined with behavioural changes, no significant reductions in carbon emissions can be gained in 2035 compared to 2005 (IPCC 2014c). In a recent article on tourism's global environmental impact, Gössling and Peeters (2015) predict that tourism-related energy use, emissions, and water, land and food requirements will double within the next 24–45 years. The growth factor for the different components varies from 1.92 (fresh water) to 2.89 (land use) for 2050. An alternative development is possible, but would require a tremendous effort by politics, industry and tourists. But as the demand for tourism is expected to increase (IPCC 2014c), mitigation options are necessary. More research is needed, especially in the transport sector (such as on switching from kerosene to biofuels) and the building sector (such as on retrofitting or energy-efficient new builds) (IPCC 2014c).

A key question is the extent to which tourists will change their travel plans to reduce their impact on global climate. Their apparent unwillingness to adapt their travel behaviour means that the greatest responsibility for mitigation remains with politicians, the tourism industry and tourism supply. According to Kreilkamp (2011), it is a matter of innovativeness: Adaption as well as mitigation actions can be used by companies that aim to differentiate themselves from competitors through innovative approaches and use such actions for effective public relations. Gössling et al. (2013) showed how climate policy may influence travel costs and tourism patterns. Countries with strong climate change policy frameworks (carbon taxes, emissions trading schemes, etc.) also show more interest in tourism-specific policies to address climate change (Becken and Hay 2012). No country has yet adopted a low-carbon tourism strategy (OECD/UNEP 2011) and academic research on tourism policy dealing with climate change is still rare (Becken 2013).

17.6 Conclusions and Future Research

Despite the many papers published up to today, an analysis of the content of four leading tourism journals showed that publications on climate change represented only 1.7 % of all papers published between 2000 and 2009. It demonstrates that 66 % of the 128 papers found were classified as studies of the potential impacts of climate change on destinations or changing visitation patterns, with 40 % on winter ski tourism and less than 10 % on small islands or coastal areas (Scott 2011). For a more detailed analysis of tourism knowledge with respect to climate change adaptation, mitigation and impacts see Hall (2012).

Gössling et al. (2012) summarised in their paper review of the complexity of demand responses and consumer behaviour influenced by climate change that some knowledge gaps remain. It is still difficult to understand the impacts of extreme weather and environmental events on tourist behaviour and this should be considered over both the short and the longer term. There is an assumption that rising temperatures will have positive effects for northern European tourist destinations. However, this does not consider the impact of negative environmental changes in the region or that tourists will still want to travel to climatically disadvantaged regions, since climate change is not the only factor affecting the attractiveness of travel destinations.

Destinations can seek to deal with climate change through adaptation measures and thereby lessen its potential impacts. Further research is needed on the relationship between the impacts of climate change and specific tourist behaviours, activities, or tourism flows to coastal destinations (Moreno and Amelung 2009). Also, as Scott et al. (2012b) pointed out, very few studies address the consequences of mitigation policy in tourism.

Despite some negative impacts, the direct consequences of climate change are expected to be mostly positive for the tourist industry in the North Sea region if supply can keep up with demand. The seasonal distribution of demand will improve substantially in summer, and the region will be able to compete better with other major destinations such as the Mediterranean Sea region due to the warmer, dryer summers expected in the future. As the season lengthens, there will be more days suitable for outdoor recreation. Overall, climate in the North Sea region for tourism will improve. However, other conditions, such as beach width, landscape, and water quality will be affected negatively.

Although the tourism industry has little influence on the behaviour of tourists (IPCC 2014c), it can still take action on tourism supply. Some researchers see a need for drastic changes in the forms of tourism and the uses of leisure time as well as in destinations (Ceron and Dubois 2005; UNWTO/UNEP 2008; Gössling et al. 2010; Dubois et al. 2011; Peeters and Landré 2012).

Further studies in the North Sea region are essential to better understand the role of climate change impacts on the attractiveness of tourist destinations; on a changing Tourism Climate Index on tourism there, on changes in tourism demand and on possible shifts in travelling. As catastrophic events show, such as terrorism or natural disasters, the tourism industry is resilient. Nevertheless, actors in the tourism industry along the North Sea coast need to minimise risks while seeking to take advantage of new opportunities. Multidisciplinary research is needed that considers tourism trends, including climate change, together with social, ecological, economic, technological and cultural developments. More research is needed on how the challenges brought by climate change could be addressed in a proactive and sustainable manner.

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Socio-economic Impacts—Coastal Protection

18

Hanz D. Niemeyer, Gé Beaufort, Roberto Mayerle, Jaak Monbaliu,
Ian Townend, Holger Toxvig Madsen, Huib de Vriend
and Andreas Wurpts

Abstract

All North Sea countries are confronted by climate change impacts such as accelerated sea-level rise, increasing storm intensities resulting in as well higher set-up of storm surges as growing wave energy and a follow-up of morphological changes. Thus it is necessary to question the effectiveness of existing coastal protection strategies and to examine alternative strategies for coastal protection under a range of scenarios considered possible. Scenarios of accelerating sea-level rise leading to changes in sea level of up to 1 m or more by 2100 and higher set-up of storm surges with increasing wave energy have been used for planning purposes. Adaptation strategies for future coastal protection have been established in all North Sea countries with vulnerable coasts, observing two propositions: (1) structures are economic to construct in the short term and their dimensions easily adapted in the future to ensure flexibility in responding to the as yet undeterminable climate change impacts and (2) implementation of soft measures being temporarily effective and preventing counter-action to natural trends. The coastal protection strategies differ widely from country to country, not only in respect of distinct geographical boundary conditions but also in terms of the length of the planning period and the amount of regulations. Their further development is indispensable and emphasis must more and more be laid on strategies considering the effects of long-term development of coastal processes for future coastal protection. Filling gaps in knowledge is essential for developing sustainable adaptation strategies.

H.D. Niemeyer (✉)
Independent Consultant, ret., Coastal Research Station,
Norderney, Germany
e-mail: hanz.niemeyer@yahoo.com

G. Beaufort
Hydr. Engineering Cons., De Meern, The Netherlands
e-mail: g.a.beaufort@gmail.com

R. Mayerle
Research and Technology Centre Westcoast, Kiel University,
Kiel, Germany
e-mail: rmayerle@corelab.uni-kiel.de

J. Monbaliu
Department of Civil Engineering, KU Leuven, Leuven, Belgium
e-mail: jaak.monbaliu@kuleuven.be

I. Townend
Ocean and Earth Sciences, University of Southampton,
Winchester, UK
e-mail: I.Townend@soton.ac.uk

H. Toxvig Madsen
Danish Coastal Authority, Lemvig, Denmark
e-mail: holger.toxvig@kyst.dk

H. de Vriend
Independent Consultant, Oegstgeest, The Netherlands
e-mail: hjdevriend@planet.nl

A. Wurpts
Coastal Research Station, Norderney, Germany
e-mail: andreas.wurpts@nlwkn-ny.niedersachsen.de

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18.1 Introduction

Climate change will create stronger challenges for coastal protection than experienced in the past. Loads on protection structures are increasing and increased flood risk in the majority of coastal areas has coincided with ongoing growth in population and investment. Since the implementation of measures in coastal protection needs a forerun of decades, the determination of boundary conditions for their design requires an appropriate and sufficiently safe margin for foreseeable developments in the future. This is presently best practice in coastal engineering but becomes more difficult and uncertain the further forward in time considered since there are no reliable forecasts for future climate change impacts, only wide-ranging scenarios. Therefore adaptation strategies for coastal protection must aim to be both economic to construct in the short term and designed such that they can be easily adapted in the future, allowing adequate flexibility in order to respond to the as yet insufficiently determinable effects of future climate change impacts. To meet these requirements, current understanding of climate change effects on coastal protection measures must be used to examine alternative strategies for future coastal protection under a wide range of scenarios for climate change impacts regarded as possible.

18.1.1 Boundary Conditions of Coastal Protection

The aims of coastal protection are first the safety of the hinterland against flooding due to storm surges and second to limit coastal retreat. An essential basis for achieving these objectives is sound knowledge of the governing boundary conditions, such as local hydrodynamic loads or morphological processes. Acceleration of sea-level rise (SLR) due to changing global climate will be a threat in all coastal areas. This threat will be compounded by a number of secondary effects of climate change that will increase loads on coastal protection structures or on dunes and cliffs providing shelter for the hinterland against flooding.

Climate change will also lead to increasing storm intensities which will—particularly in the shallower parts of the North Sea—cause higher set-ups of storm surges (EEA 2012; Woth et al. 2006; Weisse et al. 2012). As a result, water depths at the coastlines will increase for design conditions; the shallower the local coastal waters the greater the increase. Since in areas like the Wadden Sea coasts in the southern North Sea, wave heights and periods on tidal flats are strongly depth-controlled (Niemeyer 1983; Niemeyer and Kaiser 2001), any increase in local water depth would be accompanied by correspondingly higher wave loads on coastal structures or on dunes and cliffs (Niemeyer 2010).

Accelerated SLR will also be accompanied by morphodynamic responses in sedimentary coastal areas which may be unfavourable to coastal protection. For instance, adaption of tidal flat levels may no longer keep pace with SLR, and if rates exceed a certain threshold then tidal flats might even disappear (Müller et al. 2007). Water depth in front of coastal structures would then increase and result in the propagation of higher and longer waves during storm surges and thus stronger wave loads. Adaption of tidal flats to SLR is governed by the hydrodynamics of ordinary tides. In contrast, the vertical growth of saltmarshes depends on hydrodynamics during meteorologically enhanced tides and in particular on storm surges (Townend et al. 2011). In addition to this significant disparity in governing boundary conditions there are indications that salt marshes also have a limited capability to grow with sea level: above a certain threshold in the rate of SLR they will no longer keep pace. The threshold for SLR to limit the vertical growth of saltmarshes will be slightly raised, however, by an increase in the frequency of storm surges (Schuerch et al. 2013).

The response of coastal morphology to accelerated SLR is much more pronounced on wave-exposed sandy coasts and barrier islands than, for example, in front of coastlines on estuaries or tidal basins with tidal flats and salt marshes; areas with a high share of cohesive sediments. Adaption of the shoreface to erosion induced by SLR according to the BRUUN-Rule and its steepening will take place simultaneously (Bruun 1962; Stive and de Vriend 1995). Since shoreface processes affect conditions at adjacent beaches (Mulder and de Vos 1989), erosion and coastal retreat will also occur. At interrupted coasts with estuaries or tidal inlets and basins, SLR will increase basin volume and drive an increasing demand for external sediment supply to enable adaptation towards the moving target of morphodynamic equilibrium (Ranasinghe et al. 2012).

The result is erosion of coastal stretches in the vicinity of the tidal inlets, leading to stronger coastal retreat than would occur through shoreface adaption to SLR alone (Ranasinghe et al. 2012). The volume of ebb-deltas will also decline as they will act as the initial source for meeting the increased sediment demand of the basins (Stive and Eysink 1989). Since the sheltering effects of ebb-deltas depend on their sediment volume (Kaiser and Niemeyer 1999), wave penetration into the basin and onto adjacent beaches will be less restricted causing higher loads on structures, dunes and cliffs and increasing erosion of beaches and dunes and, although to a lesser extent, tidal flats and salt marshes. The impact of all such processes will increase, the more SLR is accompanied by an increase in tidal range.

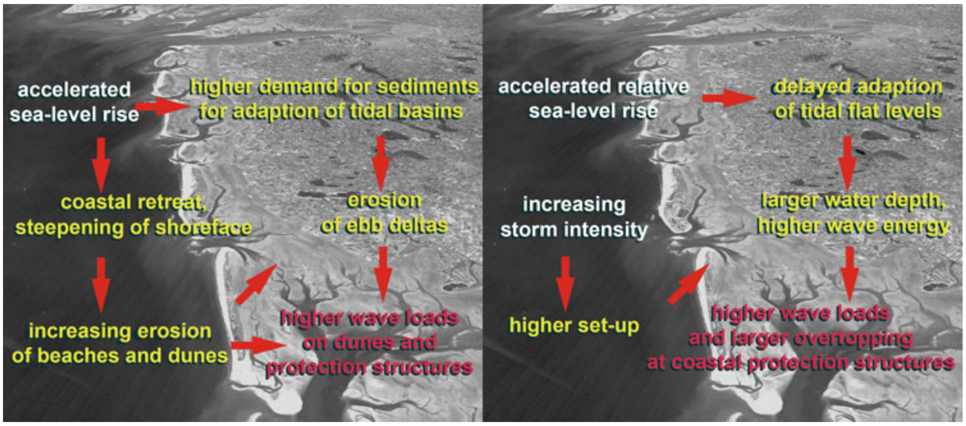

Fig. 18.1 Combined effects of climate change on a North Sea coast: morphodynamics and hydrodynamic loads at a sandy coast (barrier islands) (*left*) and on hydrodynamic loads on coastal structures at a lowland coast along an estuary and tidal basins with cohesive sediments (*right*) (Niemeyer 2015); background image from the Common Wadden Sea Secretariat (www.waddensea-secretariat.org)

These secondary effects of climate change are superimposed on each other, and may even invoke a feedback (Fig. 18.1) which further complicates the prediction of future change (Niemeyer 2015). It will be a major challenge for coastal researchers to develop and apply suitable morphodynamic models that can encompass a sufficiently wide range of scenarios for future climate change effects. Such models are needed to meet the knowledge base required for more detailed planning and development of adaptation measures for coastal protection. This is particularly the case for wave-exposed sandy coasts and barrier islands, where the secondary effects of accelerated SLR on morphology are expected to be stronger, faster and more diverse than those anticipated in front of coastlines with a high degree of cohesive sediments, where morphodynamic adaption is more predictable (Niemeyer 2015).

18.1.2 Coastal Protection Strategies in Response to Climate Change Impacts

Global warming and the resulting acceleration in SLR necessitates a thorough re-evaluation of coastal protection strategies in many parts of the world. This includes the North Sea coasts of Europe, where coastal protection has a history of more than 1000 years. For most of the North Sea coasts, maintaining a protection line through dykes, solid structures or dunes and cliffs was historically the result of human activity. The potential for faster SLR through global warming has alerted coastal managers to question whether this strategy of keeping the line will still be appropriate, or whether alternative strategies should be considered.

The Intergovernmental Panel on Climate Change (IPCC) Coastal Zone Management Subgroup identified alternative adaptation strategies for SLR: retreat, accommodation and protection (IPCC 1990), following an earlier Dutch evaluation, which also included the additional strategy of moving the defence line seaward (Rijkswaterstaat 1989). All four strategies are manifested in historical practice (Niemeyer 2005, 2010). The strategy ‘protection’ has since been further differentiated by distinguishing between traditional line protection and alternative protection schemes such as set-back or realignment and combined protection (ComCoast 2007). Although moving the defence line seaward is only suitable in very specific situations, and may not always be ethically and politically acceptable, the other strategies are regarded as options for adapting coastal protection in response to possible future climate change effects. Recent investigations have shown that simple conceptual evaluations by graphical schemalizations and purely qualitative discussion such as carried out by ComCoast (2007), are unreliable and sometimes even misleading since important boundary conditions such as hydrodynamic loads, topographic features, existing protection structures and necessary resources are ignored or misjudged. Therefore it is essential to evaluate strategies by applying scenarios for design conditions in real-world environments (Niemeyer et al. 2011a, b, 2014).

The same comments also apply to conclusions drawn by Temmerman et al. (2013) concerning the effectiveness of protection strategies that improve the ecological value of coastal and estuarine areas by a set-back of the existing protection line, since the emphasized equivalence of safety against flooding of the hinterland achieved by the protection strategy applied beforehand is only an assumption. Model tests for proving that assumption are to be carried out in the future thus allowing reliable judgements (STW 2013). The expectation of a reduction in hydrodynamic loads on structures by a set-back strategy (Temmerman et al. 2013) contradicts results being achieved for the evaluation of alternative coastal protection strategies by mathematical modelling for design conditions in similar environments (Niemeyer et al. 2011a, b, 2014). Nevertheless, potential improvements in ecological quality by applying alternative strategies should be balanced against the higher capital costs for coastal protection in respect of societal demands.

Although evaluations of protection strategies for coasts with a significant fraction of cohesive sediments yield reliable results, this is not the case for wave-exposed sandy coasts and barrier islands with higher dynamics (Fig. 18.1). The impacts of climate change on coastal processes may require a higher level of adaptation there than at other locations. Taking into account the enormous additional effort this will require, adaptation strategies for wave-exposed sandy coasts and barrier islands will need to accommodate stronger and more variable coastal processes due to future climate change impacts than at present. Such an approach could then serve as a blueprint for the development of flexible coastal protection schemes that are sufficiently adapted to future climate change impacts in order to prevent any incompatibility with future developing trends driven by nature. Such schemes are likely to prove more favourable than some of the traditional coastal protection measures.

18.2 Adaptive Planning and Regulation

Adaptation strategies for future coastal protection have been established in all North Sea countries with vulnerable coasts. These differ widely from country to country, especially in terms of the length of planning period and amount of regulation.

18.2.1 Belgium

The Flemish Government approved a Master Plan Coastal Safety (Afdeling Kust 2011) in June 2011 comprising calculations and safety assessments for the periods 2000–2050 and 2050–2100. A vision for further development of the Flemish coastal zone is on its way aiming at the integration of safety, natural values, attractiveness, sustainability and economic development including navigation and sustainable energy. This concept is referred to as *Vlaamse Baaien* or *Flanders Bays 2100* (Vlaamse Baaien 2015a, b) and includes conceptual plans for responding to climate change effects beyond 2050. This idea was initiated by a concept study launched by a private consortium of different consultant and construction companies under the name *Flanders Bays 2100* (Vlaamse Baaien 2015a). Execution of the Master Plan Coastal Safety, however, is a pre-condition that must be met before implanting the 'Flanders Bays' concept (Vlaamse Baaien 2015a). It is expected that the safety levels incorporating the projected SLR until 2050 will require maintenance nourishments thereafter. For the Belgian part of the Western Scheldt estuary the Sigma Plan was established after the floods of 1976 and was revised in 2005 to include projected SLR until 2050. New understanding of coastal management, which balances safety and environmental protection and also shipping where it plays a key role, have resulted in a vision of multifunctional and sustainable use of the Western Scheldt estuary (Sigmaplan 2016).

18.2.2 Denmark

The Danish Government announced its strategy for adaptation to a changing climate in 2008 (Danish Government 2008). The report provides an overview of the challenges arising from future climate change in terms of 11 sectors, one of which is the coastal zone. The adaptation strategy for coastal protection was developed by the Danish Coastal Authority (2012). The aim is to provide coastal communities with a regionally differentiated basis for adaptation to 2050, and then to 2100. Every five years the Coastal Authority undertakes a safety assessment of the central part of the Danish North Sea as a basis for coastal protection planning as well as financial planning. There is no fixed schedule for safety assessments in the Danish Wadden Sea: two have been undertaken since 1999. In all other parts of the Danish coasts the land owners are themselves responsible for protection.

18.2.3 Germany

For the German North Sea coast, adaptation strategies in the four federal states are regulated differently. In the Free and Hanseatic City of Bremen a sector plan was established by the ministry (SUBV 2012). The building programme matching the safety levels established in 2007 includes a heightened precaution measure for climate change effects and will be finished in 2025. For the Free and Hanseatic City of Hamburg the parliament accepted a proposal made by the state government which is a guideline for planning until 2050 (Senat FFH 2012). A safety assessment will be undertaken every ten years. In Schleswig-Holstein, design boundary conditions were revised with respect to SLR expected by 2050 and 2100 in an update to the Coastal Protection Masterplan (MELUR 2013); safety assessments are planned every ten years. In 2008, the state government of Lower Saxony established a government commission of management experts, scientists and stakeholders to develop an adaptation strategy for climate change effects including coastal protection, supported by expert groups on specific themes. A well-funded research programme was initiated in order to provide the commission with basic information on key issues like coastal protection. A report on the adaptation strategy was delivered in 2012 (MU 2012) and its recommendations for initial actions were approved by the state government in 2013: the optimal strategy for coastal protection at the mainland coast is by keeping the protection line; precautionary observations and investigation programmes are required to address identified knowledge gaps and so enable future substantiation of adaptation measures; and the need to continue the safety assessment programme with a ten-year cycle. Investigations of clay quality in the cover layer of existing dykes as a basis for introduction of increasing overtopping tolerance in future design procedures to balance—at least partly—higher hydrodynamic loads are a major component of this research programme. Of even greater importance is the identification and quantification of morphological effects due to climate change impacts in the dynamic East Frisian barrier islands region to provide the essential basic knowledge for developing a resilient adaptation strategy for the future protection of the area against flooding and effects of structural erosion. An independent commission shall be appointed to provide recommendations on implementing this programme.

18.2.4 Netherlands

In the Netherlands, consideration of climate change effects started earlier than in most other countries (Rijkswaterstaat 1989, 1990). In 2001, a safety assessment procedure was laid down in the Water Act, requiring an assessment every five years, later increased to six. The need for more advanced adaptation to climate change led to the establishment of the second Deltacommissie (2008). Starting from scenarios for SLR and river discharge, this committee produced recommendations which included, among others, the establishment of a Delta Program led by a Delta Commissioner at ministerial level, to recommend how to implement a risk-based flood safety approach and how to establish an effective organisation and legal framework. The Delta Commissie’s recommendations were approved by parliament in a Delta Act. A budget of EUR 1 billion per year was initially foreseen for planning and implementing climate adaptation measures, but this has now been revised to EUR 9 billion for the period 2013 to 2028. Adaptation to newly defined safety levels aimed at 2050 is intended to be ready by 2028. The process is accompanied by an annual National Delta Congress. The Delta Program on several strategic decisions regarding future flood safety and freshwater provision is now finished. The new safety norms are currently being laid down in the new Water Act, and are expected to come into effect as of 2017. Future safety assessments will be undertaken every twelve years (Rijkswaterstaat 2015b).

18.2.5 United Kingdom

The Climate Change Act 2008 provides a legally binding and long-term framework to cut carbon emissions in the United Kingdom, but also makes provision for an assessment of the risks of climate change for the United Kingdom to be undertaken on a five-year cycle. The first of these is the 2012 Climate Change Risk Assessment (CCRA) (DEFRA 2012). This was based on climate projections by Lowe et al. (2009) and included an assessment of the economic implications of climate change for different sectors and the potential costs and benefits of different adaptation responses. Building on the outputs of the CCRA, the government and the Devolved Administrations (Northern Ireland, Scotland, and Wales) are developing adaptation programmes that will set out Government objectives for adaptation to climate change as well as proposals and policies to deliver these objectives. The programmes will be subject to regular assessment by the Committee on Climate Change to determine progress towards implementation.

18.3 Safety Margins for Climate Change Effects

18.3.1 Sea-Level Rise Scenarios and Safety Levels

The safety levels of hydrodynamic loads are the criteria used for dimensioning coastal protection structures to ensure their effectiveness in protecting against flooding due to storm surges. Superimposed safety margins ensure that the structures remain effective against flooding over the course of their anticipated lifespan; safety margins for SLR have been in use since the 1950s and are superimposed on the safety levels for hydrodynamic loads on the structures. The safety margins associated with accelerated SLR and other potential climate change effects are considered in distinct rates in the countries along the North Sea coasts. But ultimately, the safety of the protected areas depends on the aggregated safety margins and safety levels; the latter still the more relevant in respect of the order of magnitude. A comparison of safety levels between countries makes little sense. On the one hand, some countries have introduced distinct safety levels on regional scales, while on the other a comparison of exceedance probabilities is sometimes misleading. If distinct extreme value distributions are used to evaluate design parameters, the same exceedance probability might deliver distinctive results; with the larger the difference the lower the probability of occurrence. Moreover methodological differences like choice of used values or data fitting, and length of time series prevent a credible comparison: benchmarking by exceedance probabilities or return periods is only reasonable

Fig. 18.2 North Sea Basin and surrounding countries (base map: http://de.wikipedia.org/wiki/Datei:North_Sea_map-en.png)

and provides reliable results if the methodological basis for their evaluation is compatible. Therefore the following review of current safety margins for SLR and other hydrodynamic effects due to climate change includes only a brief description of safety levels. All locations mentioned in the following texts are shown in Fig. 18.2.

18.3.1.1 Denmark

A SLR of 0.1–0.5 m by 2050 and 0.2–1.4 m by 2100 is assumed in Denmark. This is partly compensated for by a land rise of 0–0.1 m by 2050 and 0–0.2 m by 2100, leading to a relative SLR of 0–0.5 m by 2050 and 0–1.4 m by 2100. An increase in the set-up of severe storm surges of 0–0.1 m by 2050 and 0–0.3 m by 2100 is also assumed due to higher wind velocities resulting also in higher and longer waves. Peak storm surge levels may increase by up to 0.6 m by 2050 and up to 1.7 m by 2100 due to the combined effect of SLR and increasing surge set-up. Information on the changing wave climate is provided by comparing actual conditions with scenarios for the period 2071–2100. For dykes on the Wadden Sea coast, cost estimates for adaptation have been carried out. For a recently strengthened 13-km stretch of the dyke line south of Ribe a safety margin of 40 cm has been considered. The safety level in Denmark is defined for sandy coasts by conditions with a yearly exceedance probability of 10^{-3} for the city of Thyboron and 10^{-2} for the coastal stretch between Agger and Nymindegab. The width of dunes required to meet that safety level was determined empirically from historical data on dune erosion. Safety levels for the dykes at the Wadden Sea coast of Denmark range between 2×10^{-2} and 5×10^{-3}, depending on population density in the protected area. Design is aimed to achieve these safety levels until 2100, and takes into account projections for SLR, increased set-up of storm surges and changes in wave climate. The level of acceptable overtopping tolerance for dykes is 10 %, which is equivalent to approximately 10 [l× (m s)$^{-1}$] for the boundary conditions at the Danish Wadden Sea coast. The other parts of the Danish North Sea coast have no flood risk.

18.3.1.2 United Kingdom

Safety levels in the United Kingdom depend on the degree of development of the protected areas. For London and the developed parts of the Thames estuary a yearly exceedance probability of 10^{-3} is applied, whereas the corresponding safety level for all other urban areas along the North Sea coast is a yearly exceedance probability of 5×10^{-3}. For the other parts, lower safety levels are applied in respect of local circumstances. Since 1999, a SLR of 40 cm is assumed for the North Sea coast north of Flamborough Head for the design of structures with a lifespan of 100 years, and a SLR of 60 cm for the North Sea coast south of Flamborough Head. The flood risk management plan for the Thames estuary takes the following safety margins for SLR into consideration (Environment Agency 2013):

- 4 mm year^{-1} to 2025
- 8.5 mm year^{-1} for 2026–2055
- 12 mm year^{-1} for 2056–2085
- 15 mm year^{-1} for 2086–2115.

National guidance issued in 2011 advises using the UK Climate Projection 09 (DEFRA 2011) for relative SLR based on the medium-emissions 95th percentile projection for the project location. Upper-end (95th percentile) estimates are as follows:

- 4 mm year^{-1} to 2025
- 7 mm year^{-1} for 2026–2050
- 11 mm year^{-1} for 2051–2080
- 15 mm year^{-1} for 2081–2115.

Guidance is also given for storm surges, where an assessment of extremes is recommended and upper-end estimates are provided as follows: 20 cm by the 2020s, 35 cm by the 2050s and 70 cm by the 2080s. Work is underway on developing wave climate projections.

18.3.1.3 Germany

In Germany, the four federal states use three different methods for evaluating design water levels on the North Sea coast and adjacent estuaries. They have been tuned to yield similar values at the Cuxhaven gauge at the mouth of the Elbe estuary between 2010 and 2012. A matching value is achieved for the method practised in Schleswig-Holstein by adding an additional measure for the surge set-up in an estuarine mouth to the value achieved by the commonly used yearly exceedance probability of 5×10^{-3}. Hamburg has developed a new deterministic approach in order to meet the target range. Bremen and Lower Saxony met the anticipated target value beforehand by applying the traditionally used deterministic single-value method by combining the actual mean high water level with the highest values of maximum spring elevation, storm surge set-up and the chosen safety margin for climate change effects for the determination of design water levels. Design water levels in Lower Saxony and in the Netherlands at the Ems-Dollard estuary have similar values, the surge set-up of the design water level has a yearly exceedance probability of 2.5×10^{-4}. Tolerable wave overtopping at dykes is limited to 2 [l× (m s)$^{-1}$] in Schleswig-Holstein and to 3 % in Bremen and Lower Saxony corresponding to an overtopping volume in the range of approximately 0.1–1.5 [l× (m s)$^{-1}$] with a tendency to correspond to the cross-sectional areas of dykes. All four states account for future climate change effects in the evaluation of design water levels by adding a general provision margin of 50 cm for 100 years. This measure would be equivalent to a SLR of about 40–45 cm per 100 years. Since 2012/2013 in Hamburg, 20 cm of the anticipated 50 cm SLR will be taken into account in the design of coastal protection structures with a lifespan to 2050. Whereas in Schleswig-Holstein and Hamburg the provision margin is a comprehensive part of the design water level, in Lower Saxony and Bremen a different approach is used in designing coastal structures: the provision margin is split into a SLR of 25 cm and an additional increase in storm surge set-up of 25 cm. The latter requires higher storm velocities and so also takes into account higher wave energy. Furthermore, for the applied design procedure the—at least partial—adaption of tidal flats to an accelerated SLR is neglected leading to greater water depths and higher and longer waves in front of coastal structures. As a result, the incorporation of dynamic elements in the design procedure generates a higher safety margin than using an additional fixed value for design water levels. Furthermore, in Bremen, Hamburg and Lower Saxony, solid structures are constructed so as to accommodate an increase in water level beyond the anticipated safety margin; this comprises up to an additional 75 cm (Bremen), 80 cm (Hamburg) or 50 cm (Lower Saxony).

18.3.1.4 Belgium

The Flemish authorities are anticipating a SLR of about 6 mm year^{-1} by 2050 and 10 mm year^{-1} between 2050 and 2100 at the Belgian coast, and these values have been considered for planning and construction targeted at safety levels for 2050 and being ready by 2018. The safety level is a yearly exceedance probability of 10^{-3} for both water level and waves, and is based on extreme value distributions for the determinative directions for very high storm surges. The design procedure is based on a storm duration of 45 h, covering three tidal high peaks, for dunes, dykes, sluices, weirs and quay walls in harbours. The threshold of tolerable wave overtopping on dykes is 1 [l× (m s)$^{-1}$] and dune erosion must be limited to a predefined level. Quay levels in harbours, heights of sluices and weirs will be checked with the aim of matching the design water levels. Risk analyses are carried out for four scenarios, including storm surges with higher tidal peaks than considered for the design storm surge up to a yearly exceedance probability of 5.89×10^{-5}. The aim is to derive basic information for the introduction of higher safety levels on the basis of a benefit-cost ratio and risk reduction if events occur for which evacuation is necessary. In the revised Sigma Plan for the Belgian part of the Western Scheldt estuary the design of coastal protection structures was based on a cost-benefit analysis (Broekx et al. 2011; Sigmaplan 2016).

18.3.1.5 Netherlands

To date, safety levels in the Netherlands refer to the recommendations of the first Delta Committee after the 1953 flood: a probabilistic flood safety definition based on the exceedance probabilities of water levels and waves. The safety levels differ between the various parts of the country in respect of population density, economic value and risk of flooding. Two safety levels have been established at the coast: 10^{-4} for the central Holland coast and 2.5×10^{-4} year^{-1} for the southwestern Delta area and the Wadden Sea with the Ems-Dollard estuary in the Northeast. Later overtopping tolerance on dykes has been limited to 0.1–1 [l× (m s)$^{-1}$] depending on the quality of the cover layer. The Second Deltacommissie (2008) recommended raising safety standards ten-fold based on economic and population growth since 1953. Meanwhile, a decision has been made to replace the current procedure by a risk-based approach, incorporating the probability and degree to which a protection structure will fail if its design conditions are exceeded, as well as the loss of life and material damage that would occur in the event of a flood. A basic safety level is introduced, with a yearly probability of 10^{-5} as an upper limit for the loss of life due to flooding as local individual risk. For its evaluation two types of additional study are required: one on the threat to life due to flooding and one based on a societal cost-benefit-analysis. The final operational layout is expected to be introduced in 2016 in order to be ready for the safety assessment in 2017 (MIenM 2013). The Delta Commissioner expects that, to date, the safety levels used in coastal areas have led to protection structures that will meet the requirements of the new safety levels (Helpdesk Water 2015). Explorative studies of some dyke rings, however show that this new approach may lead to very different assessments of flood safety (Rijkswaterstaat 2005, 2015a). A more detailed investigation for the Lake IJssel area (Deltaprogramma IJsselmeergebied 2013) confirms this. The reason is that the failure of different stretches of dyke in a dyke ring may lead to different numbers of individuals being exposed to flooding. Safety margins for accelerated SLR due to the Delta scenarios range from 0.35 to 0.85 m until 2100 (Deltacommissaris 2013).

18.3.2 Coastline Stabilisation and Anticipation of Morphological Changes

Climate change will not only affect the hydrodynamic boundary conditions for coastal protection but will also cause morphological processes unfavourable to coastal protection. Knowledge about such developments and their consequences for coastal protection is much poorer than that available for future hydrodynamic loads. This lack of understanding about future morphological changes not only increases the uncertainties about future hydrodynamic loads but also includes the possibility that parts of the present coastal system could even disappear. A wide range of possible solutions are being considered in the coastal North Sea countries to tackle this problem, although the dimensions of morphological processes due to climate change impacts remain partly unknown. Solutions discussed in the following sections are all based on currently applied means to counter erosion.

18.3.2.1 Germany

In Germany, the Federal States of Bremen and Hamburg are responsible for relatively small sections of the open coast and have left the problem of morphological processes due to climate change impacts untouched in their adaptation scenarios to date. In the 'Masterplan Coastal Protection of the Federal State of Schleswig-Holstein' erosion due the BRUUN-rule is mentioned but only as a term without any consideration in respect of precautionary measures or as a topic for future research (MELUR 2013). Lower Saxony has developed an intensive research programme as part of the adaptation strategy, aiming to provide a robust evidence base for the planning of appropriate measures (MU 2012), but this programme has yet to start. In Schleswig-Holstein and in Lower Saxony structural erosion in sandy environments is typically compensated by artificial nourishments, particularly on barrier islands.

18.3.2.2 Denmark

Some parts of the sandy North Sea coast of Denmark experience structural erosion (Van de Graaff et al. 1991) which is compensated by artificial nourishments of 2–3 million m^3 $year^{-1}$. The total volume required is determined by the sum of:

- the annual average erosion above the 6 m depth contour between 1977 and 1996
- loss of nourished volume between the 6 and 10 m depth contour
- compensation for profile steepening since the middle of the period 1977–1996
- in the future, an extra 15 % of the sum of all three to cover uncertainties.

Since artificial nourishment steepens the shoreface, extra volumes of material are likely to be needed to offset the effects of SLR. The Danish Coastal Authority has carried out intensive empirical studies to determine the volumes required for future nourishments to compensate for erosion due to accelerated SLR, shoreface steepening and increased longshore transport due to anticipated higher wave energy. The additional artificial supply for compensating for anticipated climate change effects under three scenarios averages 17 % in 2050 and 49 % in 2100 relative to the total volume of nourishment in 2008 (Jensen and Sørensen 2008).

18.3.2.3 Belgium

Structural erosion on the Flemish coast is counteracted by shoreface, beach and dune nourishments in order to reduce flood risk. The need for nourishment varies from section to section. Houthuys et al. (2012) noted a long-term general trend along the Flemish coast ranging from slight accretion in the west at the French border shifting to mild erosion east at the Dutch border. For the period 2013–2020, an average yearly volume of 20 m^3 m^{-1} is considered necessary to meet the target safety level and provide a five-year buffer; which gives a total volume of 10 million m^3. To address structural erosion and the projected SLR, an extra annual volume of 7 m^3 m^{-1} corresponding to a total volume of 14 million m^3 is expected to be needed between 2020 and 2050 (Balcaen 2012) of which about half is needed to compensate for SLR. This is based on the assumption of 500 m^3 m^{-1} beach front for an average beach and a foreshore width of 500 m.

18.3.2.4 Netherlands

Since the 1990s, the strategy for the sandy coasts of the Netherlands has been one of dynamic management to stabilise the basal coastline (Rijkswaterstaat 1990). This strategy was extended offshore beyond the shoreface to the 20 m depth contour in 2001, thus including the area known as the coastal foundation (Mulder et al. 2007). On average, 12 million m^3 is used each year for nourishments along the sandy parts of the southwestern Delta, the closed Holland coast and on the West Frisian Barrier islands (Rijkswaterstaat 2011). Following the currently applied procedure (Mulder et al. 2007), increased demand for nourishments due to accelerated SLR and secondary effects will be identified by assessing the annual surveys every four years and then adjusting the amounts compensated within the following four years (Deltacommissaris 2013). However, the presently nourished volume is still insufficient to meet the aims (Mulder and Tonnon 2010): a total volume of 20 million m^3 $year^{-1}$ is needed in relation to current SLR. The reason for this difference is largely due to the demand for sediments from the Western Scheldt estuary and the tidal basins of the Wadden Sea (de Ronde 2008). Although they are excluded from the nourishment programme these coastal areas benefit from sediment import from the coastal foundation. Recent studies on the adaption of the tidal basins of the Wadden Sea to the closure of the Zuider Zee and sand-mining, show that imported sediment volumes have been more than adequate to compensate for current SLR (Elias et al. 2012) which might indicate a sediment transport capacity through the inlets that is large enough to accommodate higher rates of SLR than currently occur. An increase in yearly nourishment volume to 20 million m^3 is anticipated in the National Waterplan (MVenW 2009) but no decision has yet been made. The total amount of material to offset SLR is estimated to be proportional to the rate of SLR; 7 million m^3 per mm $year^{-1}$. The Deltacommissie (2008) suggested that sediment budgets may need to increase to 85 million m^3 $year^{-1}$ by 2050, to compensate for a SLR of 12 mm $year^{-1}$ along the whole Dutch coast including the southwestern Delta and the Wadden Sea, whereas the actually introduced scenarios for SLR assume rates of 3.5 mm $year^{-1}$ until 2050 and 8.5 mm $year^{-1}$ between 2050 and 2100 (Deltacommissaris 2013).

18.3.2.5 United Kingdom

With a coastline of about 18,000 km, the United Kingdom is characterised by a wide range of shoreline types, inlets and estuaries. Historically, responses to coastal stabilisation were piecemeal and highly variable. Solutions included both hard constructions such as seawalls, breakwaters, groynes, and offshore reefs, and soft measures such as shingle recycling, beach nourishment and salt marsh generation. This local response has now been replaced by a more coherent and regional approach, through the adoption of Shoreline Management Plans to balance the requirements for safety against hazards and economic effort. The aim is to determine defence needs at a regional scale before defining the most appropriate form of protection to fulfil the strategic need. Central to this planning is a systematic and risk-based approach, underpinned by regional monitoring. Consideration is given to coastal geomorphology, geology, ecology, exposure, flood and erosion risk, protection type, and management strategy. Programme design focuses on the monitoring requirements needed to deliver new coastal engineering schemes over the next 30 years. Baseline surveys were undertaken for each survey category. Thereafter, a weighted sampling programme was developed according to identified risks, which determines the temporal and spatial frequency of data collection, reflecting factors such as the local geomorphology, exposure to wave climate and management strategy, to determine data requirements. Essentially, those areas that present high risk of erosion or flooding, or are heavily managed have more data collection than stretches of unmanaged coast. Hence, the entire UK coast is monitored at an appropriate level of detail to provide a strategic region-wide overview of coastal change. Consistent observation, specification, quality control, metadata and analysis techniques have been developed for each programme element. Web delivery includes online tools to view data and real-time observations of an extensive network of wave and tidal observations. In addition, a range of end-user products based on annual and cumulative analysis of the data enables coastal managers to develop a region-wide understanding of coastal evolution patterns (Channel Coastal Observatory 2013).

The shoreline management programmes will become more and more effective with an increasing data basis allowing more and more purposeful reactions of regional coastal managers in order to keep coastlines stable following the same basic criteria nationwide.

18.4 Adaptation Strategies

18.4.1 Monitoring Climate Change Effects

All coastal North Sea countries undertake coastal monitoring programmes to support the planning of construction and maintenance of coastal engineering schemes. Such programmes also provide a basis for scientific studies on process analysis, improving design procedures and verifying or driving models. Current monitoring programmes include a wide range of observation techniques including:

- terrestrial surveys by GPS and LIDAR of salt marshes, tidal flats, beaches and dunes or cliffs for moderate conditions, and the upper shoreface, beaches, dunes or cliffs for post-storm conditions
- bathymetric surveys of channels, shoreface and ebb deltas by GPS and sounding
- permanent water level monitoring by gauges
- permanent measurements of currents and salinity
- permanent wave monitoring by buoys or gauges
- monitoring of sediments and habitats.

Measuring campaigns are also undertaken to strengthen the data base for analysing and modelling hydrodynamic and morphodynamic coastal processes. Measurements are supplemented by model results covering hydrodynamic and morphodynamic processes and developments.

Although all North Sea coastal countries regard coastal monitoring as essential the approaches used vary widely, particularly in terms of spatial distribution and sampling frequency. Nevertheless, these data are still useful for detecting climate change impacts and developing coastal protection measures. However, it is important to keep the national monitoring programmes under review in respect of their suitability to deliver basic information for detecting climate change impacts relevant for coastal protection. The layout of monitoring programmes on coastal hydro- and morphodynamics is generally structured according to the knowledge about coastal processes as assembled in currently used coastal classifications like, for example, that of Hayes (1979) which consider tidal range and wave climate as driving forces but no varying SLR (Hayes and Fitzgerald 2013). It is therefore advisable to check whether the existing programmes are already sufficiently structured in respect of data mining and analysis for detecting effects of climate change impacts such as accelerated SLR, increased set-up of storm surges, growing wave energy and morphodynamic adaption.

A promising tool for identifying climate change impacts would be a combination of nationwide knowledge at least at the scale of the countries surrounding the North Sea. International interdisciplinary expert groups could then evaluate which data and information would be helpful in detecting climate change impacts in coastal areas as quickly and accurately as possible. The aim of these efforts should be standardised integrated monitoring around the North Sea supplemented by specific regional programmes addressing specific regional needs. The latter could also generate high quality data sets for driving and verifying mathematical models. Emphasis should also be given to improving and further developing analytical methods for evaluating monitoring data and model results with the aim of early detection of climate change impacts, especially trends. A parallel application of distinct analytical methods and forecast tools could provide comparable results; in case that similar results were found a sounder basis for decision-making could be achieved.

Since the scenarios for climate change impacts are still accompanied by large uncertainties due to the lack of basic knowledge needed for targeted cost-effective planning for coastal protection measures, any reduction in uncertainties by monitoring and the use of models implies a very good benefit-cost ratio.

18.4.2 Belgium

The Flemish authorities aim to keep the protection line at the Belgian North Sea coast. Improvements have taken place in the harbours that are currently considered the weakest links in the protection line and through which 95 % of flooding is expected. In 2007–2008, work was undertaken to ensure a minimum safety level for a storm with a yearly exceedance probability of 10^{-2}. Quay levels must be higher than the water level with an exceedance probability of 10^{-3} and the strength of dykes, sluices and weirs are checked. A storm surge barrier will be constructed in Nieuwpoort at the entrance to the Yser estuary and to the important yacht harbour of Nieuwpoort. Although this barrier will reduce the risk of flooding from the sea, it may also increase the risk of hinterland inundation due to reduced drainage capacity unless additional measures are taken.

Repeated nourishments include a safety margin for climate change effects. In addition, groynes are used to limit longshore transport. Possible positive effects of shoreface nourishments are debated and, for the longer term conceptual ideas of increasing the height of the existing Flemish Banks to reduce wave impact on shores are under consideration. Efforts are being made to limit aeolian transport, so keeping sediments where they can best help reduce hydrodynamic loads. The main design considerations are the use of a broad berm and a mild slope close to the equilibrium beach slope for the sand under consideration, with a preference for relatively coarse sand of about 300 µm in diameter. High sand buffers in front of dykes with a minimum lifespan of five years are suggested.

In the Belgian part of the Western Scheldt an earlier study concluded that the cost of a storm surge barrier near Antwerp would not outweigh the benefits (Berlamont et al. 1982). This study did not include the possible effect of SLR and the Sigma Plan was recently revised: a combination of flood plains and heightening of dykes and quay walls is thought to provide the best solution in terms of costs for investment and maintenance and benefits such as preventing loss of agricultural production, as well as those from ecosystem services and the reduced probability of flooding in high-value areas (Broekx et al. 2011). This also means a change in strategy from a fixed safety level for the basin as a whole to a more flexible approach to safety in different parts of the basin.

18.4.3 Denmark

Protection of the hinterland against flooding at the Danish North Sea coast will continue to be achieved by keeping the protection line in its current position, with the exception of those areas where coastal retreat is regarded as acceptable and no human interference preventing it is deemed necessary. At the Danish Wadden Sea coast existing dykes are strengthened to meet prevailing safety levels and the anticipated safety margins for climate change effects are the measures used.

The protected stretch at the sandy North Sea coast of Denmark comprises those parts where the dunes are being armoured with concrete block revetments and those where the dunes are not. The minimum width for dunes with revetments is 30 m and for dunes without revetments 40 m. These values were determined using erosion data from historical storm surges. Beach and shoreface erosion is currently compensated in front of dunes without revetments and due to a lack of funding is limited to a retreat of 3.2 m year^{-1} in front of dunes with revetments, yielding narrower and lower beaches in front of the revetment. This is acceptable as long as the safety level for the revetments is not reduced beyond the safety threshold.

The adaptation strategy at the Danish North Sea coast has been developed on the basis of experience and understanding and aims less at fixed targets than at a flexible response to changing boundary conditions.

18.4.4 Germany

The Free and Hanseatic City of Hamburg generally employs the strategy of keeping the protection line in its current position. But very recently, some new infrastructure like large public buildings has been erected on dwelling mounds to prevent them flooding if dyke sections fail during a storm surge. The strategy in Schleswig Holstein for dykes at the mainland North Sea coast and on the North Frisian Islands is similar: in the current protection line dykes will be repeatedly strengthened relative to safety levels and safety margins. Since 2010, a new cross-sectional design has been applied enabling dykes to be raised up to 1.5 m for stronger hydrodynamic loads at some future date. The use of older dykes—those no longer in use due to the protection line after embankments moving seaward—is anticipated as a second protection line but is not yet implemented due to budget constraints. Tests on some sections showed the effectiveness of the second dyke line is often very limited. Nevertheless, it is considered worth preserving existing dykes in the second line as a basis for a new dyke line in the future. Information on design, dimensions and costs of strengthening dykes in the second line is lacking (MELUR 2013).

The Free and Hanseatic City of Bremen will keep the protection line in its current position. For its mainland coast and along the tidal estuaries Ems-Dollard, Weser and Elbe, Lower Saxony will do the same. This decision is the result of research on four alternative approaches. The investigations were undertaken in the Ems-Dollard estuary area which is representative of both estuaries and the Wadden Sea coast, with a stepwise increase in design water levels for a SLR of 0.65 and 1.00 m on the one hand, added to by an increase in storm-surge set-up of 0.35 and 0.5 m on the other (Niemeyer et al. 2014). The latter account for higher wind velocities on the one hand and higher and less attenuated wave energy on the other. Tidal flats were assumed not to adapt to accelerated SLR. This pessimistic scenario led to the following results:

- *Retreat* from all areas with flood risk due to storm surges in order to save on the cost of coastal protection. This implies that 1.2 million people in Lower Saxony would need to move to safe areas and about 800,000 people in neighbouring states would be at risk. However, cost savings versus economic losses mean that this strategy is out of the question, even for more pessimistic scenarios than those considered here.
- *Accommodation* by limiting coastal protection to settlements above a certain threshold of inhabitants and economic value. The costs of implementing the new coastal protection schemes are about 25 % of the capital costs of the existing protection line if only the larger cities are safeguarded against storm surges and are of the same order of magnitude if all small villages are also protected. In addition, enormous efforts would be required to keep infrastructure between the protected areas such as railways, streets, energy supply lines operational after storm surge flooding. Even excluding other major disadvantages of this strategy, it is still clear that maintaining and strengthening the existing protection line is a better economic solution.
- *Set-back or realignment* leads to higher hydrodynamic loads than occur at the corresponding outer protection line, in all those areas where it has been moved seaward. Land levels in the areas sheltered by new dyke lines after reclamation have not been subject to sedimentation and are now lower than areas seaward of the dyke, particularly in saltmarshes. The greater water depths in front of the landward-shifted dykes by set-back allow higher wave energy. Without a gain in safety and with extra investment costs exceeding the current yearly budgets for coastal protection 120-fold for new dykes (MU 2012) this alternative is not better than the strategy of keeping the protection line in its current position.
- *Combined protection* with two structures; one for wave attenuation seaward and another to contain storm surge levels landward. Collectively these two structures would require a higher cross-sectional area than a single protection line. The safety achieved by such a scheme is less than that achieved by a conventional dyke and the costs would be significantly higher than for one dyke line.

The results show that strengthening the existing protection line is still the most effective solution both in terms of safety and cost (Niemeyer et al. 2011a, b, 2014). The government commission (MU 2012) and subsequently the State Government decided to follow the strategy of keeping the line in its current position and strengthening the protection structures. This approach was approved by the self-ruling dyke communities and through representative polls of people in the protected areas (MU 2012). To date, further studies have been undertaken for a SLR of 1.0 m, an additional increase in storm surge set-up of 0.5 m and consistently higher and longer waves in the area of the Ems-Dollard estuary (Knaack et al. 2015). These studies led to the same conclusions as the previous studies: keeping the line is the optimal strategy for future protection of lowland coasts at the southern North Sea.

Successful site investigations on wave overtopping of dykes have been undertaken in Denmark (Laustrup et al. 1991), the Netherlands (van der Meer et al. 2009) and

Vietnam (Le et al. 2013). They prove that higher overtopping volumes on dykes than are currently considered tolerable will be acceptable without failure of the structure. Wave overtopping on dykes has been modelled in combination with soil laboratory tests of the covering clay to develop an integrated design that takes into account both hydrodynamics and soil mechanics (Berkenbrink et al. 2010; Richwien et al. 2011). Several tests showed cover layers remained functional for overtopping volumes up to 200 $[\mathrm{l} \times (\mathrm{m\ s})^{-1}]$. As overtopping volumes of this magnitude would probably cause severe damage in populated areas, acceptable overtopping volumes should be smaller. Studies were undertaken to quantify the extent to which an enhanced overtopping tolerance could counterbalance the effects of SLR or other climate change effects at three representative cross-sections for coastal and estuarine dykes in Lower Saxony. The results showed that an overtopping tolerance of 10 $[\mathrm{l} \times (\mathrm{m\ s})^{-1}]$ would allow a reduction in dyke crest heights for presently applied design conditions of 45–60 cm at the Lower Saxony North Sea coast and adjacent estuaries (Niemeyer et al. 2010). This suggests a survey of cover layers for all Lower Saxony coastal and estuarine dykes could help improve estimates of the design parameters for site-specific acceptable wave overtopping volumes, as part of the adaptation strategy for coastal protection (MU 2012). Such a survey would also identify weak points in the existing protection line.

Protection of the East Frisian Islands is currently undertaken using the same guidelines as in the past since the lack of understanding about climate change impacts on morphodynamic processes hampers the development of a resilient adaptation strategy (MU 2012).

18.4.5 Netherlands

The most recent decision on coastal protection strategy in the Netherlands is the adoption of a three-layer safety scheme combined with a new design procedure orientated at the probability of the loss of human life: prevention of flooding by keeping, strengthening and safeguarding the protection line remains the basis, which is extended with supporting measures to reduce the consequential damage of structural failure. The three-layer safety scheme is as follows:

- Layer 1: prevention of flooding by establishing and maintaining an effective flood protection system
- Layer 2: spatial planning such that the impact of flooding after the failure of protection structures is reduced
- Layer 3: disaster control through detailed evacuation plans, making sure that vital infrastructure is still functional in the event of a flood, and the creation of safe havens.

The self-governing waterboards ask for priority to be given to strengthening of the protection structures in order to meet prevailing safety norms, before investing in the second and third layer. The new system of risk-based safety norms differs from the current norm system based on hydrodynamic loads. The Cabinet adopted the new norm system in November 2014; its application is scheduled for 2017 and it is expected to take until 2050 for it to be implemented across the coastal protection system as a whole.

The costs of improving the structure of all existing dykes including those along inland waters, is estimated at about EUR 6.5 billion. An additional EUR 5 billion would be required for adaptation to a SLR of 0.5 m. The sum of both is beyond the likely budget for the Delta Program for 2013 to 2028 (see Sect. 18.2.4). Conceptual studies on very safe dykes (Silva and van Velzen 2008) project an overtopping tolerance of 30 $[\mathrm{l} \times (\mathrm{m\ s})^{-1}]$ for coastal dykes.

The flood protection scheme for the Netherlands has a unique configuration: dyke rings surrounding protected areas. There are currently 54 dyke rings and the associated protection structures have a total length of 3767 km, about 30 % of these are at open tidal waters. Water Plan Beaufort is currently under development and is aimed at reducing the costs involved in improving protection structures to meet future safety levels, including those associated with climate change effects, as well as increasing options for setting priorities (Beaufort 2010/2013). A major element of the plan is a reduction in the number of dyke rings from 54 to 2 in line with the overall vision of shorter protection lines along sea and rivers and free outflow of rivers to the sea. Stronger dykes and extra locks and sluices are envisaged. Implementation may be phased, and efficient use of budgets should enable an increase in safety levels. Rough estimates indicate a cost saving of 50 % compared to implementing the safety standards according to the Delta program. Water Plan Beaufort includes stronger dykes than at present and more thorough dyke inspections for detecting weak spots (Beaufort 2010/2013). The plan is still under development and not yet included in planning by the responsible Deltacommissaris (2013).

The strategy for keeping coastal dunes and protection structures safe and the coastal foundation stable by nourishments involves significant cost, although considered in terms of an insurance premium for protecting around EUR 1800 billion (Deltacommissie 2008) of invested capital in the protected area the costs seem relatively moderate and more reasonable. Nevertheless, attempts to make artificial nourishments more efficient, particularly by generating and applying knowledge of coastal processes, are still worthwhile.

An impressive example is the ‘Delfland Sand Motor’, a mega-nourishment with a volume of about 21.5 million m^3 (Fig. 18.3) which is almost as big as the currently

Fig. 18.3 Mega-nourishment 'Delfland Sand Motor'. After completion in July 2011 (*left*) and in May 2015 (*right*) after reshaping (https://beeldbank.rws.nl, Rijkswaterstaat/Joop van Houdt)

implemented two-year volume of 24 million m^3. Designing the sand motor required intensive testing by morphodynamic model predictions in order to optimise its shape and to compare its effectiveness with conventional nourishments for maintaining the coastal foundation of Delfland (Fig. 18.3). To keep pace with the present rate of SLR this requires about 5.5 million m^3 within five years (Mulder and Tonnon 2010). Model results and measurements so far indicate that the Delfland Sand Motor will contribute to the maintenance of the coastal foundation of Delfland for around 25 years and that it is more cost-effective than repeated nourishments. But the model results also indicate that five additional nourishments will be necessary to maintain the coastline for this period. The alternatives for the shape of the sand motor have been shoreface nourishment, a bell-shape and a sandy hook (Mulder and Tonnon 2010). Because the coastal processes will rapidly transform any initial shape into a bell-shaped salient, the long-term morphological effects of the alternatives are similar. Combining the aim of the mega-nourishment to create long-term safety conditions as well as extra space for nature and recreation in an innovative manner, the environmental impact assessment showed the hook shape was preferable (Mulder and Tonnon 2010). The reshaping of the mega-nourishment is monitored and analysed. The results will improve the understanding of the effectiveness of this new type of artificial nourishment.

Another option tested recently is a seaward build-out of sandy coasts by over-nourishment, partly combined with supporting solid structures (Stronkhorst et al. 2010): coastal stretches receive excess amounts of sediment, creating beaches and dunes for nature conservation and recreation. Although the Deltacommissaris (2013) stated that this is a viable option, no specific decisions on this have yet been made.

18.4.6 United Kingdom

The approach to coastal protection in the United Kingdom focuses now on 'sedimentary cells' to reflect the adaptation needs of a regionally-varying coastline in terms of landscape, sedimentology and coastal dynamics. A distinction is made between coastal zone management (CZM) and so-called shoreline management. The former is predominantly a planning issue, seeking to reconcile the demands of development with the requirement for adequate protection of the natural environment. In contrast, shoreline management focuses on one aspect of CZM, namely coastal hazards, and concerns efforts to manage flood and erosion risk at the shoreline (Nicholls et al. 2013).

In the early 1990s, the government developed guidance for the preparation of 40 Shoreline Management Plans (SMPs) across England and Wales (MAFF 1995). The main objective was to define management units along the coast and consider the most appropriate Strategic Coastal Defence Options (SCDOs). The SCDOs considered for each management unit comprised four options for the strategy to be applied:

- do nothing
- maintain the existing protection line (while possibly adjusting the protection standard)
- advance the existing protection line
- retreat the existing protection line (subsequently referred to as 'managed realignment').

The management units were then used to initiate a consultation process and the compilation of each SMP, which, in some cases was adopted by the relevant authorities but this was and remains a non-statutory process. Outputs from the first round of SMPs were frequently biased towards the status quo—a fixed shoreline—which was at odds with the desire to move towards a more dynamic and adaptive coast, where appropriate. This led to a careful review of the process (Leafe et al. 1998) and new guidance was developed to promote the preparation of the second round of SMPs (DEFRA 2001). In this new guidance, greater emphasis was placed on:

- ensuring a more consistent evidence base was established
- the engagement of stakeholders throughout the process (but particularly in objective setting and selection of preferred options)
- adoption of the plans by the relevant authorities (DEFRA 2001).

Following a series of trials, this guidance was formally released (DEFRA 2006) and applied to England and Wales (DEFRA 2011). The second generation of SMPs are currently in production and when complete will cover the entire 6000 km shoreline. The intention is that the SMPs provide a 'route map' for local authorities and other decision makers to identify the most sustainable approaches to managing risks to the coast in the short term (0–20 years), medium term (20–50 years) and long term (50–100 years), recognising that changes to the present protection structures may need to be carried out as a staged process. Each SMP will include an action plan that prioritises works needed to manage specific flood and erosion risks, along with details of the coastal erosion monitoring and further research needed to support the plan. The SMPs then inform more detailed strategy studies, which explore the most effective form of delivery, with an increasing focus on adaptation measures that are more likely to be sustainable under a changing climate. For example, the long-term strategy for managing flood risk on the Thames Estuary, termed the Thames Estuary 2100 or TE2100 Project, includes options for managing flood risk to 2100, based on current government projections of climate change. Each option comprises a sequence of interventions to 2100 and beyond and the assessment included consideration of the H++, a low probability, high consequence scenario, which considers the possibility of large contributions to SLR from the Greenland and Antarctica ice sheets. The dates of implementation depend on the rate of climate change and other factors. If change such as rising sea level, or deterioration of the safety status of protection schemes occurs more rapidly than projected in the plan, intervention dates will be brought forward and vice versa. In this way, the timing of interventions on the estuary will be optimised, taking account of actual rates of change and associated updates of scientific knowledge and future projections. While this approach was developed specifically for London and the Thames Estuary, the concepts are now being adopted more widely (HM Treasury/DEFRA 2009).

18.5 Summary and Recommendations

This overview indicates that all countries around the North Sea with coastal areas vulnerable to flooding from storm surges are ready for the challenges that climate change is expected to bring. Scenarios have been developed and investigated as a basis for policy development, regulation and guidance, to provide a structured response that should ensure continued protection with the required level of safety for coastal flood prone areas.

Scenarios of accelerating SLR leading to changes in sea level of up to 1 m or more by 2100 have been used for planning the adaptation of coastal protection schemes. Thus the safety margins considered in all countries around the North Sea are consistent with the upper limit of SLR to 2100 reported in the latest assessment of the Intergovernmental Panel on Climate Change (IPCC 2013). There appears to be a tendency for countries with higher safety levels to consider smaller safety margins for climate change impacts than those with lower safety levels. Increased storm surge set-up and higher wave energy due to higher wind velocities are incorporated in the future design of coastal protection structures in Denmark, Bremen, Lower Saxony and the United Kingdom.

The United Kingdom has established a coastal protection strategy for a flexible response to erosion that reflects the varying conditions around the coast. The resulting strategy ranges from doing nothing or set-back of the protection line by managed realignment, to strengthening of the existing protection line. Denmark allows retreat at some stretches of its North Sea coast and maintains the protection line in the rest. All other countries aim at keeping the current protection line in place to protect the hinterland. In the Netherlands, a decision on implementing additional measures for reducing damage due to the failure of protection structures will be made in 2015. Investigations showed that a reliable basis for evaluating protection strategies is only achievable if real world tests are carried out, since conceptual studies can be misleading.

In all countries, artificial nourishments are traditionally used for combatting structural erosion on sandy coasts and this is expected to increase under future climate change impacts. This approach will thus be used more often and at higher rates for keeping the coastline in position according to the current criteria for intervention. The required increase in nourishment volumes needed to stabilise coastlines has been investigated in Belgium, Denmark and the Netherlands. In the Netherlands, models and large-scale site experiments have been used to gain deeper understanding of the relevant processes with the aim of increasing the efficiency of artificial nourishments or even moving the coastline seaward. In most countries, studies have been carried out to identify borrow areas with appropriate sediments and the volumes available. But there are still knowledge gaps concerning the long-term availability of sediments needed for nourishments to compensate for projected SLR, especially in terms of their being necessary to fulfil the needed volumes for nourishments in order to compensate the impacts of climate change in the long run, in particular in respect of the quality of sediments refilling the borrow pits and their suitability for future nourishments. A good understanding of the availability of suitable sediment reservoirs for nourishment is crucial for a sustainable management strategy to protect sandy coastal environments.

Climate change studies are based on scenarios rather than forecasts and this generates uncertainties, which by the end of a chain of processes may be unquantifiable. As a result, all North Sea countries use ongoing monitoring programmes for coastal management purposes. To help detect the impacts of climate change, some countries will even extend these monitoring programmes. The data provide a sound basis for detecting changes in trends. Testing existing tools and developing new analytical tools would be beneficial. Cooperation at a European scale would not only improve the exchange of knowledge, but would also improve the availability of tools, methodology and resources for problem solving.

Present knowledge already highlights that the effects of climate change at dynamic sandy coasts are stronger than on mainland coasts with cohesive sediments, such as estuaries or tidal basins with large intertidal areas and saltmarshes. Although the morphodynamic processes that are likely to occur due to climate change are reasonably well known, their quantification—if even possible—still involves large uncertainties. Filling the enormous knowledge gaps that still remain will be a challenge for coastal engineering in the future. Mitigating the morphodynamic changes due to climate change impacts will create high budget demands. For efficient measures it is necessary to understand and predict the hydrodynamic and morphodynamic changes that are likely to result from climate change. This justifies much higher budgets for research in this particular field than at present. Advancing process knowledge and improving long-term morphodynamic modelling are indispensable preconditions for providing decision-makers with a sound basis for target-orientated optimised measures. The knowledge potential in this field of expertise is extraordinarily good in Europe. The countries surrounding the North Sea would therefore benefit significantly from a co-ordinated programme aimed at reducing the knowledge gaps highlighted in this chapter.

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19

Socio-economic Impacts—Coastal Management and Governance

Job Dronkers and Tim Stojanovic

Abstract

Climate change will have important impacts on the North Sea coastal zones. Major threats include sea-level rise and the associated increase in flood risk, coastal erosion and wetland loss, and hazards arising from more frequent storm surges. The North Sea countries—Belgium, Denmark, France, Germany, the Netherlands, Norway, Sweden and the UK—have developed strategies to deal with these threats. This chapter provides a short introduction to the present adaptation strategies and highlights differences and similarities between them. All the North Sea countries face dilemmas in the implementation of their adaptation strategies. Uncertainty about the extent and timing of climate-driven impacts is a major underlying cause. In view of this, adaptation plans focus on no-regret measures. The most considered measures in the North Sea countries are spatial planning in the coastal zone (set-back lines), wetland restoration, coastal nourishment and reinforcement of existing protection structures. The difficulty of identifying the climate-driven component of observed change in the coastal zone is a critical obstacle to obtaining a widely shared understanding of the urgency of adaptation. A better coordinated and more consistent approach to marine monitoring is crucial for informing policy and the general public and for developing the adaptive capacity of institutions and wider society. A dedicated coastal observation network is not yet in place in the North Sea region.

19.1 Introduction

Climate change will have important impacts in the coastal zones of the eight countries around the North Sea: Belgium, Denmark, France, Germany, the Netherlands, Norway, Sweden and the UK. Major threats include sea-level rise and the associated increase in flood risk, coastal erosion and wetland loss, and hazards arising from more frequent storm surges. The North Sea countries have developed strategies to deal with these threats. For each country a short introduction is given to their present adaptation strategy; differences and similarities are highlighted. All the North Sea countries face dilemmas in the implementation of their adaptation strategies. Uncertainty about the extent and timing of climate-driven impacts is a major underlying cause. Several approaches are available to deal with these dilemmas. The key findings are summarised in a final section.

19.2 Coastal Management in the North Sea Countries

This section briefly reviews coastal management practice in the North Sea countries in relation to climate change. Some working definitions of key terms used within this chapter are given in Box 1.

J. Dronkers (✉)
Deltares, Delft, and Netherlands Centre for Coastal Research,
Delft, The Netherlands
e-mail: j.dronkers@hccnet.nl

T. Stojanovic (✉)
Department of Geography and Sustainable Development,
University of St Andrews, St Andrews, UK
e-mail: tas21@st-andrews.ac.uk

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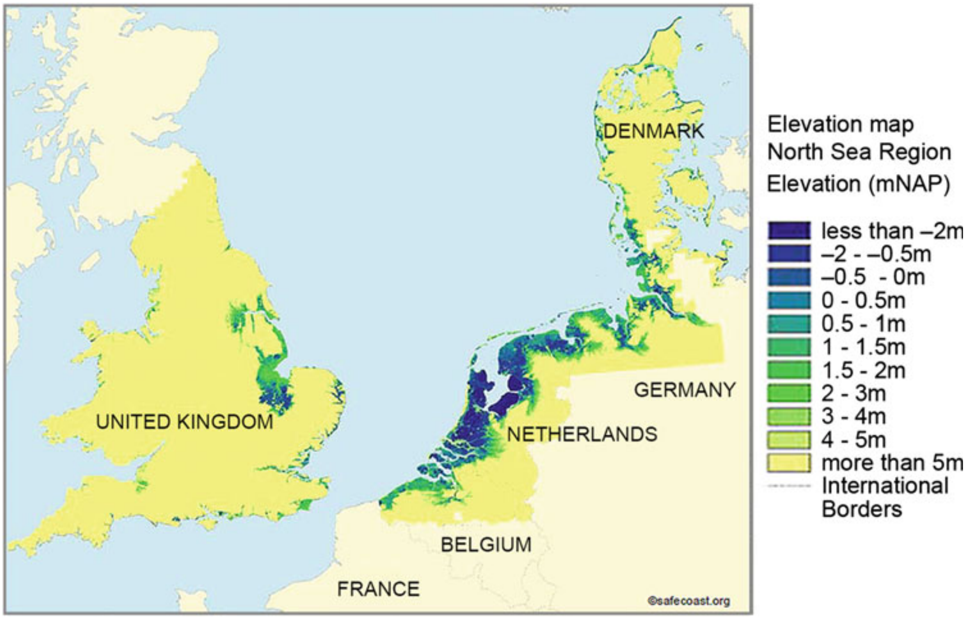

Fig. 19.1 North Sea regions potentially vulnerable to inundation by the sea (Roode et al. 2008)

19.2.1 The Coastal Zone

The shoreline is the most obviously delineated feature of the coastal zone. The North Sea countries have no commonly adopted definition of what else should be considered as the 'coastal zone'. Shoreline management mainly deals with coastal protection; this is the topic of Chap. 18. The present chapter deals mainly with coastal zone governance issues. Whether the societies in North Sea countries effectively adapt to the impacts of climate change in the coastal zone depends on a broad range of factors including continuing drivers for coastal development, and political debate about which measures should be adopted. The framework of 'governance' provides the broadest perspective to consider these issues.

In their climate adaptation strategies, all North Sea countries give particular consideration to marine-related risks. The present chapter therefore equates the coastal zone with the zone of marine-related risks. Figure 19.1 shows North Sea regions subject to marine flooding risk and Fig. 19.2 the North Sea regions with a special protection status under the EU Habitats Directive.

Each North Sea country has its own legal and institutional arrangements for coastal governance. The legal frameworks relating to the coastal zone are complex and diverse, and further complicated by the federal structure or devolution within countries (Gibson 2003). France has specific legislation for the coastal zone (Loi Littoral 1986). The UK has passed the Marine and Coastal Access Act (2009)[1] which has jurisdiction seaward from mean high water. In other countries, the coastal zone is governed through more general legal and institutional frameworks, such as 'Environment', 'Water Management', 'Climate Change Adaptation', 'Territorial Planning', 'Natural Hazards', and 'Fishery', among others. The coordination of national policies rests with the central governments. None of the North Sea countries has an authority dedicated specifically to coastal governance. The implementation of national policies in coastal zone management plans is commonly delegated to regional and/or local authorities.

19.2.2 Coastal Management Issues

The coastal zone is considered a region in its own right because of its dependence on land-ocean interaction. The coastal zone is not only shaped by human interventions, but also by the feedback of natural processes to these interventions. This imposes limitations on the uses of the coastal zone; non-respect of these limitations entails the risk of loss of life and investments. Inappropriate development entails the loss of precious ecosystem values.

Recognition of the particular nature of the coastal zone led to the development of the concept of ICZM (Integrated Coastal Zone Management) in the 1990s. The term 'integrated' points to the need for coordination of the policies of different sectors and different levels of government. The challenges of making disjointed, hierarchical and sector bureaucracies effective, are common to many forms of management and regulation. However, for the coastal zone additional requirements result from the highly dynamic natural land-ocean interaction. Large parts of the European coastal zones received a special protection status through the

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[1] www.legislation.gov.uk/ukpga/2009/23/contents.

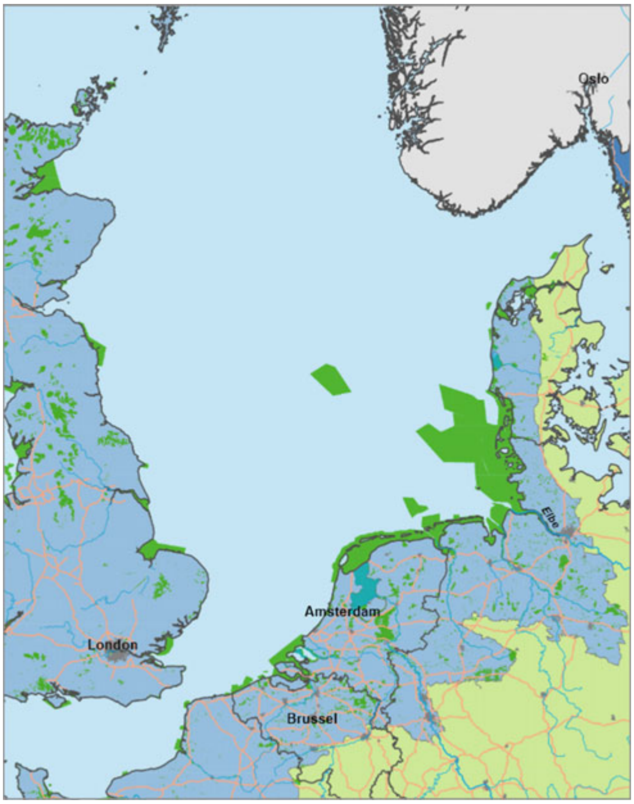

Fig. 19.2 North Sea coastal and marine regions with a special protection status under the EU Habitats Directive (marked in *green*)

EU Habitats Directive and the Natura 2000 network of the European Union. The countries around the Mediterranean Sea agreed on a protocol for ICZM that entered into force in 2011 (Barcelona Protocol 2008). In 2013, the European Commission proposed a directive binding all member states to put into practice the principles of ICZM and to develop spatial marine plans. The directive was adopted in 2014 (EC 2014), but ICZM was excluded following amendments by member states.

According to the evaluation report on IZCM prepared for the European Commission in 2006 (Ruprecht Consult 2006), major coastal issues for the North Sea region include resource management, species and habitat protection, establishment and management of reserves and protected areas, protection of the coast against natural and human induced disasters, and long-term consequences of climate change.

19.2.3 Drivers of Coastal Change

The ELOISE programme (European Land-Ocean Interaction Studies, Vermaat et al. 2005) has collected ample evidence to show that climate change will have serious impacts in the European coastal zones. The effects of climate change will add to the effects of other drivers of change. Other major drivers are related to human population growth and economic expansion. Industrialisation, shipping traffic intensity, fisheries, coastal aquaculture and port development as well as offshore mining for gas and oil have all increased greatly in recent decades, and will probably continue to do so (Stojanovic and Farmer 2013). Together with increased tourism this has led to urbanisation of highly dynamic natural zones. It is expected that climate change will exacerbate most of the adverse impacts of existing drivers of change.

The scale and type of impact that drivers can bring about varies considerably. There are various methods for classifying drivers, for example, PESTLE analysis (Political, Economic, Social, Technological, Legal and Environmental drivers, Ballinger and Rhisiart 2011). Drivers of change in coastal systems are typically external to the coastal zone. Effective coastal zone management therefore requires consideration of policies in many other fields. This implies that coastal adaptation is only a partial response to change.

19.2.4 The Challenge of Adaptation to Climate Change

Development of the coastal zone was accompanied in the past by reclamation and armouring with hard coastal defences, narrowing the active coastal zone (Nicholls and Klein 2005; Vermaat and Gilbert 2006). This process was identified as ‘coastal squeeze’. Coastal squeeze is strongly enhanced by sea-level rise and compromises the natural capability of coastal adaptation to climate change. In order to address these problems, new engineering techniques have been developed, following the principle of ‘working with nature’ (EEA 2006). This practice uses the dynamic response of marine processes, by designing interventions such that the feedback of marine processes is positive (contributes to achieving the objective of the intervention) rather than negative (opposes the intervention). Foreshore nourishment and wetland restoration are typical examples. Further examples of new coastal engineering practices are given in Chap. 18.

Owing to the strong interference of human interventions with natural processes, reversing adverse trends, such as erosion or ecosystem alteration, is not always feasible and is in any case expensive. A long-term perspective is therefore key to coastal governance. Anticipating the effects of climate change is one of the major challenges. Adaptation to climate change may already require a revision of present management strategies in some coastal regions. According to the EEA report *The Changing Faces of Europe’s Coastal Areas* (EEA 2006), coastal zones will be subject to many pressures during the 21st century. “These pressures will interact with climate change and exacerbate or ameliorate vulnerability to climate change. Coastal development cannot ignore climate change and development plans should be evaluated with respect to their sustainability under changed climate conditions”.

According to Richards and Nicholls (2009), adaptation measures should not be postponed in densely populated and industrial coastal zones. Their calculations indicate that a ‘wait and see’ strategy generates higher costs in the long run than the costs of protection.

Awareness of the challenges posed by climate change is reflected in coastal policy plans of the North Sea countries. Major features of the coastal policy plans of the North Sea countries are summarised in the following section.

19.3 Adaptation Strategies in the North Sea Countries

19.3.1 Belgium

Most of the effects of climate change at the Belgian coast relate to sea-level rise, resulting in higher storm flood levels, coastal erosion, and deterioration or loss of natural ecosystems, including wetlands. Other impacts associated with higher sea levels are rising groundwater levels and an increase in soil and groundwater salinity in coastal and estuarine areas. Freshwater lenses developed within the dunes are also vulnerable to sea-level rise, leading to threats to drinking water supplies through saltwater intrusion. Climate change will also affect fisheries and coastal tourism (Lebbe et al. 2008; Van den Eynde et al. 2011). One of the most significant social secondary effects is the number of people at risk due to flooding. Economic impacts result not only from direct damage, but also from indirect damage associated with the temporary suspension of production and loss of jobs (Van der Biest et al. 2008, 2009).

The Belgian coastal adaptation strategy for coping with climate change aims at combining flood risk control with the development of ecosystem services (NCC 2010). For controlling flood risks along the Scheldt Estuary, the Sigma-plan has been developed. This provides for the creation of controlled flood zones along the estuary, combining safety against flooding with objectives related to recreation, nature and agriculture.

An ambitious proposal for coastal adaptation has been launched by a group of private investors. The central idea is to combine the need of climate change adaptation with the development of new opportunities for the economy of the Belgian coastal zone. This plan was endorsed by the Flemish government that developed the three-track master plan Vlaamse Baaien (Vlaamse Overheid 2012). This master plan aims at (1) a safe and sustainable coastline with opportunities for economic development, (2) a resilient coastal ecosystem with opportunities for the development of ecosystem services and (3) the establishment of a supportive research platform. The time horizon of Vlaamse Baaien is 2100; the master plan therefore fully incorporates the projected impacts of climate change for this period.

19.3.2 Denmark

The Danish climate adaptation strategy has been elaborated by the Danish Energy Agency (DEA 2008); the strategy for coastal adaptation is mainly concerned with erosion control and protection from flooding. The DEA estimates that opportunities for continuous climate change adaptation in Denmark are generally good.

The DEA reports several climate-related threats. Higher sea levels and stronger storms with higher storm surges are expected. This means an increased risk of flooding and more erosion along many stretches of the coast. Since the strongest storms will come from the west, the increased risk of flooding and erosion will vary widely from the west coast of Jutland, to the Wadden Sea tidal areas and to the interior shores of Danish waters. Moreover, new waterfront construction, port-related operations and sanding up of harbour entrances pose special problems. Cities located at coastal inlets and within fjords may face a very complex set of problems, since they can be under pressure from higher sea levels, increased precipitation and runoff, and changes in groundwater levels.

Increased precipitation, altered precipitation patterns and higher sea levels—with consequent higher water levels in fjords and rivers—will exacerbate problems associated with drainage of low-lying areas, particularly in coastal areas, where about 43 % of Denmark’s population occurs. The majority of Denmark’s approximately 250,000 summer houses and 73 % of camp sites are within 3 km of the coastal zone. Moreover, increased volumes of water may result in landslides which can affect various types of infrastructure (DEA 2008).

The Danish government considers planning legislation an important means of reducing the negative socio-economic consequences of climate change. Regulations for the coastal zone already restrict new construction areas on open coasts. The Protection of Nature Act 1992 establishes a 300-m protection zone outside urban areas, where most new developments are prohibited, and the Planning Act 1992 defines a coastal planning zone that extends 3 km inland (Gibson 2003). The responsible national authorities continuously evaluate whether there is a need for a follow-up with further restrictions on new building in risk areas. Socio-economic analyses are included as a part of the decision process.

The Danish adaptation strategy allows site owners to raise the beach at their own cost by regular beach nourishment to combat coastal erosion. The same applies to channel dredging, where the amount dredged can be increased as required. Also in the case of reinforcing dikes/dunes or adapting harbour installations and ferry berths, which are relatively simple constructions, it will be possible for owners to adapt to ongoing climate change. Generally speaking, it is a land owner's own choice whether and how to protect themselves from flooding and erosion. Therefore, there are no general laws or regulations stipulating protection, or to what degree owners must or can protect themselves.

An important source of information is municipal planning, which reflects and adapts to the risks and opportunities brought by climate change. Each coastal town must develop an adaptation plan taking into account climate change impacts in the coastal zone. Municipalities are supported in this task by a National Task Force on climate change adaptation. The coastal adaptation plans focus on shoreline management.

However, the general approach of Denmark's climate policy is a stronger focus on mitigation than on adaptation, with no systematic consideration of sea-level rise in present planning policies (Fenger et al. 2008).

19.3.3 France

France has no national coastal management strategy. Coastal management is the responsibility of municipalities. The Loi Littoral imposes restrictions on urban development plans in coastal areas. These restrictions concern mitigation of coastal hazards, assurance of public access to the coast and protection of the environment. In 2013, the Conseil National de la Mer et des Littoraux was installed for the exchange of views and experience among concerned authorities and civil organisations; the Conseil will contribute to the development of a national coastal management strategy. Specific strategies for coastal adaptation in view of climate change are still in a study phase (Idier et al. 2013).

The French macrotidal coasts along the North Sea and the Channel are mostly fairly stable (Anthony 2013; Battiau-Queney et al. 2003). However, at the Pas de Calais a high rate of sea-level rise has been observed over recent decades (Héquette 2010). Some sites (Wissant, in particular) are subject to severe erosion, requiring the construction of seawalls to protect settlements. Climate change will exacerbate erosion and increase the instability of soft cliffs along the French Channel coast (Lissak 2012).

19.3.4 Germany

According to the National Adaptation Strategy on climate change (GFG 2008), coastal regions will be increasingly at risk from sea-level rise and changes in the storm climate. However, there is great uncertainty about the extent of future changes in sea level and the storm climate. One aspect of special importance is the potential danger to wetlands and low-lying areas and to regions with high damage potential, such as the port of Hamburg. There is also concern about saltmarsh ecosystems (Bauer et al. 2010), safety of the estuaries, erosion on coastlines and beaches, safety of shipping traffic and about the future development of the port industry (Reboreda et al. 2007).

The German North Sea coast is part of the Wadden Sea region. The Trilateral Wadden Sea secretariat has developed a climate adaptation strategy for the Wadden Sea, which has been endorsed by the three Wadden Sea countries—Germany, Denmark and the Netherlands (TWS 2014). This strategy comprises seven basic elements: Natural dynamics, Interconnectivity, Integration, Flexibility, Long-term approach, Site specific approach and Participation.

German coastal states are following a strategy mainly based on hard coastal protection measures against flooding, see Chap. 18. This coastline defence policy entails the risk of coastal squeeze on the seaward side, endangering important coastal ecosystems such as tidal flats (Wadden Sea), saltmarshes and dunes when the sea level rises (Sterr 2008).

The German adaptation strategy also attributes importance to 'soft' auxiliary measures such as research, knowledge dissemination, awareness raising and capacity building. Significant organisational and steering measures are also considered necessary. Above all, the National Adaptation Strategy (GFG 2008) places considerable emphasis on the importance of spatial planning, as a means of making a thorough assessment of all relevant adaptation needs within individual regions. Spatial planning provides a formal means through which all concerned parties are able to present their interests and cooperate in the development of a coherent spatial structure and an integrated programme of measures (Swart et al. 2009).

The national adaptation strategy is implemented at state (Länder) level.

19.3.5 Netherlands

As a low-lying country, the Netherlands is particularly vulnerable to sea-level rise and river floods. The damage costs of climate change impacts without adaptation are likely to be substantially higher than for all other North Sea countries combined (Richards and Nicholls 2009). Major impacts expected are increased flood risk in the historic towns of the downstream section of the Rhine-Meuse delta and shortage of fresh water to prevent salinisation of the polders, when river discharges are low. In wet periods, the present capacity of discharge sluices and pumping stations will be insufficient to control inland water levels, in particular in the lake IJssel. There are also concerns related to the loss of ecosystem values in the Wadden Sea and in the heavily modified south-western Delta basins. National study programmes have been launched for assessing other potential climate change impacts and for investigating possible adaptation measures (Oude Essink et al. 2010; Klijn et al. 2012).

The Dutch government has designated a Delta Commissioner, who coordinates a national programme for adapting the Dutch water infrastructure to climate change, in order to secure safety against high water and availability of sufficient fresh water. The Dutch adaptation policy follows a risk-based approach, as in the UK. New adaptation measures are implemented when, as a consequence of climate change and other developments, a tipping point is reached, that is, a point where previous adaptation measures are no longer sufficient to keep damage risks below a certain predefined threshold (Kwadijk et al. 2010).

The Water Test is an important legal instrument that requires regional and local authorities to ensure that water issues, including climate adaptation, are taken into account in spatial and land use planning, such that negative effects on the water system are prevented or compensated for elsewhere.

Sediment management (using sand nourishments) and *Making Space for Water* (realignment of dikes) are the major adaptation strategies for the coastal zone (Aarninkhof et al. 2010) and the lowland fluvial system (Menke and Nijland 2008), respectively.

19.3.6 Norway

Although most of the Norwegian coast is not very sensitive to sea-level rise, there is concern for the low-lying areas in the southwest, which are characterised by soft, erosive coasts. Along the western and northern coastlines, the extensive and well-developed infrastructure of roads, bridges, and ferries linking cities, towns, and villages is likely to be adversely affected by sea-level rise, particularly if this is concurrent with an increased risk and height of storm surges. The potential economic costs of rebuilding and relocating infrastructure and other capital assets in these regions may be considerable (Aunan and Romstad 2008).

The Norwegian Water Resources and Energy Directorate has developed a climate change adaptation strategy that includes monitoring, research and measures to prevent increased damage by floods and landslides in a future climate (NME 2009). Under the Planning and Building Act, municipalities are responsible for ensuring that natural hazards are assessed and taken into account in spatial planning and processing of building applications. Adaptation to climate change, including the implications of sea-level rise and the resulting higher tides, is an integral part of municipal responsibilities. To enable municipalities to ensure resilient and sustainable communities, the central government therefore draws up guidelines for the incorporation of climate change adaptation into the planning activities of municipalities and counties.

The premise of the Norwegian climate adaptation policy is that individuals, private companies, public bodies and local and central government authorities all have a responsibility to take steps to safeguard their own property. If appropriate steps are taken, public and private property are protected from financial risk associated with extreme weather events by adequate national insurance schemes.

19.3.7 Sweden

Rising sea levels are expected to aggravate coastal erosion problems in southern Sweden and increase flood risk along the western and southern coasts. As in the other Scandinavian countries, coastal protection policy in Sweden is mainly focused on spatial planning (EC 2009; OSPAR Commission 2009). The Nature Conservation Act of 1974 states that the first 100–300 m of the coast needs to be free of exploitation. Spatial plans of the different municipalities need to comply with this Act. In addition, new development projects must incorporate a certain safety margin to protect against future erosion or higher water levels. To reduce the vulnerability of Sweden's coasts and to adapt society to long-term climate change and extreme weather events, the Swedish Commission on Climate and Vulnerability made the following recommendations in 2007:

- Spatial planning should be considered the most important tool to protect against marine hazards;
- The risks of coastal erosion in built-up areas should be investigated, bathymetric information should be compiled and evaluated, and extreme weather warning systems should be expanded;
- Compensation and subsidy systems for preventive measures for coastal erosion in built-up areas should be developed;
- Areas of the coastal zones without private or public interests should not be protected but given back to the sea (managed retreat).

19.3.8 UK

Major perceived threats are related to coastal protection. Higher sea level and more intense and frequent storms due to climate change will increase damage to coastal defences.

Approximately one third of existing coastal defences could be destroyed if the level of expenditure on coastal defence does not keep pace with coastal erosion in the coming decades (DEFRA 2010, 2012). Extensive coastal erosion around parts of the UK, in particular along estuaries and the east coast, reduces intertidal area (OST 2004). Loss of intertidal areas (coastal squeeze) occurs mainly where hard defences are present. This in turn causes loss of land, property and coastal habitat, particularly saltmarshes and mud flats, which are also bird feeding grounds.

In the UK, policies for adaptation to sea-level rise are more advanced than in most European coastal countries (De la Vega-Leinert and Nicholls 2008). The UK coastal climate change adaptation policy is based on the appraisal method for dealing with the risks of climate change impacts, as outlined in the DEFRA Policy Statement (DEFRA 2009). This appraisal method is based on a comparison of different options (including the managed adaptive approach, the precautionary approach and the no-regret approach) with respect to costs, benefits and residual risk.

The *no-regret* approach is generally preferred where possible. The *managed adaptive* approach aligns with principles in *Making Space for Water*, which promotes a holistic and long-term approach for flood and coastal management, and reinforces existing climate change policy on ‘no-regret’ actions and longer term adaptation. This approach promotes flexibility in the appraisal options to respond to future change, during the whole life of a measure, as well as the uncertainties (DEFRA 2009). The *precautionary* approach may be adopted where it is not possible to adapt with multiple interventions on a periodic and flexible basis. Figure 19.3 illustrates the different approaches.

‘Managed retreat’ as an element of coastal management policy has thus far been applied mainly for ecological reasons and where the retreated area has relatively low value.

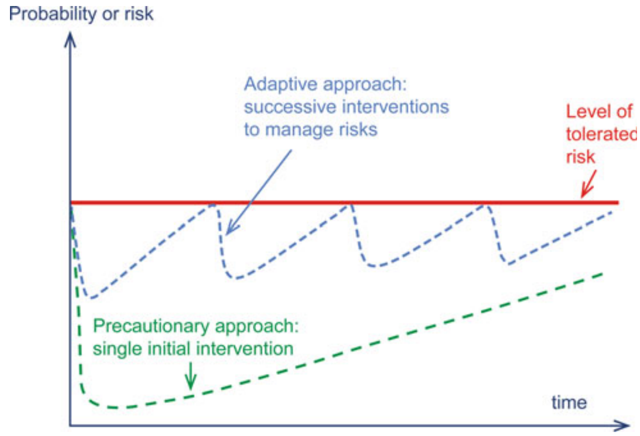

Fig. 19.3 Schematic representation of different adaptation approaches for the UK coastal zones (based on DEFRA 2009)

The Planning Policy Statement (DCLG 2010) obliges local authorities to develop climate adaptation policies and to report on progress. The Marine (Scotland) Act[2] stipulates that forthcoming national and regional marine plans should set objectives relating to the mitigation of, and adaptation to, climate change. An independent UK body, the Adaptation Subcommittee, assesses the preparedness to meet the risks and opportunities of climate change.

In this context adaptation is required to include protecting and restoring marine habitats to increase their resilience to climate change. More than 25 % of English waters is designated as Marine Protected Areas and managed as a network of habitats to aid the movement of species affected by climate change and to decrease threats such as overfishing. The National Heritage Protection Plan sets out how England’s landscapes, archaeological sites and historic buildings will be protected from the impacts of climate change. This includes actions such as the continuation of ‘Rapid Coastal Zone Assessment Surveys’ that record and assess the risk to heritage assets on the coast (DEFRA 2013).

19.4 Governance Issues and Dilemmas for Adaptation

This section compares the various adaptation strategies adopted by the North Sea countries, as well as the dilemmas arising during their implementation and the means by which these dilemmas may be addressed.

19.4.1 Top-Down and Bottom-Up Strategies

The North Sea countries are following different approaches for adapting to change in the coastal zone. In Germany, the Netherlands and Belgium, implementation is steered by national or regional government, whereas in the UK, Sweden, Norway and Denmark, implementation is delegated to local authorities aided by civil organisations and private stakeholders.

Richards and Nicholls (2009) estimated the adaptation costs required for avoiding extra damage related to sea-level rise, and compared them to the costs actually spent on coastal defence measures. They estimated that in Germany, the Netherlands and Belgium more money is presently spent on coastal defence than the avoided damage costs. This can be imputed to a different governance culture, but also to a higher flood-risk awareness and higher standards for acceptable risk. Current adaptation plans in these countries involve large infrastructural projects, with planning

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[2] http://www.scotland.gov.uk/Topics/marine/seamanagement/marineact.

procedures similar to other infrastructural projects. National and regional governments bear almost all the costs. In the UK, Sweden and Denmark, governmental steering of adaptation is more indirect, and operates through regulation and guidance. Local and private initiatives play an important role in the implementation plans. In the UK, many local institutions and associations are actively involved in coastal planning and adaptation through the Shoreline Management Planning process.

Several studies (EC 2011; IPCC 2012) have found that national systems play a crucial role in countries' capacity to meet the challenges brought by the observed and projected trends in exposure, vulnerability, and weather and climate extremes. Effective national systems comprise multiple actors from national and regional governments, the private sector, research bodies, and civil society including community-based organisations. Organisations beyond the state are increasingly playing a role in planning and risk management.

Governance theorists highlight different 'modes' of governance, including hierarchies, networks, markets, adaptive management and transition. Coastal management in the North Sea region shares many characteristics with the 'network' mode of governance, focusing on participation, using non-regulatory approaches to achieve progress, and the involvement of multiple actors. However, the evaluation and 'lesson drawing' components have been assessed as somewhat weak (Stojanovic and Ballinger 2009). A key analytical question is which modes of governance have the best 'fit' for the challenges of climate adaptation? (Young et al. 2008).

19.4.2 Public Participation

The recent OURCOAST inventory of coastal management practices in Europe (EC 2011) shows that awareness of coastal and marine issues by the general public and the responsible authorities is strongly stimulated when the public is involved in the development of adaptation strategies. Adaptation strategies are more effective when they are informed by and customised to specific local circumstances and when there is a broadly shared understanding of long-term coastal change. Public participation leads to less conflict between coastal managers or coastal developers and other involved parties. Local populations document their experiences with the changing climate, particularly extreme weather events, in many different ways, and this self-generated knowledge can uncover existing capacity within the community and important current shortcomings. Local participation and community-based adaptation lead to better management of disaster risk and climate extremes. Improvements in the availability of human and financial capital and of disaster risk and climate information customised for local stakeholders can enhance community-based adaptation (IPCC 2012).

Adaptation strategies can widely differ, according to the values to be protected, when, to what extent, how and by whom. The choice between different adaptation strategies is basically a political choice. Valuing coastal assets is intrinsically subjective, even if attempts are made to express some values, such as ecosystem services, in monetary terms. These attempts do not result in generally agreed answers on how to mutually rank different types of damage: loss of human life, loss of economic assets (including ecosystem services), loss of biodiversity and loss of cultural values.

According to the EEA (2006), there is often a fundamental conflict between protecting socio-economic activity and sustaining the ecological functioning of coastal zones in Europe under conditions of rising sea level—a conflict that cannot be resolved by technical or scientific means. Integrated, long-term coastal management should not be exclusively orientated to physical planning and technical solutions, but to combinations of social and physical management mechanisms. The policy and governance strategies for coastal conflict and natural resource management should therefore be improved by developing adaptive, participatory and multi-scale governance (Stepanova and Bruckmeier 2013).

Prerequisites for public participation in coastal adaptation strategies include: political legitimacy through securing broad political support; a process-driven approach in an inclusive, voluntary and culturally sensitive manner; the empowering of historically disadvantaged individuals, groups and communities; building partnerships to provide the basis upon which stakeholders can learn about and appreciate the interest of others; deepening public deliberation through alternative forums and participatory methodologies; and promoting innovation, reflection and feedback in response to changing circumstances and stakeholder interests (Henocque 2013).

Social Impact Assessment (SIA) has been proposed as an instrument to reduce likely future expenditure by the early identification and resolution of potential issues that could otherwise lead to litigation, delays to approval, costs in the form of managing protest actions, and business lost through reputational harm (Vanclay 2012). However, there is little practical experience with SIA to date.

19.4.3 Uncertainty and Awareness

North Sea countries will have to face the implications of climate change and some impacts are already occurring. However, separating the impacts of climate change from change resulting from other natural or human causes is far from obvious. This is illustrated by a study of past ecosystem shifts in the North Sea region. There is evidence, for instance, that these regime shifts are related to decadal-scale fluctuations in the North Atlantic Oscillation index (Kröncke et al. 2013). The full long-term impacts of climate change are still uncertain, especially the question as to when they will occur. For instance, present data do not yet show clear evidence for an increase in the average rate of sea-level rise in the North Sea region (NOAA 2015).

Uncertainty is a serious (perhaps the most serious) obstacle to raising public awareness and to getting climate adaptation high on the political agenda, compared to issues with a more immediate impact (EEA 2014). Uncertainty about the possible impacts of climate change is not the only reason for this. The fact that the greatest impacts are related to exceptional extreme events, plays also a role. According to an enquiry among policymakers, the occurrence of an extreme weather event is presently the most important trigger for progress in climate adaptation (EEA 2014).

While some countries—especially those with low-lying coasts—are traditionally alerted to sea-level rise and flooding, awareness is still low in other countries (Ruprecht Consult 2006). Due to the absence of recent coastal flood disasters in North Sea countries there is a risk of decreasing societal awareness and support for protection measures in specific, flood prone areas. This highlights the need and importance of risk communication and awareness raising to ensure the continuity and support for coastal risk management strategies (Safecoast 2008).

In the Netherlands, risks associated with climate change are made more tangible through tipping-point analysis. This involves testing the robustness of existing policies for addressing anticipated climate-driven changes in environmental conditions, such as temperature, precipitation, and sea level. ‘Tipping points’ are the thresholds in future environmental conditions at which existing policies fail to keep risk (potential damage) within acceptable limits. Awareness of these tipping points guides policymakers to prepare the necessary adaptation strategies, even if uncertainty remains regarding the timing of required adaptations (Kwadijk et al. 2010).

Greater awareness can also be pursued by internalising costs. Development projects in the coastal zone often increase climate change adaptation costs. According to the EUROSION study (Doody et al. 2004), the costs of reducing coastal risks are mainly supported by national or regional budgets in the North Sea countries and almost never by the developers or the owners of assets at risk. Only in Denmark and Sweden are adaptation costs (partly) supported by owners and the local community. Hence, risk assessment is hardly incorporated in decision-making processes at the local level and risk awareness of the public is poor. The impact, cost and risks associated with coastal development are better controlled through internalising adaptation costs in planning and investment decisions: thus an appropriate part of the risks and risk mitigation costs is transferred to the direct beneficiaries and investors. Risk monitoring and mapping is a prerequisite for incorporating risk into planning and investment policies. The distribution of risks and costs requires due consideration of the interests of all stakeholders in order to guarantee social justice (Safecoast 2008; OST 2004).

19.4.4 Risk-Based Adaptation

The largest climate change impacts in the coastal zone result from extreme events which have a low probability of occurrence within a given time interval. The concept of risk, defined as the product of probability of occurrence and resulting damage, provides an objective measure for the need to adapt to such impacts. By evaluating what damage is avoided at what costs, informed choices can be made among different adaptation strategies. Coastal adaptation strategies of the North Sea countries are increasingly based on risk management considerations. Uncertainty in the probability of occurrence and uncertainty in the extent of damage can be incorporated in risk estimation—for instance, by defining probability distributions for all variables and using a Monte Carlo method. The application of the risk concept in adaptation strategies is limited, however, by the difficulty of quantifying uncertainty in the probability of occurrence and by the more fundamental difficulty of predicting possible damage caused by rare extreme events.

A further complication arises when a choice has to be made among different possible adaptation measures: which temporal and spatial scales must be considered when these measures are evaluated through ranking methods such as cost-benefit, cost-effectiveness or multi-criteria analyses? This choice strongly influences the results. This complication is enhanced by uncertainty about the future in general. How are present values affected by other future global or local change, in addition to climate change? The combination of these different sources of uncertainty is sometimes termed ‘deep uncertainty’.

Scenarios provide a way to deal with limitations related to quantifying uncertainty (the probability that some damage will occur) and to quantifying possible damage (loss of certain values). Scenarios describe different futures that can be imagined. These scenarios should be internally consistent, but need not necessarily be expressed in terms of probability and money. Their main function is to open those who are involved in climate adaptation to the wide spectrum of situations and adaptation options that should be considered. Scenarios help in avoiding suboptimal sector approaches and a unilateral focus on certain adaptation options, which are major shortcomings of present coastal adaptation strategies in the North Sea countries (EEA 2005). But scenarios do not of course, in themselves, answer the question as to which adaptation strategy of the options available should be preferred.

The EEA (2007) has provided methodological guidance for quantifying and costing climate change impacts at the global and regional scale. These methods include: treatment of scenarios (both climate and socio-economic projections); issues of valuation (market and non-market effects); indirect effects on the economy; approaches taken to spatial and temporal variation; uncertainty and irreversibility (especially in relation to large-scale irreversible events); and coverage (which climate parameters and which impact categories are included). However, there is limited application of exploratory scenarios at the local level and those applications involving local stakeholders are even rarer. This highlights the need for pilot projects to evaluate, demonstrate and disseminate the effectiveness of scenario approaches to the ICZM community, including predictive, exploratory, and normative scenarios (Ballinger and Rhisiart 2011). To date, few projects have attempted to downscale SRES scenarios to the regional and local level in the North Sea region (Andrews et al. 2005; Holman et al. 2005a, b; Nicholls et al. 2006).

19.4.5 Adaptation Pathways

There is broad agreement that adapting to the impacts of climate change is inevitable and that preparatory actions should already be initiated. But once it becomes clear that a fundamental revision of present coastal policies is needed, questions arise as to which actions are most appropriate to cope with the impacts of climate change at the long term. Revised policies need to deal not only with uncertainty related to the future impacts of climate change, but also with uncertainties related to future social and economic developments. A blueprint plan is inadequate, as the future can unfold differently from what is anticipated. Actions that are appropriate for the foreseeable future could turn out to be inadequate for the long term and could even hinder actions that may become necessary later.

One way of dealing with this problem of ‘robust decision making’ is the strategy of adaptive pathways (Hallegatte 2009). According to this strategy, adaptation pathways are developed that comprise different sets of successive adaptation actions. Each pathway leads to successful long-term adaptation within a particular scenario of climate change and socio-economic development. Analysis of the different pathways enables the selection of short-term actions that are suitable (no adverse lock-in effects) within different scenarios. The most promising actions are those with the best performance in terms of societal benefits and costs. The exercise of pathway definition and analysis is repeated when new follow-up actions become needed; the lessons of the first actions (‘learning-by-doing’) as well as the latest knowledge of climate change and socio-economic development serve as input. A sophisticated version of this approach (‘strategy of dynamic adaptive policy pathways’) was used to underpin the Dutch Delta programme for adaptation to climate change (Haasnoot et al. 2013). A similar method has been developed by Sayers et al. (2013) and applied to the Thames Estuary, UK (McGahey and Sayers 2008).

19.4.6 No-Regret Adaptation Strategy

The measures envisioned in the North Sea countries for adaptation to climate change are similar. Preference for certain measures depends on the nature and seriousness of the climate change threats and on social acceptance. In all North Sea countries there is consensus that adaptation to climate change is inevitable and that some action is already required. Climate change projections for the economic life cycle of coastal infrastructure are currently incorporated in the development of long-term investment plans. This is done, for instance, by adjusting design criteria for the renovation of coastal protection works (see Chap. 18). Spatial planning is recognised as a key instrument for the integration of adaptation measures in a broader coastal management policy and for taking into account developments at larger temporal and spatial scales. Spatial reservations are made for future reinforcement or realignment of coastal defences, and set-back lines for new buildings in the coastal zone are revised. In most North Sea countries, studies are undertaken on how far adaptation should go and whether investment can be postponed. At present, no major public investments are being made with the sole purpose of long-term climate change adaptation.

There is an increasing preference for flexible measures with as much as possible a no-regret character. Potential low-regret measures include early warning systems; risk communication between decision makers and local citizens; sustainable land management, including land use planning; ecosystem management and restoration; improvements to water supply, sanitation, irrigation and drainage systems; climate proofing of infrastructure; development and enforcement of building codes and better education and awareness (IPCC 2012). Such measures deliver additional benefits, such as opportunities for tourism, recreation, nature development and other ecosystem services.

Beach and shoreface nourishment and wetland restoration are examples of no-regret measures already practiced in North Sea countries. They are often part of a broader water management strategy that includes land-use planning in the upstream catchment area. Such measures are implemented step-wise, allowing for adjustment when better knowledge of the impacts of climate change impacts becomes available. They also respond to the insight that natural dynamics generally offer greater long-term resilience (self-regulating capacity) against climate change impacts than hard man-made structures (Dronkers 2005).

An important notion in this context is that present levels of greenhouse gases already imply a commitment to sustained adaptation for several centuries to come (Nicholls et al. 2007; Wong et al. 2014). In some cases, this might lead to more radical strategies, such as the wholesale re-location of coastal settlements, or design of housing infrastructure which can cope with being regularly inundated.

19.4.7 Knowledge and Monitoring

Adaptation efforts benefit from iterative risk management strategies because of the complexity, uncertainties, and long time frame associated with climate change (IPCC 2012). An iterative risk management strategy consists of an iterative process of monitoring, research, evaluation, learning, and innovation. Addressing knowledge gaps through enhanced observation and research reduces uncertainty and helps in designing effective adaptation and risk management strategies.

Because uncertainty is a major obstacle to preparing for climate change adaptation, more reliable predictions of climate change and its impacts are needed (EEA 2014). Many studies address climate change prediction at the global scale. However, there are indications that global-scale projections of climate change may not be representative for the North Sea region, especially in relation to the characteristics of the North Atlantic Gulf Stream (Nicholls et al. 2007). Better understanding of the coupled ocean-atmosphere system for the North Atlantic is therefore a highly relevant and urgent research topic (Vellinga and Wood 2007; Rahmstorf et al. 2015).

Monitoring is also essential for a better understanding of climate change impacts in the North Sea coastal and marine zone. Many data are collected within the different North Sea countries, by public agencies, research institutes and private companies. However, the European Commission (EC 2010) notes that “There are restrictions on access to data, and on use and re-use. Fragmented standards, formats and nomenclature, lack of information on precision and accuracy, the pricing policy of some providers and insufficient temporal or spatial resolution are further barriers.” It may be expected that the situation will improve by progress in the implementation of the EU Water Framework Directive, the EU Marine Strategy Framework Directive and the EMODnet marine data network (EC 2012).

A better coordinated and more consistent approach to marine monitoring is essential for a proper analysis of change in the coastal and marine system. This analysis should focus on establishing cause-impact relationships, which make it possible to distinguish climate change impacts from natural variability and other impacts. Monitoring data are often not directly fit for policy evaluation; translating data into indicators pertinent to policy making is a further subject of special attention (Breton 2006; Martí et al. 2007; EEA 2012). This kind of knowledge is crucial for informing policy and the general public and for developing the adaptive capacity of institutions and wider society.

19.5 Summary and Conclusions

1. Strategy

All North Sea countries have developed a climate adaptation strategy. In these strategies special consideration is given to the coastal zone.

2. Perceived Risks

The North Sea countries consider flooding by the sea and coastal erosion as major climate-related coastal risks.

3. Aggravation of Existing Trends

Several studies show that climate change will enhance erosion and habitat loss that occur already, as a result of existing pressures related to use and development of the coastal zone.

4. Governmental Steering

In all North Sea countries, actors at national and regional level have been designated for initiating and coordinating adaptation to climate change. In the Netherlands, the country with the highest number of potentially threatened people, a special governance mechanism, the Delta Commissioner, has been created.

5. Centralised Versus Decentralised Implementation

In Germany, the Netherlands and Belgium coastal adaptation is steered by national and regional programmes and plans. In the UK, Denmark, Sweden and Norway, regional and local governments are responsible for adaptation; coastal communities have the duty to develop adaptation plans and to report (in the UK) on the implementation progress.

6. Public Participation

In all North Sea countries, adaptation plans are subject to public consultation. The UK and the Scandinavian countries pursue active public involvement by accruing adaptation responsibilities to private stakeholders.

7. Risk-Based Adaptation

In all North Sea countries some form of risk assessment (comparison of adaptation costs with costs of avoided risks) is considered for the prioritisation of adaptation measures. However, at present there is no generally accepted methodology.

8. Uncertainty

Uncertainty about the extent and timing of climate-driven impacts is a major obstacle to political and public mobilisation on the issue of climate adaptation. Different methods to deal with uncertainty of climate impacts are being developed, involving scenario development, tipping point analysis and more robust decision-making techniques (such as adaptive pathways).

9. No-Regret Measures

In view of the uncertainties, adaptation plans focus on no-regret measures. The most considered measures in the North Sea countries are spatial planning in the coastal zone (set-back lines), wetland restoration, coastal nourishment and reinforcement of existing protection structures.

10. Monitoring and Research

The climate of the North Sea countries is strongly influenced by the North Atlantic Oscillation (NAO) and the Gulf Stream. Better understanding of ocean-atmosphere dynamics in the North-Atlantic region is important to reduce the uncertainty in climate predictions for the North Sea region. The difficulty of identifying the climate-related component in observed changes of physical and biological parameters in the coastal zone is a critical obstacle to obtaining a widely shared understanding of the urgency of adaptation. A dedicated coastal observation network is not yet in place in the North Sea region.

Box 1

Working definitions of key terms used within this chapter

Governance: The exercise of political, economic and administrative authority in the management of a country's affairs at all levels. Governance comprises the complex mechanisms, processes, and institutions through which citizens and groups articulate their interests, mediate their differences, and exercise their legal rights and obligations (UNDP 1997).

Integrated Coastal (Zone) Management: A continuous process of administration, the general aim of which is to put into practice sustainable development and conservation in coastal zones and to maintain their biodiversity. This involves the coordinated management and synchronised planning of multiple issues and areas of overlapping interest (EC 1999). In Europe this has been characterised by the implementation of the EU Recommendation on Integrated Coastal Zone Management (cf synonyms ICM, ICZM, CZM, ICAM.).

Shoreline Management Planning: Strategic approach to managing the risks of coastal flooding and erosion, especially as they relate to changes in coastal processes (DEFRA 2009).

Coastal Adaptation: Efforts and actions (in the coastal zone) targeted at vulnerable systems to deal with actual or expected problems with the objective of moderating harm (IPPC 2001).

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