Developing sustainable coastal areas: A comparison between the Netherlands and the United Kingdom

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A U T H O R S I N F O

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A B S T R A C T

In this paper we compare current adaptation measures and decision-making processes, in accordance with the EU Floods Directive, in vulnerable coastal regions of the Netherlands and the United Kingdom. For both countries causes of climate change, current and future effects on the environment, impacts for society and responses of the society to the growing challenges are analysed and compared using the Drivers-Pressures-State-Impact-Responses (DPSIR) framework. The analysis shows that increasing flood risk and coastal erosion are the main problems for society and environment. The Netherlands and the United Kingdom follow similar decision-making paths to implement adaptation measures, yet due to geographical and geological differences, current adaptation measures in these countries are not overall the same. However, in order to generate proactive adaptation measures that take into account natural processes and stimulate prosperity levels, both countries use a transdisciplinary, multi-stakeholder approach.

K E Y W O R D S (in alphabetical order): *Climate change; DPSIR; European Floods Directive; Integrated Coastal Zone Management; The Netherlands; United Kingdom.*

1. Introduction

Coastal areas, constituting the demarcation between the land and the sea, are very complex systems affected by both terrestrial and marine processes. Coastal regions are characterized by high population densities and accompanying (conflicting) economic, social and environmental interests (Lescrauwaet et al. 2006). Furthermore, the possible effects of climate change put extra pressure on coastal regions (Nicholls et al. 2007).

In the last few decades, European coastal regions were traditionally protected by hard flood protection measures such as sea walls (called dikes), dams, tidal barriers, sheet pile walls, groynes, and floodgates (Linares 2012). In order to develop sustainable European coastal regions, it is of great importance to follow integrated and participatory approaches. This includes to balance environmental, economic and social interests by taking a long-term view into account, to develop coastal infrastructure and spatial planning that are multi-functional and adaptable to changing conditions such as the effects of climate change, and to work in line with natural processes (da Vriend et al. 2014; Lescrauwaet et al. 2006). Hard measures alone will not be sufficient to create sustainable coastal areas. Furthermore, instead of using only reactive mitigation measures (attempts to reduce greenhouse gas (GHG) emissions and impacts of climate change on a global scale), it is crucial to develop proactive adaptation measures that take into account natural processes and stimulate prosperity levels (reduce vulnerability by reducing risk and impacts on local to regional scale) (da Vriend et al. 2014; Fischer et al. 2007; van Wesenbeek et al. 2014). Regarding a sustainable coastal development in accordance with Recommendation 2002/413/CE regarding the implementation of Integrated Coastal Zone Management (ICZM), the European Commission approved the EU Floods Directive (Directive 2007/60/EC) on the assessment and management of flood risks. The Floods Directive, linked to the Water Framework Directive, aims to reduce and manage the risks that floods pose to human health, the environment, cultural heritage and economic activity (Directive 2007/60/EC).

The Netherlands and the United Kingdom have a long history of coping with floods. Traditionally, the flood management policies of both countries used technological solutions to reduce flood risk by focusing on the construction of hard defence measures (Brown and Damery 2002; van Wesenbeeck et al. 2014). To better understand the changing views with respect to coastal protection and climate change, we analyse how two different European North Sea regions located in the Netherlands (Zeeland, Zuid-Holland, Noord-Holland, and Friesland) and the United Kingdom (estuaries of the Greater Thames area) are affected by the changes of climate change and how they respond to them. The comparison is done by using the Drivers-Pressures-State-Impact-Responses (DPSIR) framework (EEA 1999). The framework integrates natural and socio-economic information into a broad context of causality. The strength of the framework is that management problems can be analysed by structured cause-effect relationships: external drivers lead to pressures on natural and societal systems, the pressure affects the state of these systems, resulting in impacts which need (policy) responses (Ness et al. 2010). Although the DPSIR framework offers a generalized context, there is interest in its application to evaluate sustainability in European coastal regions and to support the decision-making processes concerning the management of these regions (e.g. Atkins et al. 2011; Borja et al. 2006; Cave et al. 2003; Elliot 2002; Ness et al. 2010; Pirrone et al. 2005; Wamsley 2002).

The central aim of this paper is to identify suitable measures to adapt to the threats arising from climate change in the vulnerable areas of the coastlines of the United Kingdom and the Netherlands. To meet this aim, we determine (1) which threats and challenges arise or are expected to arise from climate change in the two areas (drivers and pressures), (2) which adaptation methods exist (state), (3) what the advantages, disadvantages, challenges and risks of these measures are (impact), and (4) what measures to deal with the problems are applied in the two regions with their specific social, ecological and political situations (response). We conclude with lessons that can be learned, based on the comparison of the two coastal regions, to counteract possible negative effects of climate change and to secure sustainable development in the future by combining traditional and new approaches.

2. Materials and methods

To analyse and structure the data from our literature review, the DPSIR -framework was applied to both case study regions. Therefore, socio-economic drivers, environmental pressures and the state of the coastal areas are determined and resulting impacts on human well-being as well as governmental and societal responses are delineated (Karageorgis et al. 2005). However, to attain the central aim of this research, the main focus is on the impacts that are related to climate change and the accompanying responses in accordance with the Floods Directive and ICZM. The final DPSIR framework provides the ability to compare the policy processes and the effectiveness of the adaptation measures of the two coastal regions towards sustainable development.

2.1 Case study areas

The comparative case study takes the Netherlands´ coastal provinces of Zeeland, Zuid-Holland, Noord-Holland and Friesland, and for the United Kingdom the region of South East England, including East Anglia, Essex, Kent and Outer London into account. Especially adaptation measures are taken on regional scale (Fischer et al. 2007). These regions deliver examples how particular programmes and policies work, and provide literature about quantitative and qualitative data for investigating similarities and differences how to develop sustainable coastal areas.

2.1.a The Netherlands

The geological development of the Netherlands was determined by a combination of erosion, transport and sedimentation processes. The Netherlands is located in the delta of the Rhine and Meuse rivers (de Moel et al. 2011).

The geological appearance of the Netherlands forced the floodplain inhabitants to live on artificial dwelling mounds since the 7th and 8th centuries. Additionally, the settlements were protected by small ring dikes. Increasing sea levels and population led to the building of a closed dike line, which started around 1100 A.D. (Knottnerus 2005). Today, about 65% of the population lives in areas that are protected by flood defences (de Moel et al. 2011). Furthermore, socio-economic developments in coastal regions have boomed in recent decades thus currently 80% of the GNP is potentially threatened by floods (Taal et al. 2006). Figure 1 shows the four coastal provinces of Zeeland, Zuid-Holland, Noord-Holland, and Friesland.

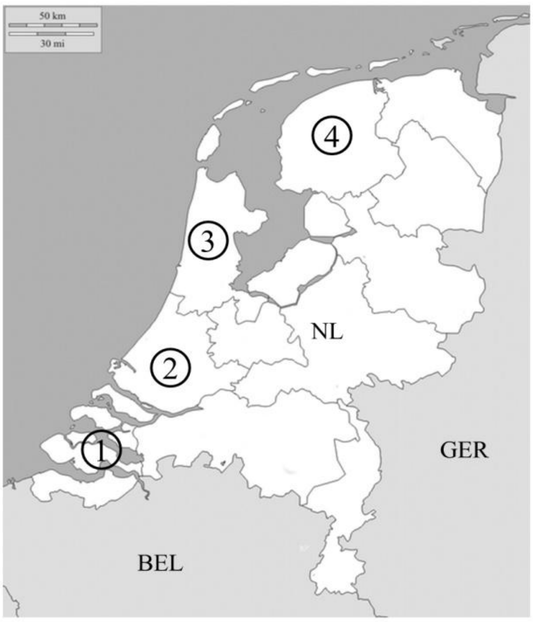

Figure 1: Coastal provinces of the Netherlands: 1) Zeeland, 2) Zuid-Holland, 3) Noord-Holland, and 4) Friesland.

2.1.b The United Kingdom

The South East of England is characterized by estuarine shores, such as the Greater Thames Estuary and the estuaries in Essex. These flat and low-lying estuaries comprise ecologically important coastal lagoons, salt marshes, wet grasslands and reedbeds (Esteves et al. 2014). Seventy five per cent of the property value that is located near the coastline of the United Kingdom is centred in London and the surrounding Thames tidal flood plain (Bingley et al. 2008). This study's focus will be on the region of South East England (Figure 2), including the counties of Kent, Essex, East Anglia and Outer London which belong to the most vulnerable regions.

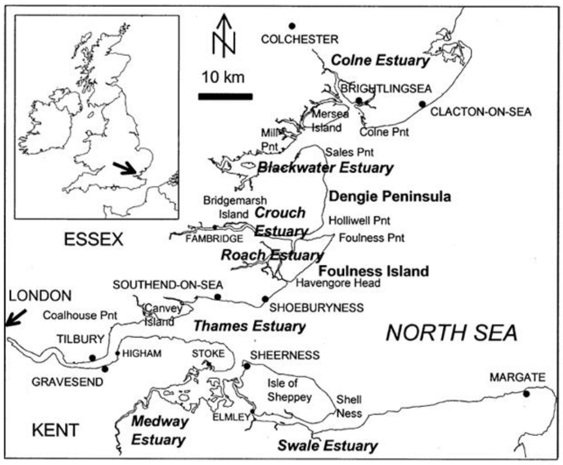

Figure 2: *Estuaries of the Greater Thames area in the United Kingdom (van der Wal and Pye 2004).*

2.2 The DPSIR framework applied to the case study regions

In 1999, the European Environmental Agency (EEA) developed the 'Drivers-Pressures-State-Impact-Responses' (DPSIR) framework, based on the previously developed 'Pressure-State-

Response' (PSR) framework of the Organisation for Economic Co-operation and Development (OECD) (Camanho et al. 2010; Martins et al. 2012). The DPSIR framework is based on a concept of causality (Pirrone et al. 2005) and describes the relationships between human activities and the environment. As described in Carr et al. (2007), the 'drivers' in DPSIR comprise driving forces, that are factors or processes which shape human activities and have effects on the environment (such as the use of fossil fuels or change in population). The 'pressures' directly result from the 'drivers' and are described by human activities impacting the environment (such as GHG emissions or land use). 'Pressures' influence the 'state' of the environment and condition future trends as well. The 'impacts' describe changes in the state that influence human well-being (such as impacts of climate change). On institutional level, efforts undertaken to address the changes in 'state' are called 'responses' (such as fulfillment of policy goals or projects to find innovative solutions).

In general, the DPSIR is a useful framework to capture problems caused by human activities and to identify responses as sufficient solutions (Pironne et al. 2005). For example, the DPSIR approach has been used to identify the impacts of socio-economic developments on the state of European marine waters in order to assess the most suitable responses in accordance with the Water Framework Directive and Floods Directive objectives (e.g. Borja et al. 2006; Karageorgis et al. 2005; Pirrone et al. 2005). As proposed by Atkins et al. (2011), a DPSIR cycle (Figure 3), which highlights the multiple interactions between the individual elements of the DPSIR framework, has been used in this paper, and the different steps of the DPSIR framework are based on the definitions of Carr et al. (2007), EEA (2002), and FAO (1999).

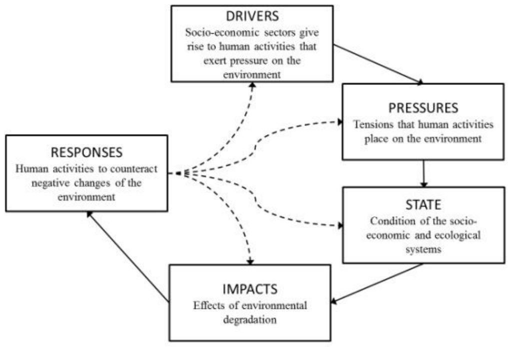

Figure 3: *Causal links in the generic DPSIR framework.*

In order to compare the case study regions, a set of indicators (Table 1) was used to analyse the different components of the DPSIR framework. The indicators have been selected because GHG emissions and intensification of land use are two major pressures making a sustainable development of coastal areas necessary. These pressures are driven by human needs (here described by the demand of fossil fuels and population balance and density). The state of the environment is affected – climate change as well as coastal erosion- and hard defence measures lead to impacts such as groundwater salinization, disappearance of salt marshes, biodiversity loss and water management challenges. The society and institutions need to find new ways to adapt to these impacts and respond: in terms of recognition that climate change has an impact, doing scientific research, following goals of ICZM and the Flood Directive and increase the awareness of the society. These indicators are used as qualitative or quantitative parameters to characterize the current condition of an environmental aspect or its change over time. We analysed statistical data to compare the different indicators provided by i.e. Eurostat or the World Bank. Whenever possible, regional data were used. In the absence of regional data, national data of the United Kingdom and the Netherlands have been analysed. Furthermore, we screened policy documents to analyse the flood risk management strategies provided by i.e. the Government of the Netherlands or Environmental Agency and provided practical response-examples from different national institutions.

3. Results

Figure 4 illustrates the relationships and multiple interactions of the DPSIR elements. The drivers of change lead to pressures which influence the current state of the case study regions. As described in detail in the following paragraphs, this causes impacts on habitats and water management issues. In order to cope with these impacts, (policy) responses are necessary to tackle possible impacts of climate change, and to secure and develop innovative flood protection measures to make settlements and land use possible.

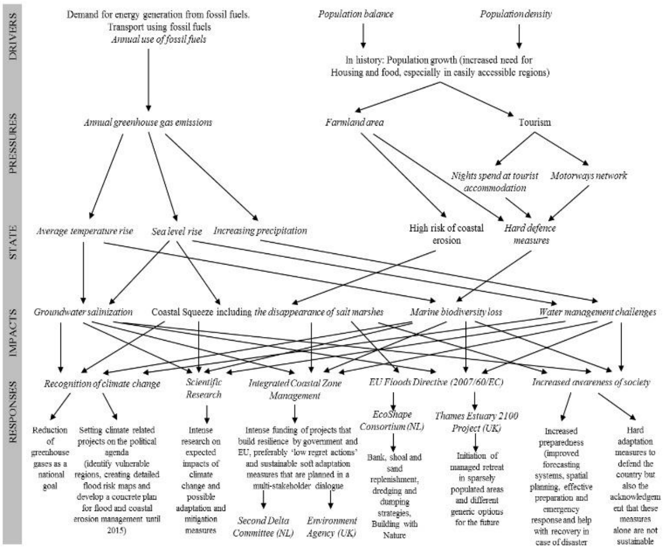

Figure 4: *Multiple interactions between DPSIR elements applied to the case study areas. Italics delineate the indicators.*

3.1 Drivers

The indicator *annual use of fossil fuels* is directly related to the global emissions of GHG that enhance climate change (IPCC 2014). The fossil fuel energy consumption of the Netherlands comprised 91.5%, and of the United Kingdom 85.2%, of the total annual energy consumption in the year 2012 (World Bank 2015a). These percentages are relative since the actual annual final consumption in the United Kingdom is almost twice as high as the annual final consumption in the Netherlands (Table 2).

Table 1: *Selected indicators to identify the major DPSIR elements for the case study areas.*

Drivers	Annual use of fossil fuels	Population balance	Population density		
Pressures	Annual greenhouse gas emissions	Farmland area	Nights spent at tourist accommodation	Motorways network	
State	Average temperature rise	Sea level rise	Increasing precipitation	High risk of coastal erosion	Hard defence measures
Impacts	Groundwater salinization	Coastal squeeze including disappearance of salt marshes	Marine biodiversity loss	Water management challenges	
Responses	Recognition of climate change	Scientific research	Integrated Coastal Zone Management, Second Delta Committee (NL), Environment Agency (UK)	EU Floods Directive (2007/60/EC), EcoShape Consortium (NL), Thames Estuary 2100 project (UK)	Increased awareness of society

Table 2: *Energy balances (2012) of the United Kingdom and the Netherlands in thousand tonnes of oil equivalent (according to International Energy Agency 2015a; 2015b).*

Energy balances 2012 (in thousand tonnes of oil equivalent)	**Coal**	**Crude oil**	**Oil products**	**Hydro**	**Geo-thermal and solar**	**Biofuels and waste**	**Elec-tricity**	**Heat**	**Total**
United Kingdom									
Total primary energy supply[a]	38873	73158	-14665	455	1941	6753	1036	0	192231
Total final consumption[b]	2377	0	51716	0	154	1967	27311	1232	127570
Industry	1764	0	4018	0	0	416	8412	795	23970
Transport	9	0	37579	0	0	930	352	0	38870
Other[c]	604	0	3707	0	154	621	18547	438	57857
Non-energy use[d]	0	0	6412	0	0	0	0	0	6873

Table 2 (*continued*)

Energy balances 2012 (in thousand tonnes of oil equivalent)	**Coal**	**Crude oil**	**Oil products**	**Hydro**	**Geo-thermal and solar**	**Biofuels and waste**	**Elec-tricity**	**Heat**	**Total**
The Netherlands									
Total primary energy supply[a]	8199	60415	-29492	9	500	3675	1471	0	78578
Total final consumption[b]	878	4405	22490	0	37	861	9157	1917	61051
Industry	645	2275	511	0	0	87	2985	1057	12534
Transport	0	0	10867	0	0	335	154	0	11373
Other[c]	11	0	795	0	37	439	6017	860	22468
Non-energy use[d]	222	2130	10317	0	0	0	0	0	14675

[a] Total primary energy supply is made up of the sum of indigenous production, import, export, international marine and aviation bunkers and stock changes (i.e. the difference between opening stock levels at the first day of the year and closing levels on the last day of the year).

[b] Total final consumption is the part of the total primary energy supply that is consumed after transfers, transformation processes and energy industry own use.

[c] Energy for residential, commercial and public services, agriculture, forestry, fishing and non-specified.

[d] Non-energy use comprises fuels that are used as raw materials in the different sectors and are not consumed as a fuel or transformed into another fuel.

Table 3: *Population balance and population density between 2002 and 2013 of the Netherlands and the United Kingdom (according to Eurostat 2015d; 2015e; World Bank 2015b).*

Population	**2002**	**2013**		**2002**	**2013**
The Netherlands	16,105,285	16,779,575	United Kingdom	59,239,564	63,905,297
Friesland	636,184	646,862	East Anglia	2,188,252	2,419,478
Noord-Holland	2,559,477	2,724,300	Essex	1,620,694	1,747,002
Zuid-Holland	3,423,780	3563,935	Kent	1,585,163	1,756,588
Zeeland	377,235	381,077	Outer London	4,474,732	5,052,557
Population density (persons per km^2)	**2002**	**2013**		**2002**	**2013**
The Netherlands	478	498	United Kingdom	245	264
Friesland	190	194	East Anglia	175	193,3
Noord-Holland	960	1025	Essex	443	478
Zuid-Holland	1214	1272	Kent	426	472
Zeeland	209	214	Outer London	3578	4058

Table 3 delineates the *population balance* and the *population density* of the provinces and the counties that comprise the coastal regions between 2002 and 2013. Noord-Holland, Zuid-Holland, and Outer London have the highest population densit (Eurostat 2015d; World Bank 2015b). The population balance is connected with the need for infrastructure, land, food, employment, public services, motorways, flood protection and housing. The *population density* (Table 3) is a second important indicator. All of the case study regions show an increase in population density. Noord-Holland and Zuid-Holland show large population densities compared to the other regions and Outer London stands out with a population density of 4,058 persons per km^2 (Eurostat 2015e). A large population density enhances the importance of ICZM in order to fulfil the human needs in a sustainable way.

3.2 Pressures

According to the IPCC (2014), anthropogenic GHG emissions depending on economic growth, fossil fuel use and population growth, are extremely likely the dominant cause of the observed warming since the mid-20th century. Consequently, the pressure -indicator is the *annual emission of greenhouse gases* in the Netherlands and the United Kingdom. Through the Kyoto Protocol, both countries were committed to reducing their GHG emissions between 2008 and 2012. The Netherlands was forced to reduce its GHG emissions by 6% relative to the baseline year 1990. For the United Kingdom, the target was set on a 12.5% decline relative to the baseline year (EEA 2010). Both countries achieved their Kyoto Protocol targets, with the United Kingdom even exceeding it (see Table 4).

Table 4: *Greenhouse gas emissions between 1990-2012 of the United Kingdom and The Netherlands in CO_2-equivalents (according to EDGAR 2015).*

Greenhouse gas emissions (in CO_2-equivalents) **by year**	United Kingdom	The Netherlands
1990	777,244.23	224,468.09
1995	728,336.09	235,053.00
2000	673,897.41	220,320.00
2005	659,108.09	217,084.00
2010	609,586.56	212,418.45
2012	585,779.78	195,873.76

The *farmland area* in the Netherlands increases whereas the United Kingdom shows a decline with the exception of Outer London (Table 5). Population growth and changes in socio-economic interests (increasing tourism and the accompanying need for infrastructure) increase the demand for food and the need for land. The intensification of farming techniques (fertilisers, pesticides) leads to environmental damages (Lescrauwaet et al. 2006). This process has introduced other environmental problems such as high risk of coastal erosion.

The number of nights spent at tourist accommodation emphasizes the economic importance of tourism in the case study regions but it also represents the pressure that tourists exert on the environment. An increasing number of tourists requires an increasing amount of infrastructure and land. Furthermore, the consumption of energy and water as well as the production of waste peak during the high season (Lescrauwaet et al. 2006). In both countries, there is a general increase of the number of nights spent at tourist accommodation (Table 5). However, a decline can be ascertained in some of the case study regions.

In order to attain sustainable development in the coastal regions, it is important to meet traffic requirements in such a way that reachability and safety are enhanced. Table 5 shows the change in *the motorways network* in the United Kingdom and the Netherlands. The Netherlands shows an increase in the motorways network whereas the United Kingdom shows stagnation between 2002 and 2013. An increase of the motorways network and the associated traffic can affect the environment and human health negatively. On the other hand, it increases reachability of the coastal areas, which makes the motorways network a necessary infrastructure to amplify economic activities (Lescrauwaet et al. 2006).

3.3 State

The state -indicators mainly focus on observed climate changes in the case study regions. A socio-economic dimension is added to the state through the description of the prevailing measures to counteract flooding in the United Kingdom and the Netherlands.

The Netherlands is characterized by *an average temperature rise* that is 1.7°C higher than a century ago (PBL Netherlands Environmental Assessment Agency 2013). In the United Kingdom, the average temperature is 1°C higher than 100 years ago. The temperature in both countries is rising faster than the global trend (Jenkins et al. 2008).

Sea level rise directly affects the development of intertidal habitats such as mudflats and salt marshes. In natural conditions, these intertidal habitats are able to counteract sea level rise through inland migration and vertical accretion. However, inland migration is often hindered by the presence of hard defence measures and the vertical accretion is hindered by a human-induced lack in sediment supply (Esteves et al. 2014). In the Netherlands, the average sea level has risen by 20 cm during the past century. Due to human interventions, such as dredging operations and the construction of dikes and dams in the past, the regional rise in sea level varies considerably (PBL Netherlands Environmental Assessment Agency 2013). Consequently, sea level in this region has risen by 13 cm whereas Zuid- and Noord-Holland have shown an average sea level rise of 24 cm throughout the last century (PBL Netherlands Environmental Assessment Agency 2013). In the United Kingdom, the average sea level has risen by 13 cm during the past century (Lowe et al. 2009). The land mass of the United Kingdom is moving as a result of the melting of the ice-sheet since the end of the last ice age. Consequently, there are regional differences in the average sea level rise since there is a general upward land movement in the north and a downward movement in the south. The latter enhances flood risk challenges in the low-lying coastal areas along the southeast coast from Lincolnshire to the Thames estuary (Lowe et al. 2009).

Increasing precipitation puts a lot of pressure on drainage systems. Low-lying coastal areas are particularly vulnerable to flooding since gravity drainage depends on the difference in elevation between the drained area and the area to which the water flows. Consequently, low-lying coastal areas are characterized by forced drainage through pumps (Titus et al. 1987). Increased precipitation may overload these drainage systems in the future, inducing surface water flooding and sewerage flooding. With rising sea levels, the time in which the water can be naturally discharged by gravity into the sea will decrease. Consequently, more water has to be actively pumped into the sea, which is very cost-intensive. During the last century, a significant precipitation increase has been observed in the Netherlands (Daniels et al. 2014): both mean and extreme precipitation accrued on seasonal and annual time scales for the period 1951-2009. The highest increase was noticed during the last 30 years. According to de Leeuw et al. (2015), the United Kingdom is located at the downstream end of the North Atlantic storm-track and the country is characterized by large variations in precipitation. There exist a wide variety of studies investigating the emergence of trends in the UK precipitation on different timescales (e.g. Hand et al. 2004; Jones and Conway 1997; Maraun et al. 2008; Osborn et al. 2000). Most of these studies conclude that the annual mean precipitation in the United Kingdom has not changed since recording started in 1766. Nonetheless, large differences were observed in seasonal precipitation totals, indicating a trend of increased precipitation in the winter (and to a lesser extent in autumn and spring) and a decrease of precipitation in the summer.

In both countries, there is a *high risk of coastal erosion.* Coastal erosion is a natural phenomenon: due to an imbalance in sediment supply and sediment drain, scouring in dunes or cliffs may appear. Natural activities such as wind, waves, storms, near-shore currents and weathering processes influence coastal erosion (Safecoast 2008). However, hard defence measures, land claim, river water regulation works (dams), dredging, gas mining, vegetation clearing and water extraction are human actions that enhance coastal erosion (Eurosion 2004). Furthermore, the changing state of the climate and sea level rise put extra pressure on the, originally natural, coastal erosion processes (Safecoast 2008). However, it remains difficult to quantify to what extent human activities and

Table 5: *Pressure indicators; Farmland area in hectare, nights spent at tourist accommodations and motorways network in kilometre (according to Eurostat 2015a; 2015b; 2015c).*

Farmland (ha)	**2005**	**2007**		**2005**	**2007**
The Netherlands	2.035.230	2.074.800	United Kingdom	16.839.770	17058.920
Friesland	241.490	247.930	East Anglia	1.004.790	990.180
Noord-Holland	145.000	148.490	Essex	257.130	256.210
Zuid-Holland	145.770	151.190	Kent	241.400	244.610
Zeeland	122.850	124.730	Outer London	11.870	12.680
Nights spent at tourist accommodation[a]	**2002**	**2012**		**2002**	**2012**
The Netherlands	82.371.500	84.050.408	United Kingdom	263.769.000	303.564.528
Friesland	5.312.300	4.625.356	East Anglia	11.060.000	13.755.880
Noord-Holland	17.161.700	19.961.251	Essex	2.630.000	2.273.249
Zuid-Holland	8.581.200	8.142.256	Kent	4.642.000	5.555.577
Zeeland	7.647.100	7.226.760	Outer London	not available	15.920.757
Motorways (in km)	**2002**	**2013**		**2002**	**2013**
The Netherlands	2516	not available	United Kingdom	3611	not available
Friesland	180	201	East Anglia	48	48
Noord-Holland	277	290	Essex	82	82
Zuid-Holland	340	362	Kent	170	170
Zeeland	79	68	Outer London	60	60

[a] Tourist accommodations include hotels, holiday and other short-stay accommodations, camping grounds, recreational vehicle parks and trailer parks

global warming influence coastal erosion (Nicholls et al. 2007). Table 6 delineates the coastal erosion in the Netherlands and the United Kingdom in 2001. 18% of the Netherlands' coastline is affected by coastal erosion, whereas 27% of the coastal area in the United Kingdom was affected by erosion in 2001. The steady increase in coastal erosion might affect flood protection, property loss, tourism, historic landmarks, industrial development and ecosystems. Acknowledging this problem, the European Commission proposed in 2004 a number of recommendations to improve coastal erosion management (Mulder et al. 2011). The key finding is that a more strategic, proactive approach is needed for a sustainable development in coastal areas that are characterized by a shortage of space and sediment supply (Mulder et al. 2011).

Table 6: *Extend of coastal erosion (2001) in the Netherlands and the United Kingdom in km. (according to Salman et al. 2004).*

	United Kingdom	**The Netherlands**
Total length of the coastline	17,381	1,206
Eroding coastline (protected and unprotected)	3,009	134
Artificially protected coastline	2,373	146
Eroding coastline in spite of protection	677	50
Total coastline impacted by coastal erosion	4,705	230

The Netherlands and the United Kingdom show a long history of coping with flooding from both tidal and fluvial sources (e.g. Brown and Damery 2002; van Wesenbeeck et al. 2014). Flood management policies of both countries traditionally favoured technological solutions to reduce flood risk by focusing on the construction of *hard defence measures* (Brown and Damery 2002; van Wesenbeeck et al. 2014). In 1953, both countries were startled by a major storm surge with a catastrophic outcome: 2,100 people and 200,000 animals died, a total of 2,500 km^2 of land was flooded and 120,000 people needed to be evacuated (Safecoast 2008). This devastating storm surge stimulated the beginning of intensive reinforcement of flood defences in both countries. At that time, policy processes in both counties were technocratic as decisions were based on technological knowledge (Brown and Damery 2002). In the Netherlands, most of the flood measures were taken in the Rhine-Meuse delta since the province of Zeeland was the most affected by the 1953 storm surge. After the government approbated the advice of the Delta Committee in 1958, the Delta Law formed the legal base to start the infrastructural pursuits of the Delta Works (Deltawerken 2004). By 2010, all the dikes were reinforced, the coastline was intensely shortened and three movable storm surge barriers, one bridge and nine dams were built. The Delta Works generate a minimum safety standard of a flooding probability of 1/2,500 years and a maximum safety standard of 1/10,000 years (Klijn et al. 2004). The former estuarine inlets have become isolated fresh- and saltwater lakes providing new services such as flood safety, opportunities for tourism and freshwater supply for agriculture (van Wesenbeeck et al. 2014). The Delta Works were innovative at the time of construction but the upcoming environmental degradation was not foreseen. In the United Kingdom, the east coast was the most struck by the 1953 storm surge (Lumbroso and Vinet 2011). The government decided that the best solution to protect London was building a tidal surge barrier with movable gates across the Thames, raising the river banks and pursuing a good system of flood warnings (Lavery and Donovan 2005). The Thames Barrier and Flood Prevention Act provided the legal base to start the construction of the Thames Barrier and the accompanying defences. By 1982 the Thames Barrier was operational. According to Lavery and Donovan (2005), the Thames Barrier currently offers not only flood protection for the next decades, but also the opportunity to 'buy time' to consider possible strategies for long-term sustainable flood management. London is expected to be protected against floods with an annual probability of 1/1,000 until the year 2030 (Lavery and Donovan 2005). Regarding the impacts of climate change, only hard defence measures will not be sufficient to ensure flood safety.

3.4 Impacts

Groundwater salinization in the Netherlands occurs mainly in the low-lying coastal areas. The construction of hard defence measures in combination with drainage activities in coastal areas resulted in land subsidence (Pauw et al. 2014). Consequently, polders are located below mean sea level and lateral saltwater intrusion occurs. According to Oude Essink et al. (2010), salt water intrusion is a problem in the low-lying areas in a broad coastal strip of about 10 km. Freshwater supply in the South East of England is limited due to large population density and relatively low annual rainfall. Furthermore, almost 120,000 new homes are planned on either side of the Thames Estuary to the east of London. This puts extra pressure on the (already scarce) freshwater supplies in the area and will enhance saltwater intrusion (EA 2006). A lower river discharge in the summer and an increasing sea level will accelerate the saltwater intrusion in both countries. This increased saltwater intrusion will reduce the availability of both fresh surface water and groundwater. Furthermore, it will have a negative impact on agricultural activities, since high salinity in the root zone can induce crop damage and salt intrusion contaminates drinking water for cattle (PBL Netherlands Environmental Assessment Agency 2013).

Salt marshes are located at the interface between marine and terrestrial zones in low-energy environments within estuaries (Allen 2000; Foster et al. 2013). Both countries face problems of coastal squeeze including the disappearance of salt marshes. Coastal squeeze describes the disruption of the natural dynamics of salt marshes caused by hard defence measures, such as dikes, which hinder the inland migration of the salt marsh (Pontee 2013). Sea level rise in combination with decreased sediment availability lead to changes of these valuable ecosystems (Ma et al. 2014). Since the adoption of the Convention on Wetlands of International Importance in Ramsar in 1971, the importance of saltmarshes for biodiversity and human well-being was acknowledged (Foster et al. 2013). Saltmarshes offer habitats for migratory and wintering birds and they are used as spawning and nursery areas. Furthermore, salt marshes are able to dampen wave and tidal energy and to improve water quality by fixing the excess of nitrogen (van der Wal and Pye 2004). In the Netherlands, salt marshes can be found in the regions of Friesland and Zeeland. Not all salt marshes developed naturally: in order to reclaim land, sedimentation was actively stimulated on the seaward side of the dikes through drainage systems in the mudflats and through the construction of brushwood groynes (Dijkema et al. 2011). The construction of the Delta Works had a large impact on the salt marsh area in Zeeland. Due to damming, former saltwater areas changed to freshwater lakes leading to the disappearance of salt marshes in the 1970s (de Jong et al. 1994). After the storm surge barrier in the Oosterschelde was finished in 1986, the salt marsh area decreased dramatically by more than 50% over the following 15 years. Although accretion rates are lower than the pre-surge barrier period, current research by Ma et al. (2014) reveals that remaining salt marshes are expected to survive under the present sea level rise rate. According to van der Wal and Pye (2004), lateral erosion of the salt marshes of the estuaries in the Greater Thames area started at the beginning of the 20th century. There are several causes for the erosion of the salt marshes: land claim, embankment constructions and a continuous rise of extreme water levels. However, all the salt marshes in the Greater Thames estuary were able to keep pace with rising sea levels during the last century through vertical sediment accretion. Furthermore, van der Wal and Pye (2004) concluded that changing wind and wave magnitude has been the determining factor for enhanced lateral marsh erosion and vertical accretion in the Greater Thames area during the last decades.

Impacts on marine biodiversity loss are caused by changing sea temperature, which will become increasingly profound in the future (Hopkins et al. 2007). An increasing water temperature interferes with timings of seasonal events, leading to a disturbance of synchronicity between species and the availability of food (Hopkins et al. 2007). Furthermore, an increasing water temperature generates suitable conditions for alien warm-water species, leading to changes in the native community structure. For example, Weijerman et al. (2005) found a positive relationship between increased water temperature and an increase in numbers of grouper (*Dicentrarchus labrax*), solenette (*Buglossidium luteum*), small weever (*Trachinus vipera*) and scaldfish (*Arnoglossus laterna*) in the North Sea. However, the increased water temperature in these regions caused the disappearance of the plaice (*Pleuronectes platessa*), which is a commercially important species (van Keeken et al. 2007).

An increasing water temperature provoked similar species shifts in the United Kingdom. Arnott and Ruxten (2002) found a negative relationship between sand-eel (*Ammodytes marinus*) recruitment and higher winter sea surface temperatures in the United Kingdom. The low recruitment of sand-eels has an impact on predator species that feed on them. Consequently, sand-eel feeders like kittiwakes (*Rissa tridactyla*) have shown a low breeding success in winters with higher winter sea surface temperature (Frederiksen et al. 2007). Furthermore, the numbers of warm-water fish such as stingrays (*Dasyatidae*) and triggerfish (*Balistes*) increased in the coastal waters of southern Britain whereas numbers of cold-water species such as the acorn barnacle (*Balanus perforatus*), dabberlocks alga (*Alaria esculenta*) and the zooplankton species (*Calanus finmarchicus*) declined (IACCF 2010).

The changing state of the climate has an impact on the current flood defence measures and *provides water management challenges* of the United Kingdom and the Netherlands. The construction of the flood defence measures after 1953 were innovative at that time but some of them do not meet the current safety standards anymore. Consequently, dikes and dunes of the Netherlands are currently reinforced and in Zeeland, rubble and steel slag deposits are needed to strengthen the dikes. During the construction of the Thames Barrier in the United Kingdom, it was anticipated that the barrier needed to cope with sea level rise resulting from a natural decrease of land levels. According to the EA (2014) further protection will be needed in the short term (25 years), medium term (the following 15 years) and long term (to the end of the century) in order to safeguard the flooding safety standards. In the Netherlands, large low-lying coastal areas are used for agriculture and human settlement. In these regions, precipitation drains into small canals and flows towards the downstream pump station (van Overloop 2006). Today, the best solution to cope with increased precipitation in the Dutch polders is to increase pumping activities (Ritzema and Stuyt 2015). However, the combined changes in precipitation, sea level rise, subsidence and urbanization will require more fundamental structural changes (Ritzema and Stuyt 2015). Consequently, the Netherlands and the United Kingdom face great challenges concerning their water management in the future. According to the Greater London Authority (2005), surface water flooding is probably the greatest short-term climate risk to London. Increased winter rainfall, increased heavy rainfall events, poor maintenance of drains and gullies, reduced water permeability of the soil caused by use of impermeable materials and the fact that London drainage systems are designed for high-frequency, low-volume rainfall amplify the probability of surface water flooding in London.

3.5 Responses

Recognition of climate change and accompanying scientific research towards adapting the effects is important in both regions. Along with the development of the Intergovernmental Panel on Climate Change in 1988 and the establishment of the United Nations Framework Convention on Climate Change (UNFCCC) in Rio de Janeiro in 1992, climate policies in the Netherlands and the United Kingdom started to evolve. In 1997, the Kyoto Protocol was adopted, which entered into force in 2005. This international treaty emanated from the UNFCCC and obligates developed countries (including the Netherlands and the United Kingdom) to foster climate change mitigation by reducing their GHG emissions. In the Netherlands, the Ministry of Housing, Spatial Planning and the Environment (2006) launched the 'Initial Report of The Netherlands, under the Kyoto Protocol' and in the United Kingdom, the Department of the Environment, Transport and the Regions (2000) launched its 'Climate Change Programme' in response to the Kyoto Protocol. Furthermore, the Dutch climate research community developed two transdisciplinary research programmes in order to attain a climate-compatible development: 'Climate changes Spatial Planning' (2004-2012) and its successor 'Knowledge for Climate' (2008-2014). The two programmes focused on gathering scientific and applied knowledge. The 'Knowledge for Climate' programme designated eight areas in the Netherlands that are vulnerable to the effects of climate change. Two of them comprise the coastal areas of Zeeland and Friesland. In all of the eight regional hotspots, transdisciplinary research was conducted concerning different themes including flood protection, fresh water supply and water quality, governance, adaptation and policy instruments (Kennis voor Klimaat 2015).

In the United Kingdom, the work of the Climatic Research Unit of the University of East Anglia, founded in 1972, played a major part in navigating the study of climate change and in setting climate change on the political agenda. In order to mitigate or adapt to the possible effects of climate change, the Tyndall Centre for Climatic Change Research was founded in 2000, including scientists, economists, engineers, social workers, policy advisors and business stakeholders in a transdisciplinary manner to develop sustainable responses to climate change (Tyndall Centre 2015).

3.5.a Integrated Coastal Zone Management (ICZM) Recommendation and the EU Floods Directive

Before the Earth Summit in 1992 in Rio de Janeiro, European policies in coastal zones were predominantly reactive and issue-oriented (Safecoast 2008). After the adoption of ICZM as one of the principal recommendations of Agenda 21 at the Earth Summit, the ICZM concept gained prominence and political legitimacy (Queffelec et al. 2009). The ICZM recommendation takes into account the serious threats to the coastal regions (Recommendation 2002/413/CE). The main goal of this recommendation is to guide the European coastal zones towards more sustainable scenarios by facilitating the links between economic, social and environmental European Directives and policies (Lescrauwaet et al. 2006). Sorensen (1993, p. 49) defines ICZM as '*a dynamic process in which a coordinated strategy is developed and implemented for the allocation of environmental, socio-cultural, and institutional resources to achieve the conservation and sustainable multiple use of the coastal zone*'. The ICZM process is characterized by vertical integration across local, regional, national and international government levels and by horizontal integration across different sectors. The traditional top-down approach is gradually substituted by a bottom-up governance approach, where consideration is given to key stakeholders and communities in the decision-making process (Queffelec et al. 2009).

The Floods Directive is an integrated policy instrument that targets ICZM. Its aim is to reduce and manage the risks that floods pose to human health, the environment, cultural heritage and economic activities (Directive 2007/60/EC). It commits all member states to identify vulnerable regions by 2011, draw flood risk maps by 2013 and establish flood risk management plans. The Floods Directive will be carried out in accordance with the Water Framework Directive and, as proposed by ICZM, member states will need to allow public participation in the preparation of the flood risk management plans (Directive 2007/60/EC).

Practical examples to fulfil the goals of ICZM and the Floods Directive are the *Second Delta Committee* and *EcoShape consortium* in the Netherlands, and the *Environment Agency (EA)* and *Thames Estuary 2100* project in the United Kingdom.

In the Netherlands, the Dutch Cabinet founded the *Second Delta Committee* in 2007 to come up with recommendations to avoid a disaster (Verduijn et al. 2012) and to delineate long-term solutions concerning flood protection and freshwater management (Deltacommissie 2008). Different framing strategies to create (public and political) awareness and support in order to influence the public agenda and the climate adaptation policy were used (Verduijn et al. 2012). In 2008, the Second Delta Committee was disbanded but the government accepted its advice: since 2012, the Delta Act forms the legal base. The Delta Programme is a national, transdisciplinary enterprise in which central government, provincial and municipal authorities, water boards, civil-society organisations, business communities and scientific organisations are congregated, with a two-fold aim: providing protection against flooding now and in the future, and ensuring freshwater supplies (Government of the Netherlands 2015). The programme uses a phased model of decision-making in which uncertain long-term developments are taken explicitly and transparently into account, called the Adaptive Delta Management model (Marchand and Ludwig 2014). The results of Adaptive Delta Management within the Delta Programme are used to meet the Floods Directive (Government of the Netherlands 2015).

In the United Kingdom, many coastal bodies were formed as a consequence of the Earth Summit in Rio de Janeiro in 1992. Their goal was to establish an effective and holistic management system to ensure a sustainable development of the individual sections of the coastline (French 2004). The *Environment Agency* (EA) was founded through the Environment Act of 1995. This was the first time that all environmental issues were treated together by one agency with the goal of ensuring a sustainable development of the country (Jewell and Steele 1996). The EA is responsible for flood risk management arising from the main rivers and the sea. It coordinates, plans, and finances measures to reduce either the likelihood or the impacts of floods. Therefore, the EA is also responsible for flood warnings and flood risk maps to increase awareness of the public. Current policies of the EA are influenced and guided by the Floods Directive. By now, there are detailed maps publicly available about the flood risks in all areas that are situated close to rivers or the sea (EA 2015a). The EA explicitly works together with the government, communities, individuals, voluntary groups and private and public sector organizations. The goal is to establish a partnership between the authorities and local stakeholders (Stojanovic and Barker 2008). Next to stakeholder participation the following general principle should be fulfilled when measures are planned in the UK: because of the large uncertainty in climate projections, all long-term measures need to be flexible, i.e. it should be possible to adapt them quickly to any future scenario. Best suited to fulfil this criterion are so-called “low regret” actions. These are measures that are accompanied with benefits for today’s society and that can at the same time run under any future conditions.

The *EcoShape Consortium* in the Netherlands, an inter- and transdisciplinary multi-actor network, deals with the unforeseen problems (such as erosion, eutrophication) that arose after the termination of the first Delta Works, and emphasizes the implementation of flexible soft protection structures in harmony with the sea (Waterman 2010). The Netherlands currently uses the 'Building with Nature' principle in order to develop sustainable coastal areas. This is in line with the Floods Directive, which focuses on flexible, sustainable solutions (Directive 2007/60/EC). Several flood risk measures have been implemented due to the EcoShape Consortium. The first measure was sand nourishment to counteract erosion at a large tidal flat in Zeeland (da Vriend et al. 2014). The second measure started in 2009 and is based on the use of Pacific oyster reefs to protect tidal flats and dispel wave energy in Zeeland (Jones et al. 1994). Oysters are able to combat erosion as they protect the underlying sediment against efflux. The first monitoring has shown that the tidal flats show no erosion, whereas the unprotected tidal flats show 2-3 cm erosion per year (da Vriend et al. 2014). A third measure is the construction of the Delfland sand engine on the Holland coast in 2011. Twenty million m^3 of sand were placed in one location, in order to be gradually redistributed along the shore by wind waves and currents. This innovative approach should counteract erosion for the next 20 years while it also provides new possibilities for nature and recreation (da Vriend et al. 2014). The main features of the preferential strategies for flood risk management in the different regions of the Netherlands are summarized in Table 7.

The *Thames Estuary 2100* project (TE2100) is a comprehensive action plan to manage flood risk (EA 2012). The plan delineates recommendations and actions to manage flood risk based on a multi-stakeholder collaboration. The TE2100 project delineates four generic estuary-wide options with accompanying sub-options (Table 8) to manage flood risk. Nevertheless, the efficiency and reliability of barriers are generally threatened by inundation from river water (e.g. after heavy rain or ice melting) and from local floods when the present drainage networks are overwhelmed. Therefore, the EA supports sustainable drainage systems, which reduce the risk of floods resulting from rain water. These are replications of natural systems (e.g. basins, rain gardens, reed beds) that collect, store and clean the water before they slowly release it. Hard measures are combined with other adaptation and mitigation strategies. One of the most important alternatives is better land management, which often includes managed realignment whereby land with low population density (for instance farmland) is converted to salt marshes and natural flood plains (French 2006; Turner et al. 2007). An example for realignment projects is the "Essex Wildlife Trust" which has already bought and converted 84 ha of (lowly productive and sparsely populated) farmland to salt marshes (Myatt et al. 2003).

Table 7: *Summarized features of the preferential strategy for flood risk management in the three coastal regions of the Netherlands (according to Government of the Netherlands 2015).*

Region	Preferential Strategy	Flood risk management features
Southwest Delta	Room for innovative dikes	• The current dikes remain and will be improved • All dikes improvements will be investigated in order to make them multifunctional (i.e. possibilities for nature, recreation and living).
	Peak water storage and tides	• Investigation if peak water storage can be used to diminish the flood risk elsewhere. • If (limited) tides return, research will be necessary to investigate if the tides offer possibilities to combine ecologic recovery with sustainable energy (for example a tidal power station).
	Flood defence system, dikes, sand	• Adjusted management of storm surge barriers. • Bank and shoal nourishments to combat erosion. • Innovative (multifunctional) dike improvements.
	Dredging and dumping strategy	• Combination of innovative dikes with improved dredging and dumping strategies.
Holland Coast	A safe, attractive, economically robust coast	• Creating a sustainable coast with focus on safety, attractiveness and economic activities.
	Connecting flood risk management and spatial ambitions	• Connecting flood risk management, spatial development, nature conservation and recreation.
	Adaptive flood defence system, dikes and sand	• Design adaptive and sustainable protection measures
Wadden	Intertidal zone: adapt to rise in sea levels	• Preserve the buffer effect of the Wadden islands and the intertidal area as much as possible. • Annual replenishment of 12 million m3 sand.
	Primary flood defence systems: innovative and comprehensive	• Innovative dikes that create added values for nature, recreation and the regional economy.

Table 8: *Four generic options and accompanying sub-options of the TE2100 project to manage flood risk in the upcoming century (according to the EA 2012).*

Options	Sub-options	Flood risk management features
1. Improve the existing defences	1.1 Raise defences when needed 1.2 Allow future adaptation of defences 1.3 Optimise balance between defence, replacement and repair 1.4 Optimise defence repair and replacement, allow adaptation to future change	• The four different sub-options comprise different maintenance schedules and different decision paths of when and to what extend walls should be raised. • Until 2070, option 1.4 is the preferred option according to the TE2100 appraisal.
2. Tidal flood storage		• Storage of tidal waters could reduce extreme water levels at the Thames Barrier. • This option could 'buy time' to replace or improve the Thames Barrier (although it is not optimal).
3. New barrier	3.1 Tilbury location 3.2 Long Reach location	• Design of barriers to resist the highest predicted storm surge tides. • There would still be a need for defence upstream.
4. Barrier with locks	4.1 Tilbury location 4.2 Long Reach location 4.3 Barrier with locks at Thames Barrier (when closures per year reach their limit)	• Ship locks would allow vessels to pass through the barrier when it is closed. • The barrier with locks would be designed 'fail-safe' in order to close it as frequently as necessary without losing its reliability. • The most expensive option. • Most environmental damaging option.

3.5.b Increased awareness of society

According to the Floods Directive and ICZM, informing the population about flood risks and what to do in the event of flooding, is one of the key elements of an effective flood management approach.

To meet this requirement, the Netherlands included a "Multi-layer safety" approach in the Delta Programme: layer 1 represents the preventive measures to limit the probability of a flood, layer 2 represents the spatial organisation of an area to limit the consequences of any flood, and layer 3 represents the disaster and crisis management to respond effectively to any flood (Slomp 2012). In the United Kingdom, improved forecasting systems, improved spatial planning, effective preparation and emergency responses and help with recovery in case of disaster (the Flood Re contract) meet the requirement of the Floods Directive.

Both countries have made efforts to increase the awareness and preparedness of the public. In the Netherlands, risk communication campaigns as 'The Netherlands Lives with Water' and 'Think Ahead' were launched (Flood Aware 2013). Despite these efforts, there is still a large public awareness gap relating to flood risks (OECD 2014). To counteract this gap, the Dutch government has launched a new campaign in 2014: 'Will I flood?'. People can download the app or visit the website in order to access information on regional flood risks and emergency responses (Starflood 2015). In the United Kingdom, risk communication campaigns such as 'Know Your Flood Risk' and 'Co-FAST', as well as the 'National Flood Forum' and 'Risk and Regulation Advisory Council', have been more successful. Unlike the Netherlands, the United Kingdom instantly used an online marketing strategy to raise awareness. The use of various awareness strategies and techniques (TV, You-Tube, social media, personal e-mails) had more impact since they reinforced one another (Flood Aware 2013). Furthermore, since 2012 the EA has an online live flood warning system where people can consult local flood alerts and flood warning statuses (EA 2015b).

4. Conclusions and discussion

The results show that both countries aim to develop sustainable coastal management plans. The measures taken follow long-term integrated and participatory approaches and aim to balance environmental and socio-economic interests. The provided examples illustrate that progress is made in developing multi-functional, planning-based adaptive solutions to deal with pressures and impacts. Especially the combination of hard and soft coastal protection measures lead to innovative approaches (Tables 7 and 8). The responses to the effects of climate change of the Netherlands and the United Kingdom show a lot of similarities. Although the responses are not exactly the same, they are often based on a similar underlying idea. Figure 5 represents the five major similarities between the responses of the two regions.

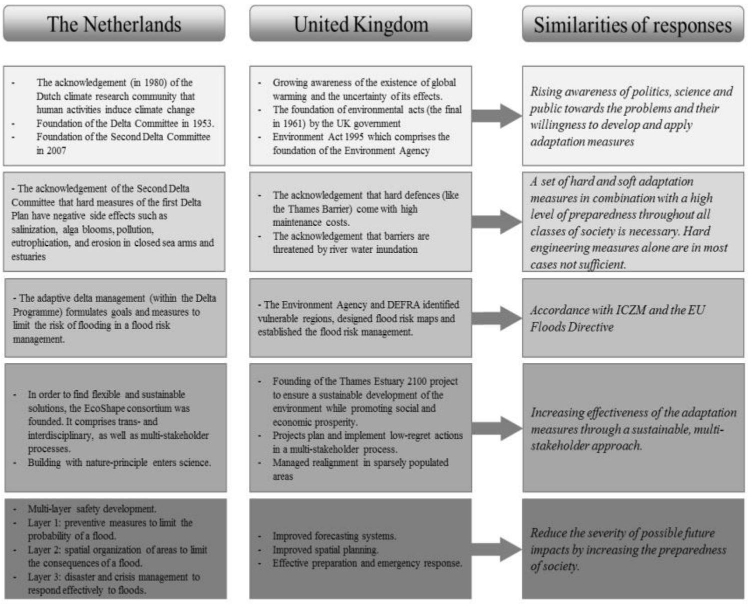

Figure 5: *Similarities between the responses of the Netherlands and the United Kingdom. The first two columns delineate a summary of responses, the third column represents the similarities between the responses of the two countries.*

Despite these similarities, the actual adaptation measures reveal some distinct differences. Firstly, the United Kingdom chooses hard defence measures in combination with managed realignment as the preferred adaptation method. In contrast to the Netherlands, where the paradigm is that no land should be lost, the United Kingdom has a more pragmatic approach. Where affordable, land, people, and property are defended by expensive but effective hard defence measures like the Thames Flood Barrier, while sparsely populated land might be given back to nature via structured realignment.

The second difference is an extension of the first one. The United Kingdom tries to combine a sustainable development with flood risk management but this is mainly the case in areas with low population density. The Netherlands, on the other hand, emphasizes sustainable development in all of its coastal regions. The EcoShape Consortium works on the boundaries between nature, engineering and society. Influenced by negative side effects of earlier-built hard measures, the Netherlands started to focus on flexible soft measures in harmony with the sea. However, there are cases where necessity is the mother of invention: in 2009, the province of Zeeland authorized the dumping of rubble and steel slag in order to make the dikes 'climate proof'. Yet the impact of the steel slag, containing heavy metals, on ecosystems was not taken into account when the slag deposit was authorized. Consequently, nature organizations have protested against steel slag deposits in the Oosterschelde (Stichting De Oosterschelde 2015).

A third major difference is in the options to manage flood risk in the future. In the Netherlands, the Building with Nature solutions are tailor-made and based on site-specific knowledge. After the termination of the projects, monitoring is crucial to operate and manage the Building with Nature -infrastructure, as there are no other generic options provided in the Netherlands (da Vriend et al. 2014). The United Kingdom, on the other hand, did provide different generic options in the South East region. Due to the uncertainties of climate change, it chose to first monitor the development of climate change effects, population and property in order to choose the most credible adaptation option by 2050 (EA 2012).

The coastal areas of the Netherlands and the United Kingdom are vulnerable to the effects of climate change. Due to the rising temperature, induced by the human GHG emissions in combination with land use changes, the coastal areas have to deal with threats like sea-level rise, precipitation changes, increased frequency of severe storms, rising wave heights and growing river water discharge. Consequently, these threats induce an increased risk of floods, a deterioration of intertidal ecosystems, saline seepage, coastal squeeze, rising water tables and an impeded drainage which engender large economic impacts.

Lessons learned by the comparison of the two coastal regions are that the Netherlands and the United Kingdom followed the same path towards their current adaptation measures to combat the effects of climate change. First of all, there was a rising awareness in policy, science and society of the climate change problem. Consequently, the willingness to develop and apply adaptation and mitigation measures grew. Secondly, both countries acknowledged that hard measures alone are not sufficient. The Netherlands needed to cope with adverse effects (such as salinization, eutrophication, and erosion) due to the hard engineering measures. In the United Kingdom, the high maintenance costs of the hard measures and the threat of inundation by river water necessitated the supplementary use of soft measures. Thirdly, both countries needed to come up with a flood risk management in accordance with the Floods Directive (Directive 2007/60/EC). Fourthly, both countries abandoned the top-down approach and tried to increase the effectiveness of the adaptation measures through a sustainable, multi-stakeholder approach (ICZM). Finally, both countries have involved society and increased its preparedness regarding the possible effects of climate change.

Due to their geographical and geological differences, adaptation measures of the Netherlands and the United Kingdom are not overall the same. The United Kingdom differentiates between urban centres and sparsely settled rural areas: In urban areas with high population density and huge economic relevance, the method of choice is defence against flood risk by hard adaptation methods. For rural areas the importance as natural habitats, flood zones and recreation areas is stressed and hence managed realignment is the method of choice to ensure a sustainable development. As opposed to the approach of the United Kingdom, in the Netherlands the paradigm is that no land should be lost. Consequently, hard defence measures and sand replenishment in combination with more sustainable soft adaptation methods are widely used. Hence, the Netherlands emphasizes a sustainable ecological, social and economic development in all its coastal regions.

Further research is necessary to show if the current adaptation measures are indeed sustainable, but this research can conclude that the current adaptation measures arose out of a transdisciplinary, sustainable way of thinking. Measures to counteract the effects of climate change and to secure sustainable development in coastal regions are currently based on a continuous, flexible process of multi-stakeholder collaboration, reflection and research. The development of sustainable coastal areas includes the use of existing hard protections measures in combination with new, nature-based soft adaptation measures.

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