Interreg

European Union

2 Seas Mers Zeeën

SARCC

European Regional Development Fund

The Interreg SARCC project 2017-2023

NATURE-BASED SOLUTIONS FOR COASTAL CITIES

Gravelines
Blankenberge
Middelkerke
Ostend
Vlissingen
Newlyn
Southend-on-Sea

CONTENTS

NATURE-BASED SOLUTIONS FOR COASTAL CITIES

Sustainable and Resilient Coastal Cities

INTRODUCTION

Climate change is undoubtedly one of the great challenges of the twenty-first century. The effects of warming are already being felt around the world today, with more intense heatwaves, droughts, floods and hurricanes, the melting of sea and land ice, the acidification of oceans and the issue at the centre of this publication, sea level rise.

According to (conservative) estimates, the global mean sea level will rise by about 80 cm by 2100 and will continue to rise in the coming centuries. By how much exactly it will rise is something we ignore at present, but IPCC projections range from 2 to 5 m by 2300. This will have dramatic consequences for many of the Earth's regions. Not only remote islands but also densely populated metropolises in fertile river deltas and at the coast are threatened. According to the United Nations, about 40 per cent of the world's population currently lives within 100 km of the coast. Countries and regions bordering the North Sea and Channel must also prepare and arm themselves against an unprecedented rise in water levels.

What are we to do? First, of course, we need to eliminate the causes as much as possible and drastically reduce or even zero our carbon dioxide and methane emissions. But 'mitigation' (emissions reduction) will not be enough. 'Adaptation' is also needed, because many of the consequences of global warming are irreversible. Even if we were to completely stop greenhouse gas emissions today, sea levels would continue to rise for centuries. We need to adapt to this new reality now.

For the past century, we have mainly protected our coasts from erosion and sea flooding with 'hard' walls of defences such as concrete dykes, revetments and sea walls. This publication advocates changing tack and protecting ourselves from the sea with the means nature has given us.

Nature-based Solutions

SARCC (Sustainable and Resilient Coastal Cities) is an Interreg 2 Seas programme involving seven coastal cities in four countries around the North Sea and the Channel that joined forces to investigate – and immediately test in pilot projects – how best to achieve this goal. From 2017 to 2023, a broad international and interdisciplinary coalition – consisting of the seven coastal cities, national and regional governments, universities, knowledge institutes, and private partners – conducted research into the possibilities, benefits and

> This publication advocates changing tack and protecting ourselves from the sea with the means nature has given us.

feasibility of Nature-based Solutions (NbS) for coastal protection as an alternative or addition to the usual 'grey' or 'hard' infrastructure. The European Commission defines NbS as follows: 'solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions.' In other words, NbS involve harnessing nature to cope with climate change impacts. Specifically, in the 2 Seas area, this includes soft solutions (nearshore, beach and dune replenishment), species-oriented solutions (biogenic reefs, dunes and beach vegetation) and hybrid solutions combining soft and hard elements (for instance, the creation of a dune-before-dyke).

Why choose Nature-based Solutions?

Several hypotheses were formulated, examined and tested during the SARCC process. This publication broadly advances five arguments:

1) **NbS are better for the environment, for climate and for biodiversity.** 'Grey' infrastructure is usually made of concrete and steel, and therefore the production is very carbon-intensive and harmful to environment and climate. While that grey infrastructure forms a hard border between land and sea, with few opportunities for flora and fauna, NbS restore, enhance and expand biodiversity and ecosystems.

2) **NbS are flexible, dynamic and robust.** While hard sea walls can offer an effective defence against sea level rise in the short term, continuing to rely on their protection against a sea level rise of more than 1 m will be neither practical nor affordable for many locations. In contrast, NbS are often more resilient in the long term and in some cases even capable of growing with sea level rise.

3) **What's good for nature is good for people.** Healthy and robust ecosystems provide various benefits and services to people

and society: ranging from food, clean water, clean air and carbon storage to landscape experience, recreation, health and psychological well-being.

4) **NbS are an asset for amenities and tourism.** Hard sea walls such as dykes and storm walls form impenetrable boundaries between land and sea, disrupt the landscape and seascape and, in the long term, as sea levels continue to rise and ever-higher walls are required, are of little appeal to residents and tourists.

5) **NbS may be cheaper in the long run.** Traditional hard sea walls such as dykes and storm walls require intensive and expensive maintenance.

Three parts

This publication is structured in three parts. In the first, we provide a brief overview of the scientific knowledge available today on climate change and sea level rise. We describe the dynamics of the sea under the influence of tides, wind and waves and explore the different forms of coastal protection known in our regions, from hard infrastructure to soft NbS. We then elaborate on the differences and similarities between the four countries bordering the North Sea and the Channel, both in terms of their landscape, geographical, hydrological, historical and economic contexts and their policy approaches.
We conclude the first part with an intriguing essay by Garry Momber, director of the Maritime Archaeology Trust (UK), who argues that we should put the issues of coastal protection and coastal erosion in historical perspective and look at the longue durée. Momber draws the surprising conclusion that when humans intervene to fix the coastline with hard infrastructure, the land is subject to more erosion. Over the centuries, natural processes provided much greater resilience, stability and robust protection against climatic changes.
In the second part, we take a look at the seven pilot projects implemented and extensively monitored under SARCC over the past six years. The NbS in the seven cities vary from region to region and depend heavily on specific landscape and marine characteristics. In Gravelines, Middelkerke, Blankenberge and Ostend on the French and Flemish North Sea coast (where sand is abundant), it mainly involves the creation and strengthening of dunes in various forms (as natural dunes or as hybrid dune-before-dykes or grass dykes). In

Newlyn in the English county of Cornwall, the landscape is very different from the continental North Sea coast. Here you will find a more rocky coast. The pilot project incorporated 'eco-blocks' into a structure that breaks the waves and protects the town from the incoming water. The eco-blocks are made of materials which marine life such as algae and molluscs can easily attach to, creating a rich and vibrant biotope. The city of Southend-on-Sea chose to initiate not one but several smaller pilot projects, each contributing in its own way to biodiversity and coastal protection, from restoring beach vegetation to constructing a green sea wall. Finally, the pilot project in Vlissingen in the Netherlands at the mouth of the Western Scheldt estuary is remarkable and somewhat controversial. Here, instead of building ever higher dykes to protect the city from the sea, the choice was made to allow the sea, in the exceptional situation of a heavy storm surge, to flow into the city in a controlled way, the water being collected in a reservoir.
Lastly, in the third part, we list ten lessons we have learned from six years of intense international and interdisciplinary cooperation with all our partners. They are lessons we would like to pass on to all those who want to start working with NbS after us.

Scaling up pilot projects

Hard coastal protection such as dykes and storm walls have proven their effectiveness in the past, but that does not mean they can continue to adequately protect us in the future as sea levels continue to rise. During the twentieth century, we lost sight of the effectiveness of natural systems. And unknown is often unloved. Today, there is still much resistance among policymakers and citizens to rely on soft solutions and NbS. This is why the knowledge and experience gained during the SARCC project are so crucial. Only by implementing NbS as pilot projects in practice can we not only prove their effectiveness in terms of coastal protection, but also demonstrate their added value for people and nature.
SARCC is both a research and a testing programme. It is a process of 'learning by doing'. The question, of course, is how can a pilot project transcend its one-off nature. Will this project go no further than these seven trials in the seven cities, or can NbS be adopted in other places and multiplied on a larger scale? Important prerequisites for scaling up pilot projects are the exchange, dissemination and disclosure of knowledge, not only among academics and policymakers, but also among a wider public, whose interest in NbS needs to be roused for them to drop their resistance and embrace the new solutions.
This publication aims to contribute to this goal. It does so in a concise manner accessible to everyone. The knowledge gathered here, however, is only the tip of the iceberg. We invite anyone inspired by the pilot projects in this publication to consult the studies and research reports that have been prepared over the past six years by policymakers, officials and researchers from a wide variety of disciplines. The list of these documents is available at the end of this publication.

The Editorial Board

More info on www.sarcc.eu

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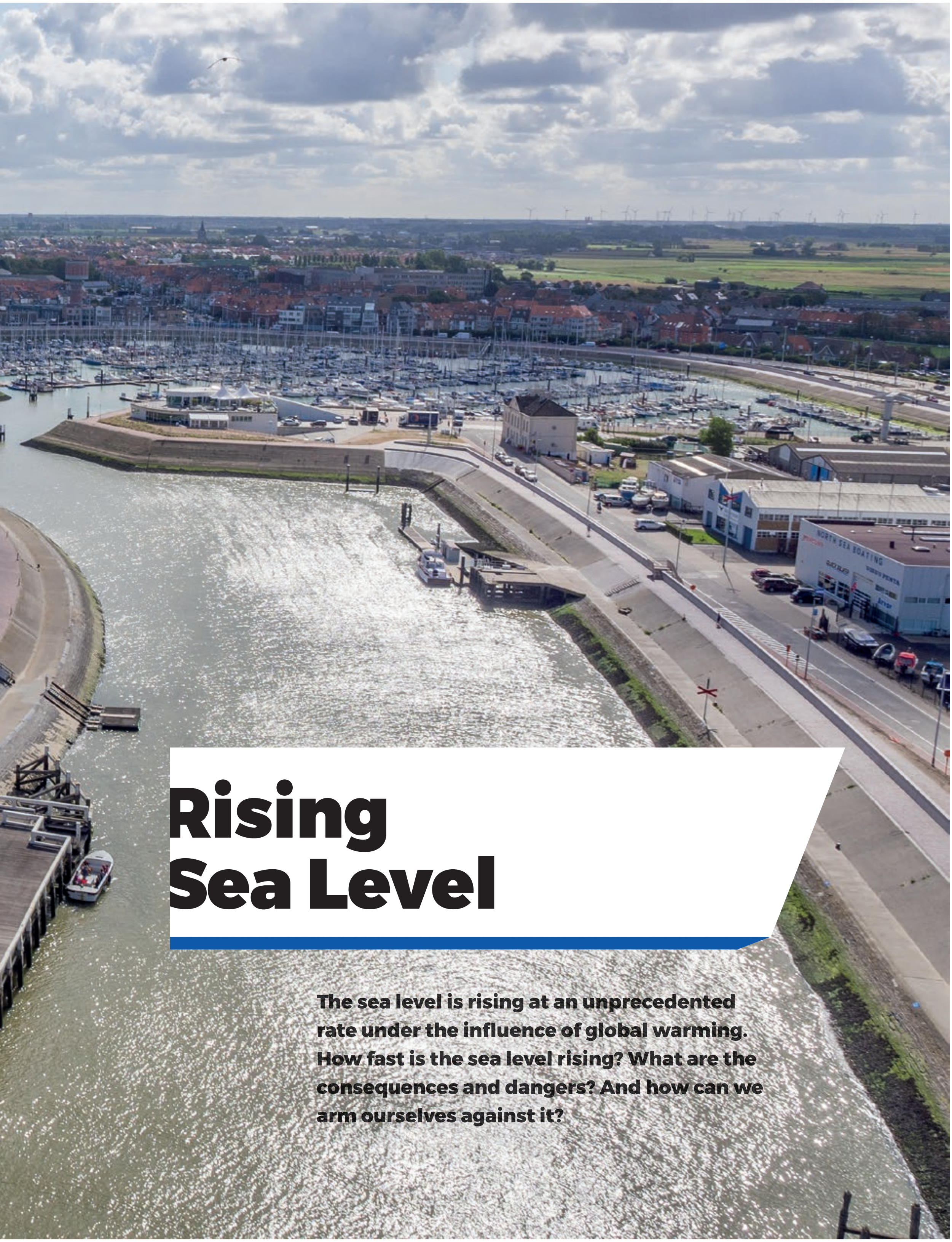
PART 1

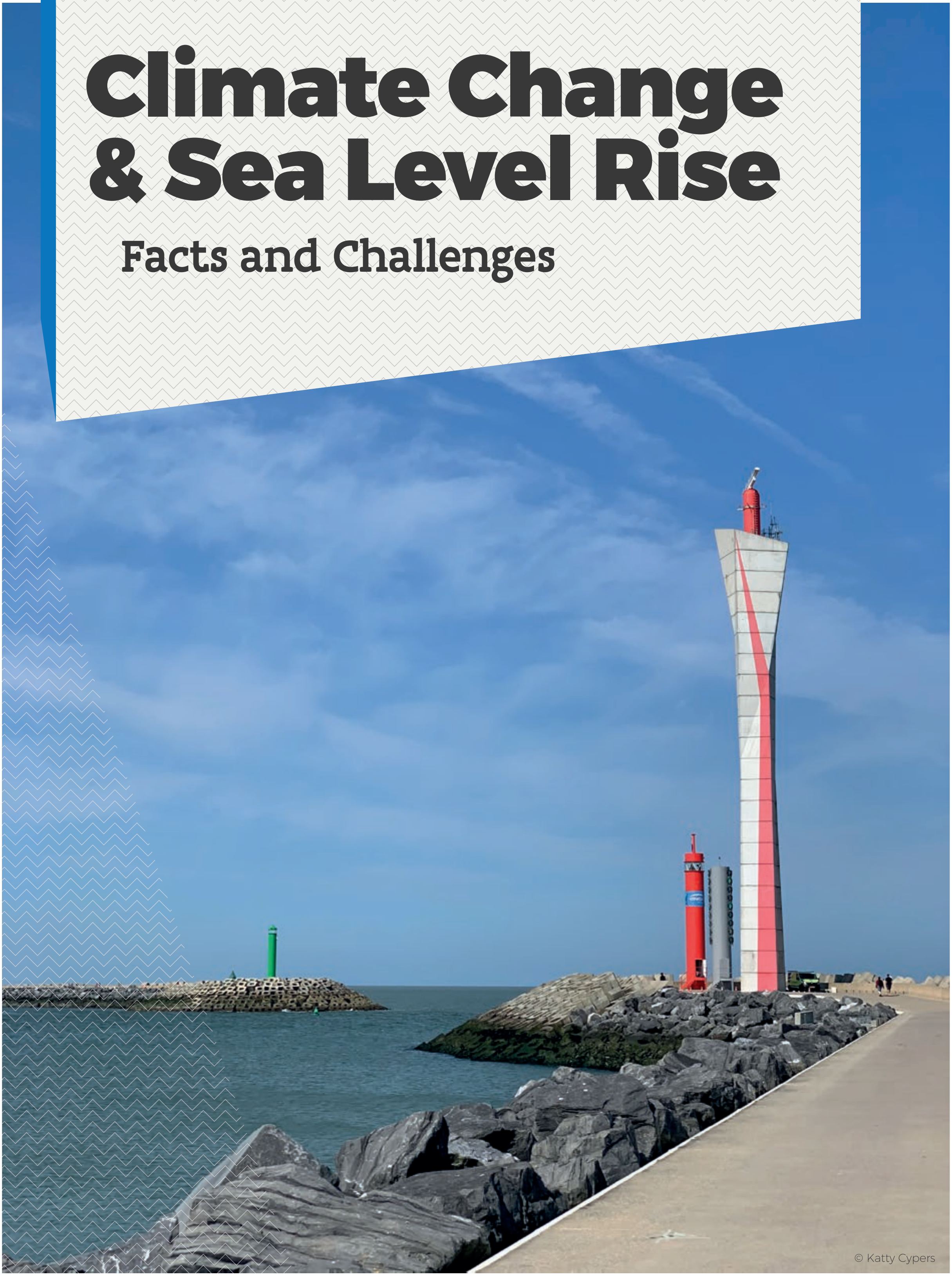


Rising Sea Level

The sea level is rising at an unprecedented rate under the influence of global warming. How fast is the sea level rising? What are the consequences and dangers? And how can we arm ourselves against it?

Climate Change & Sea Level Rise

Facts and Challenges



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Earth is warming up

The climate is changing. Earth is warming up. Globally, the average temperature has risen by 1°C since the Industrial Revolution. This century, temperatures will continue to rise further (and at an increasingly rapid rate). According to the most optimistic scenarios, by 2100 temperatures will rise by 1.5 to 2°C compared to pre-industrial levels. According to the most pessimistic scenarios, by up to 4°C or more. Scientists agree: climate change is the result of human activity. The main culprit are greenhouse gas emissions, especially CO_2, released when fossil fuels are burned.

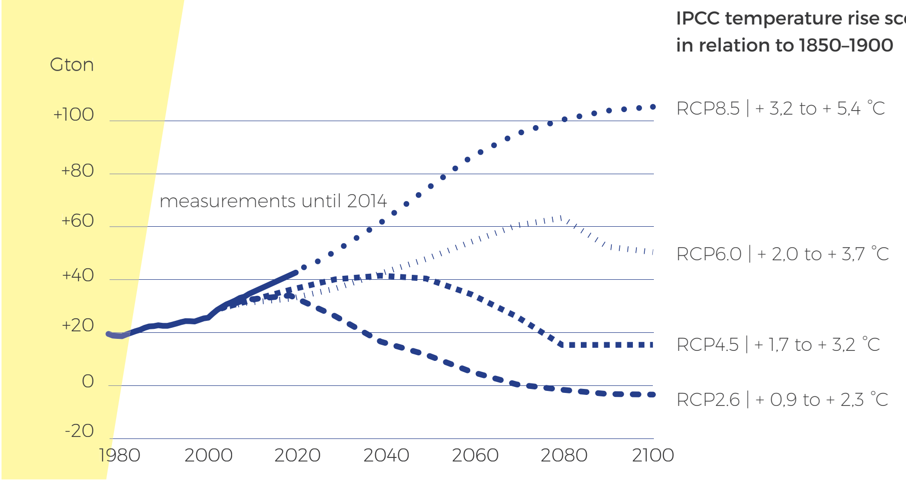
Exactly how much global warming will occur in the future, we do not know. Much depends on global policies, especially the ambition and ability to reduce or even ban greenhouse gas emissions completely. There are other unknown factors, such as the degree of technological innovation (the switch to renewable energy, for example), global population growth, initiatives to increase the sense of responsibility, and economic growth.

With these many uncertainties in mind, scientists on the United Nations climate panel (Intergovernmental Panel on Climate Change or IPCC) calculated four different climate scenarios called Representative Concentration Pathways (RCPs). The scenarios cover four possible trajectories for greenhouse gas concentrations in the atmosphere up to the year 2100. The RCPs range from a substantial reduction (RCP2.6) to a scenario of sustained emissions increase (RCP8.5) and everything in-between. In the Paris Climate Accords (2015), the world's policymakers decided to keep the temperature rise within 2°C compared to pre-industrial levels, with an ambition to limit it to 1.5°C. Today, it is becoming clear that this ambition may no longer be achievable.

Effects of global warming

The effects of climate change are already clearly measurable today. Since measurements began (roughly in the first half of the nineteenth century), statistics have shown

Possible scenarios for the warming of the Earth.
Global CO_2 emissions due to the use of fossil fuels, in GT.



significant shifts in average temperature, precipitation and sea level, among others. Some major global impacts of climate change include:

- Rising average annual temperature
- More extreme hot and tropical days; more heatwaves
- Increase in drought and desertification problems
- More extreme rainfall
- Increased risk of flooding
- Increased risk of stormy weather
- Warming of seas and oceans
- Sea level rise and land disappearance
- Disruption of ecosystems and loss of terrestrial and marine biodiversity

Sea level rise

Sea level rise has several causes, the main ones being the rise in sea water temperature (as water expands when the temperature rises) and the melting of land ice such as ice caps and glaciers.

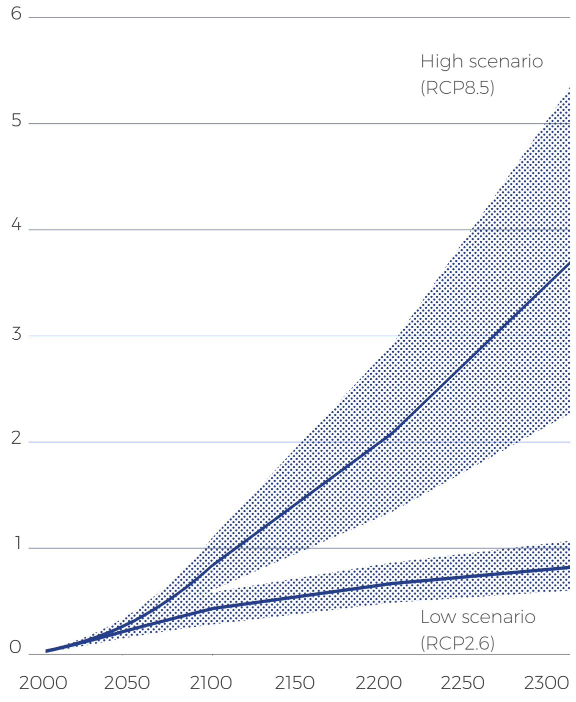
Between 1901 and 2015, the average sea level on Earth increased by 1.7 mm annually and by 19.5 cm in total. Moreover, since the 1950s, a significant acceleration in global sea level rise appears to have begun. By comparison, the global mean sea level (GMSL) rose at a rate of 3.3 mm/year between 1993 and 2018, while it rose at a rate of 3.7 mm/year between 2006 and 2018.

IPCC climate models expect sea level to rise by 0.84 m between 2015 and 2100 under the warm RCP 8.5 scenario. Even after 2100, the sea level will continue to rise, according to scientific predictions. Climate models predict a rise between 2.3 to 5.4 m by 2300 for RCP 8.5 and a rise between 0.6 to 1.1 m for RCP 2.6. This means that, even in the most optimistic scenario, many of the world's coastal areas are under serious threat and could disappear underwater.

Local differences

Sea level rise is not experienced equally around the world. Local differences have to do with such factors as differences in water density, the impact of ocean circulation, the attraction that land and ice masses exert on water, or ascending and descending movements of the Earth's crust. In Europe, for example, sea levels are expected to rise across all areas except the northern part of the Baltic,

The sea can rise by many metres. Height of sea level in relation to now, in metres. The sea level will continue to rise after 2100. The climate models predict an increase of between 2.3 to 5.4 m by 2300 for RCP8.5 and a rise of between 0.6 and 1.1 m for RCP2.6.



where sea level is falling slightly. This is due to the melting of glaciers and land ice, which reduces the weight on the land and thereby slowly raises the land.

Since 1900, sea levels in Belgium and the Netherlands have risen faster than elsewhere in Europe. In the Dutch city of Vlissingen, for example, sea level has risen by an average of 2.34 mm/year, while in Newlyn, England, sea level has risen by an average of 1.91 mm/year.

Increased risk of stormy weather

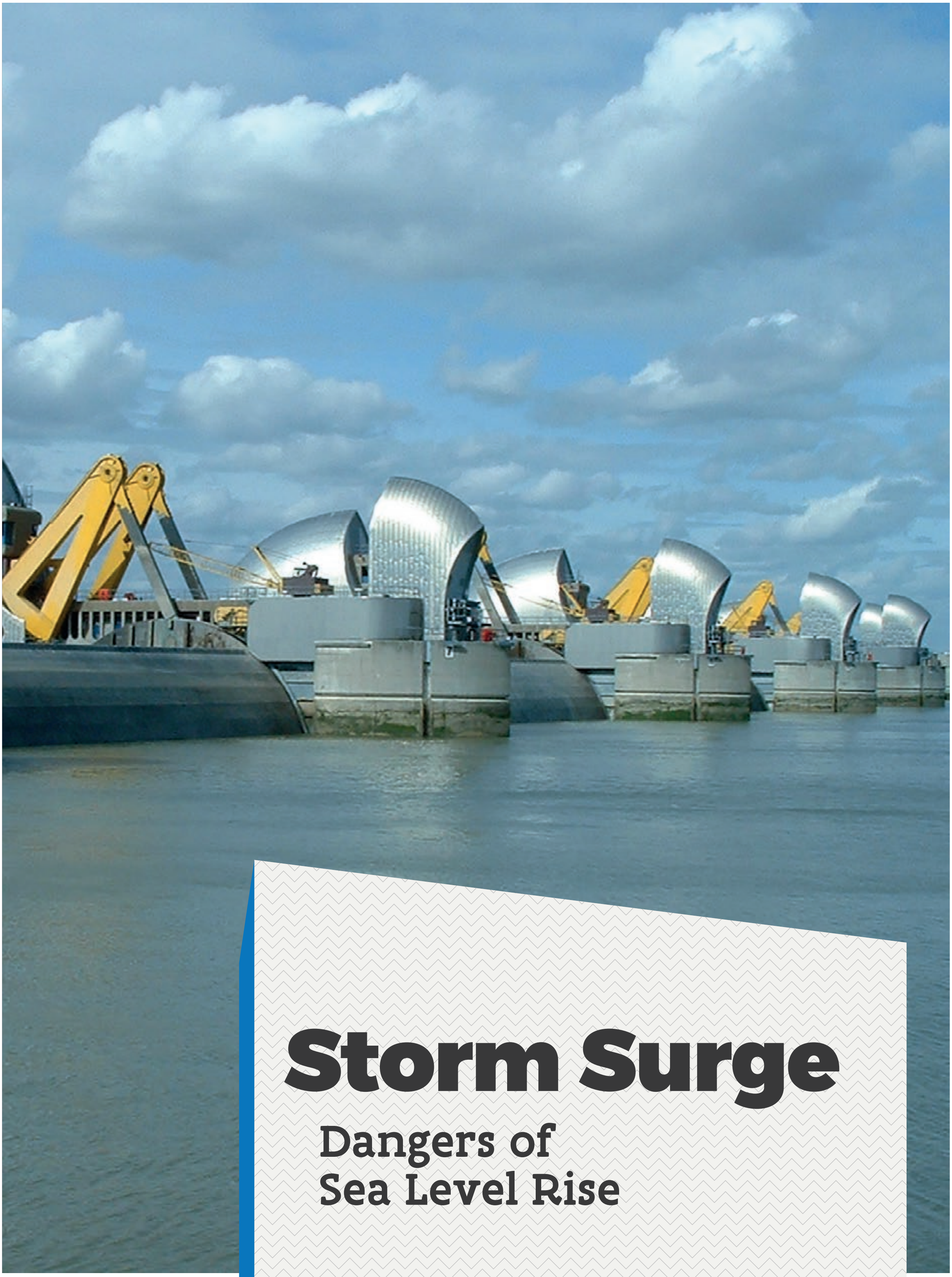
One possible consequence of climate warming is an increase in the frequency and strength of storms. Storms may become more severe due to influences such as changing sea-surface temperatures, the extent of sea ice and the position and strength of global jet streams and currents. At present, measurements in the North Sea region do not show a clear trend in annual average wind speed or highest measured wind speeds. As a result, there remains uncertainty about how an increase in storminess will manifest itself. We may experience an increase in the intensity of storms, a greater frequency of storms, increased likelihood of clusters of storms occurring in quick succession, or a combination of these effects.

That said, the risk of flooding and coastal erosion from storms is increasing under the influence of rising sea levels. After all, a higher sea level increases the impact of a storm surge because the water can reach further inland, but also because the water depth close to the coastline increases, making the wave power stronger. Moreover, storms are usually accompanied by heavy rainfall, so the danger from the water comes from both sides.

Disturbances to marine ecosystems

The oceans absorb much of the CO_2 released into the atmosphere by human activity. Indeed, water (H_2O) absorbs CO_2, creating carbonic acid (H_2CO_3). The result is ocean acidification. The pH value of ocean water has dropped from 8.2 to 8.1 since the beginning of the industrial age and, according to models, may drop to 7.7 or 7.8 by 2100. Acidification has harmful consequences for numerous organisms (especially if they use calcium carbonate or lime, such as shellfish and corals).

Aquatic life is also particularly sensitive to a rise in temperature. In the North Sea, we are already witnessing a shift in the area of distribution of organisms. Over the past forty years, certain species of animal plankton from the North Sea and southwest of the British Isles have migrated some 1,100 km further north. The North Sea waters are home to more and warmer-water species such as sardines and anchovies. Species living in colder waters (cod, haddock, halibut, grey shrimp, various molluscs and crustaceans) are migrating further north.



Storm Surge

Dangers of Sea Level Rise

Looking no further than 2100, a sea level rise between 50 and 80 cm (depending on the scenario) seems manageable in terms of flood protection. But, of course, the water of the sea does not stand still. It is whipped up and set in motion by wind and by the cycle of ebb and flow.

Ebb and flow

Ebb and flow and wind exert great forces on water. The tides are created by the gravitational force that the Moon, and to a lesser extent the Sun, exerts on the Earth's water mass. Twice a month (at full and new Moon), the Sun and the Moon align and the gravitational force is at its highest, resulting in a spring tide. Ebb and flow are not equivalent everywhere on Earth. On the Flemish and French North Sea coast, the average tidal range – the difference in height between high and low tide – is about 4 m, at spring tide reaching 5 m. On the English coast, the tidal range goes from an average of 4 m (7 to 8 m at spring tide) in Cornwall, to an average of 5 m in the Thames estuary (up to 6 to 7 m deeper inland). In Mont-Saint-Michel Bay (Normandy), the difference in height between ebb and flow is no less than 15 m. In enclosed sea areas like the Mediterranean, the tidal range is barely 30 cm. Several factors determine the tide, such as distance from the equator, the depth of the water, and the presence and shape of land masses. In the North Sea, the tidal range is relatively large because the tide forces large amounts of water from the Atlantic through the narrow Channel.

Storm surge

A storm surge is an abnormal rise in the water level caused by a storm, the water rising higher than the predicted astronomical tides. Indeed, apart from the tide, the wind also exerts an important influence on the water level. Heavy storms can be accompanied by a rise in water levels due to the 'whipping up' of water towards land. This phenomenon, in which a fast wind pushes water towards the coast over a long distance, is called 'wind set-up'.

A storm surge is a highly complex phenomenon that is influenced by many factors, including (obviously) the speed and strength of the wind, but also the angle at which the wind approaches the land, the shape of the land mass relative to the sea (think, for example, of the difference between a bay or a straight coastal strip), the depth of the water, and the slope of the continental shelf. When a storm surge coincides with a spring tide (at a full or new Moon), water levels can be very high. It is no coincidence that the major disasters in history, such as the St Vincent Flood of 22 January 1394 or the 1953 North Sea flood, coincided with spring tides. Atmospheric pressure also plays a role, albeit a smaller one. After all, severe storms are caused by low-pressure areas. When the pressure drops and there are fewer forces acting on the surface of the sea, a vast 'bulge', so to speak, is created on the surface of the water, causing the water to rise slightly.

Wave set-up

A storm surge is defined as the rise of the water level above the normal tidal level. Besides the storm surge level there is also the 'wave set-up'. Although directly driven by the wind, the effect of waves is distinguishable from the currents of a storm whipped up by the wind (the wind set-up). Although waves in open water transport relatively little water, they can be responsible for significant transport of water close to shore. Wave height at the coast is strongly influenced by the underlying topography. A coast with relatively deep water and a steep transition from land to sea (like in Cornwall) usually produces very powerful waves, but has a more moderate storm wave energy. By contrast, a coast with shallow water and a gentle slope (like the Flemish coast) usually produces powerful storm surges but has a more moderate surge.

Flooding due to heavy precipitation

Flood risk comes not only from the sea, but also from the land. During a heavy storm, when it rains hard, the surface water system becomes saturated. Especially when the land behind the sea wall is low-lying (think of the polders in Belgium, the Netherlands and northern France), when the sea level is raised (due to storm surge and/or spring tide), the inland excess water can no longer flow naturally to the sea, or only with greater difficulty. To remedy this, both hard and soft measures are possible. Hard measures include installing pumps that pump excess water over the dykes or sea walls. Soft measures include widening rivers, creating flood plains and ensuring that rainwater is buffered on land and in the soil as much as possible. Heavy rainfall can also cause problems in large estuaries – like the Thames – as water brought in by the storm surge and water flowing downstream from land into the sea meet at the head of the estuary.

1000-year storm surge

In studies of sea defences, the strength of a storm is not defined using the Beaufort scale but rather the return period. For example, we speak of a 100-year, 1,000-year or 10,000-year storm surge. The term is somewhat misleading, however. A 1,000-year storm surge is not a storm surge that occurs only once every millennium, but a storm surge that can occur in any given year with a probability of 1 in 1,000.

Flood risk is the product of the probability of a flood occurring and the consequences that such a flood may have (risk = probability x consequence). A super storm surge can cause enormous economic damage and even cost human lives. So the consequences are huge. To contain the risk, it is important to ensure flood risk management solutions are designed to allow only low probability of damage occurring. Flanders has decided to allow only a 1 in 1000 chance on the coast. By contrast, the Netherlands, which is far more vulnerable to sea floods, has opted for a sea defence structure that can withstand a 10,000-year surge for most of its coastal area. In places where the coast is much more diverse in terms of topography, geology, land use and so on – think of the French or English coast – there will also be diversity in the level of protection. In predominantly agricultural and sparsely populated areas, where the consequences of flooding are less dramatic, a higher probability can be allowed.

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Coastal Protection

Grey Infrastructures vs Nature-based Solutions


01 © MDK

There are many ways to protect the coast from the dangers of the sea. Until now, people often opted for hard infrastructures such as dykes, sea walls or groynes. These methods have proven their effectiveness in the past. However, such hard infrastructures also have many drawbacks. They are very expensive to build, their production is often very carbon-intensive (after all, they are mostly concrete structures), they require constant maintenance and repair, and they are not always beneficial to the environment and biodiversity. Lastly, their effectiveness today is no guarantee for the future. If sea levels continue to rise, we will have to reinforce, raise or replace these infrastructures. Besides hard infrastructures, 'soft' or nature-based solutions can also be used to achieve effective coastal protection. Whether hard or soft, every form of coastal protection has its upsides and downsides, and not every solution is suitable for every environment. Sometimes a hybrid approach is appropriate, where hard infrastructure and NbS go hand in hand.

GREY INFRASTRUCTURES

01
Groyne

Groynes are elongated structures laid out at regular intervals that reach deep into the sea. They are usually made out of blocks of bluestone, concrete blocks, sometimes even hardwood. Groynes serve to stabilize the coastline, slow the sea current parallel to the shore and trap sediments (sand).

02
Breakwater

A breakwater is a stone or concrete structure built parallel or at an angle to the waterline to break waves or currents so that the water reaches the shore, estuary or port with reduced force. For example, breakwaters or harbour walls make it possible for ships to enter the harbour unhindered by heavy seas and tidal currents.


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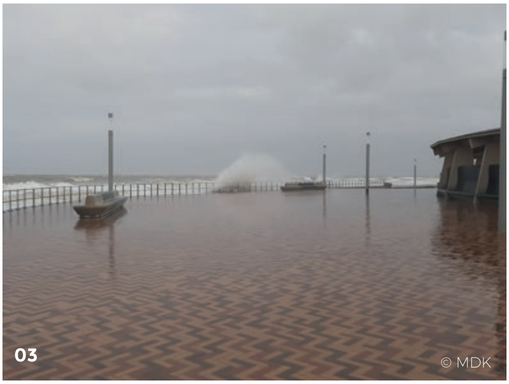

03 © MDK


04 © MAT


05 © MDK

03
Sea wall

A dyke or a sea wall is an infrastructure that protects land from water. They usually run parallel to the surf and are made of hard materials such as concrete or stone, making them sufficiently robust to withstand the force of the waves. The height (crest) of a sea wall is determined by the flood risk. The often sloping embankments break the waves so that they crash over the crest of the dyke at reduced speed. Regular maintenance is important to ensure the sea wall functions properly.

04
Revetment

Revetments are generally sloped structures built from rock or concrete units which act to both protect a soft coast or sea wall from erosion and to absorb wave energy through friction and voids.

05
Storm wall

A storm wall is a wall built on the sea wall or along a harbour to hold back breaking waves or excessive water levels. Storm walls are raised when it appears that existing sea walls or quay walls will not provide sufficient protection. A storm wall can be either a permanent structure built on the quay wall or dyke, or it can be a mobile barrier raised when a storm surge is predicted.

06 © Middelkerke

07 © Andy Roberts

06
Stilling wave basin

A stilling wave basin is a second, forward, often slightly lower part of a sea wall or dyke in front of an existing sea wall. Such a basin consists of a 'tank' between two sea walls in which the breaking waves lose their energy, making them a lesser threat to the areas in the hinterland.

07
Storm surge barrier

A storm surge barrier is a hydraulic structure that can be closed during spring tides or storm surges to prevent large volumes of water from entering the port, the mouth of a river or an estuary and hence leading to flooding. The Delta Works, built after the North Sea flood of 1953, included several storm surge barriers in the estuaries of the Scheldt. Storm surge barriers were also built in the Thames between 1974 and 1984 to protect London from flooding.

NATURE-BASED SOLUTIONS

08
Dunes

Dunes are sand hills that form along sandy coasts with a shallow sea, the wind usually coming from across the sea. Dunes are not fixed habitats. As long as sand drift persists, dunes move. Only when the sand drift becomes stationary due to the colonization of vegetation can we speak of fixed dunes.

A dune is formed by salt-loving plants such as sea rocket *(Cakile maritima)* and sand couch grass *(Elymus farctus subsp. boreoatlanticus)* retaining small mounds of banked sand. Such embryonic dunes are very fragile and can be quickly destroyed by natural phenomena (wind, spring tides) or human intervention (beach cleaning). However, if the vegetation is given sufficient opportunities, embryonic dunes can grow into full-fledged dunes. Marram grass *(Ammophila arenaria)* plays a crucial role in this process. Marram grass is a fast-growing and hardy plant that is resistant to drought, heat, strong winds and drifting sand. It has an extensive underground system of rhizomes with which it can keep up with a sand growth of 1 m per year. In other words, marram grass is quite capable of growing with the sand drift. This makes it possible for the dune to expand rapidly.

On the Flemish, French, Dutch and English coasts, extensive natural dune belts can still

08 © MDK

09 © MDK

be found in some places, sometimes several kilometres wide. Such wide dune areas provide natural, solid and highly effective coastal protection which, moreover, can grow along with sea level rise. In the past, these natural sea defences were opened up in many places to make way for buildings, infrastructure, recreation and tourism, as a result of which they have disappeared or largely lost their function as a sea defence.

The role of dunes in coastal protection is well known, but often the public place more faith in sea walls. After all, dunes are subject to erosion: just think of the cliffs that sometimes form during violent storms. Yet dunes are capable of repairing themselves. After all, dunes are active, living systems: thanks to marine and aeolian sedimentation (supply of sand by the sea and wind) and a biotic component (the crucial presence of vegetation such as marram grass), they grow naturally and can recover over time after storms. Dunes that are cut off from the natural process – for example, by constructing a dune base or dyke in front of the dune – have a reduced self-healing capacity after a storm surge.

Existing dunes can be strengthened in various ways. Dune nourishment can be used to widen dunes or fill missing segments, which then may or may not be planted with marram grass to stabilize the sand. One can also allow dunes to emerge or grow naturally. The SARCC pilot projects in Gravelines, Ostend and Blankenberge are each in their own way experiments to allow young dunes to grow into robust, natural sea defences.

One of the greatest benefits of dunes is that while they do provide solid defence against storms, they are also mobile and adaptable. If they have space to move they can naturally adjust their height and position in response to rising sea levels. This is a critical part of why they can be employed as an effective nature-based solution.

09

Sand nourishments on beach and subtidal zone

Wide sandy beaches that slope down to the sea with a low gradient – as on the French, Flemish and Dutch North Sea coasts – make excellent sea defences. As the water gradually becomes shallower, the beaches break the force of the waves.

Sand nourishments on beaches and the subtidal zone (the stretch of beach just below the low-tide mark) are today one of the most important forms of coastal protection on the Flemish and Dutch coasts. Beaches are made wider and higher with sand extracted at sea or in harbour channels. Dredging boats bring the sand in front of the coast and pump it onto the beach with pressure pipes or pump it on the subtidal zone. This process is repeated every five or six years on average.

It goes without saying that beach nourishment has a much greater impact on slowing waves than subtidal zone nourishment, which is deeper in the sea. The effect of subtidal zone nourishment plays out more over a longer period of time: the sand on the subtidal zone will, over time, under the influence of natural processes such as waves and sea currents, move in a larger area towards the beach, strengthening it.

Beach nourishment is a very flexible solution that allows beaches to be maintained with sea level rise. However, beach nourishment requires continuous monitoring of weak links and places where erosion has occurred. After a heavy storm, for example, deep cliffs may have been carved into the beach. However, research shows that the sand has not simply 'disappeared': it is on the subtidal zone and, over time and under the right conditions, beaches can be restored to their previous state. An additional benefit of beach nourishment is that it creates a wider dry beach, creating more opportunities for tourism and recreation.

Sand replenishment is best done in winter, not only to avoid disturbing tourism, but also because beaches and sandbanks are breeding grounds for numerous fish, molluscs and microorganisms in spring and summer. Research shows that after sand replenishment, life on the seabed needs one or two years to fully recover.

10
Dune-before-dyke

Dunes form a natural and stable sea defence. Even if a dyke or sea wall is already present – for example, in seaside towns – a dune seaward of the sea wall can provide additional protection against floods and waves. Moreover, dunes provide larger sand storage that protects beach and subtidal zone from erosion. In an ideal scenario, the dune ensures that the dyke does not need to be raised further. Lastly, the dune-before-dyke principle is beneficial to biodiversity and can also add value in terms of tourism.

11
Sand engine

An alternative to regular sand replenishment is the construction of a 'sand engine'. Instead of depositing the sand where you want it, you deposit it elsewhere, for example deeper into the sea or as a large peninsula along the coastline. Then you let nature do its work. Under the influence of tides, sea currents, waves and wind, the sand will spread further along the coast over the years. In time, the sand will create a larger and higher coastal plain there too, better able to break waves and limit damage during storm surges. While sand replenishment is necessary at regular intervals (about every four or five years), a sand engine is an intervention that is expected to have to be repeated only once every twenty years, thus

significantly reducing damage to the marine ecosystem.

In 2011 the Netherlands built a sand engine off the coast of Hoek van Holland. Here, the sand engine took the form of a peninsula about 5 km long and 1 km wide. It required no less than 20 million m^3 of sand. Today, ten years later, the sand engine at this location has proven to be a good way to strengthen the coast in the long term. Evaluations show that the coast is widening in a zone dozens of kilometres wide, dune growth is well under way and recreational users really appreciate the area.

Following the Dutch experiment, a 'sand engine' has also been constructed off the coast of Bacton in the UK: 1.5 million m^3 of sand was placed along the coast to protect a 5 km stretch of the UK's east coast, including the nationally critical Bacton Gas Terminal together with its neighbouring communities.

12
Biogenic reefs

Sandbanks on the subtidal zone are an excellent sea defence because they soften the force of the waves. But those sand layers are subject to erosion and not always stable. Biogenic reefs can be an efficient and natural means of stabilizing the sand and attenuating incoming wave energy. A number of pilot projects are currently under way on the Flemish coast to stabilize the sand on the subtidal zone by using organisms that attach themselves to the seabed. A first experiment involves seaweed or sea grass planted on large textile mats attached to the seabed. A second one involves the creation of a mussel reef on an underlying textile mat. Mussels stick together and create a natural reef with their shells. The third experiment relies on tube worms. Tube worms nest in the sand and create a calcareous tube to protect themselves. In doing so they stabilize the soil. Lots of worms together will build their tubes higher and higher, making it possible for a reef to form.

In Newlyn, England, a pilot project with 'eco-blocks' is under way within SARCC. These are artificial, low-carbon blocks that provide an ecological alternative to rock material or the classic concrete blocks. The eco-blocks provide a suitable surface (with the right acidity) for rapid colonization by marine fauna and flora.

Biogenic reefs have several advantages: the sandbank is less subject to erosion and rich ecological habitats emerge that can also serve as food for other organisms and animals.
The algae and shellfish could also serve for human consumption or provide the setting for ecotourism (diving and snorkelling).

13
Flood areas

Paradoxically, flood areas can also provide protection from the sea. Salt marshes, mud flats and tidal flats are natural environments between land and sea that are periodically flooded by seawater. Thanks to the sediments deposited by the sea, the land will develop growths in the long term. A vegetation of halophytes (salt-tolerant plants) or colonization by algae and shellfish are essential for the stability of these environments because they retain sand and other sediments. On the North Sea coast, the area of mudflats and salt marshes has been greatly reduced by reclamation since the Middle Ages. The Zwin (Belgium) and the Drowned Land of Saeftinghe (on the border between Belgium and the Netherlands) are examples of mudflats and salt marshes that are still in direct contact with the sea. But since they are separated from the reclaimed coastal plain by sea walls, their significance in terms of sea defence is relatively limited. They do, however, provide additional protection for the dykes. In the UK, there are still extensive salt marshes in several places, including in the Thames, Crouch and Blackwater estuaries, where there are numerous creeks and islands. The Environment Agency has undertaken a number of managed realignments along England's south and east coasts to restore salt marsh, partly for flood risk, partly for habitats. Salt marsh is also present in south-west estuaries, although generally smaller areas than along the east coast.

> In the UK, extensive salt marshes can still be found at various locations, among others in the estuaries of Colne and Blackwater, where there are numerous creeks and islands.

A special example of a flood area is the SARCC pilot in Vlissingen. Instead of building the dykes higher and higher, Vlissingen decided to allow the water, in the event of an exceptionally heavy storm surge, to surge over the dyke and drain away in a controlled manner, via an existing road, into a buffer basin located in an open area in the urban fabric.

14
Artificial island

In case of extreme sea level rise, instead of reinforcing the existing coast, building a second, forward coastline in the sea can be envisaged. This would take the form of an artificial island. Such an offshore island can play a role in attenuating waves and currents. A more sheltered area is created between the island and the existing coast. Such an artificial island could take the form of a nature-based solution (e.g. a sandy island that provides a new habitat for birds and marine life), but it could just as easily be conceived as a hard infrastructure (a concrete dyke in the sea).

Nature-based Solutions and Ecosystem Services

EXTENSIVE RESEARCH WAS CONDUCTED within the SARCC project on the 'ecosystem services' (ESS) provided by nature-based solutions by comparison with traditional, hard coastal protection infrastructure such as dykes and storm walls. Thinking in terms of ESS sheds new light on the broad importance and added value of nature-based solutions.

What are ecosystem services?

ESS are defined as 'all the goods and services that ecosystems provide to society'. ESS are divided into four broad groups:

1) **Provisioning services**
These are the products from ecosystems that humans need to support themselves: think of food, water or wood.

2) **Regulating services**
These are the benefits that humans gain because ecosystems help to regulate certain processes, such as pollination by insects, water purification in the soil or protection from floods.

3) **Cultural services**
These are services that provide spiritual enrichment, cognitive development, recreation or an aesthetic experience.

4) **Supporting services**
These are all the services that support the previous services, such as the nutrient cycle, the process of photosynthesis or a healthy, living soil that enables agriculture.

The value of ecosystem services

The ecosystem approach aims to support, strengthen and improve ecosystems so that they function better and thus provide services that benefit our society. Today, ESS are either hardly or not fully considered in commercial markets or policy decisions. They are not 'valued', literally and figuratively. Scientists are therefore striving to quantify the various ESS insofar as possible in terms comparable to economic services or produced capital.

Decline of ecosystem services

Over the past century, humankind has transformed ecosystems faster and more dramatically than in any comparable period in human history, largely to meet the rapidly growing demand for food, land, fresh water, timber, fibre and fuel. About 60 per cent of Earth's ecosystems today are degraded or used unsustainably. There are strong suspicions that changes humans are making to ecosystems are leading to accelerating, abrupt and perhaps irreversible changes, with dire consequences for human well-being.

> **Everyone on Earth is completely dependent on Earth's ecosystems and the services they provide. In a sense, their total value to society is infinite.**

The 'exploitation' of the planet has contributed to significant net gains in human well-being and economic development. An important note here, however, is that not all regions and groups of people in the world have benefited equally from this process, while the adverse effects of the degradation of ESS are borne disproportionately by the poor. This contributes to increasing inequalities between groups of people and are a cause of social and geopolitical conflict.

The current neglect of ESS could ultimately jeopardize sustainable human existence in the biosphere. Society on Earth would grind to a halt without the services of ecological and living systems. In fact, everyone on Earth is completely dependent on Earth's ecosystems and the services they provide. In a sense, their total value to society is infinite.

Ecosystem services on the coast

In the coastal region – especially in the seven pilot cities – economic, social and ecological interests are strongly intertwined. Some coastal ESS, such as recreation or fisheries, can be quantified and expressed as an annual 'benefit'. Some ESS cannot be expressed as an annual benefit, think of water retention, climate regulation (carbon stock in biomass) or flood prevention. For these services, it is important to preserve and, if necessary, grow the existing stock. Some 'services' are extremely difficult to quantify. For instance, it can be argued that a healthy coastal zone contributes to people's mental well-being. Supporting mental health also improves the overall resilience of a community, both physically and mentally.

Take the example of a dune belt. Dunes provide many ESS. Firstly, if they are wide enough and robust enough, they constitute an effective form of coastal protection which, unlike hard infrastructure, can spontaneously recover over time after a heavy storm and can even grow with sea level rise. Dunes also provide other ecosystem services. They are attractive for small-scale recreation and thus contribute to people's mental well-being. They are valuable nature areas and constitute a habitat for rare flora and fauna. Finally, dunes are important for rainwater infiltration. Dunes purify water and contain a freshwater lens that is useful for the extraction of drinking water and provides a buffer against salty seawater.

To link as many ESS as possible to coastal protection techniques, it is important to consider potential ESS early on in the design phase. Therefore, efforts should be made to maximize the use of ESS in the widest possible spectrum (provisioning, regulating, cultural, supporting).

European Policy and Goals

UN

In the Paris Climate Accords, policymakers worldwide decided to limit the rise in temperature to 2°C above pre-industrial levels and to make efforts to limit it to 1.5°C. European countries and the UK have also committed to this 2015 agreement.

In February 2022, the UN Intergovernmental Panel on Climate Change (IPCC) published its sixth report on climate change, with a focus on impacts, adaptation and vulnerability. The report states that without immediate and drastic reductions in emissions across all sectors, limiting global warming to 1.5°C above pre-industrial levels is beyond our reach. The report confirms that climate change is here to stay and that some of its effects are now inevitable. Around the world, the climate crisis is putting lives and livelihoods at risk, especially for the most vulnerable. One of the report's key findings is that man-made climate change is already affecting nature and humans more intensely, more frequently and over a wider geographical area than previously thought.

The report argues that, in addition to mitigation (reducing emissions), we should also focus on climate adaptation (adapting our environment to the changing climate), and in that context it explicitly refers to NbS: 'Nature-based Solutions ... can be cost-effective and deliver social, economic and cultural benefits, while contributing to the conservation of marine biodiversity and the reduction of cumulative anthropogenic causes.'

EU
Green Deal and Climate Law

Climate change and environmental pollution pose an existential threat to Europe and the world. To meet these challenges, the EU has set a binding target with the Green Deal and the European Climate Law to be climate neutral by 2050, i.e. net zero greenhouse gas emissions by that year. As an intermediary step towards climate neutrality, the EU has committed to reduce emissions by at least 55 per cent by 2030.

Besides drastically reducing greenhouse gas emissions, the Green Deal also focuses on climate adaptation. NbS occupy a privileged place in this commitment, including for maritime areas. In coastal and sea areas, NbS can strengthen coastal defence while delivering other benefits such as carbon storage and tourism opportunities as well as biodiversity conservation and restoration. In other words, the EU recognizes that NbS are particularly suited to mitigate climate impacts.

© MDK

2 Seas, 4 Countries, 7 Cities

Characteristics and National Policies

THE SARCC PROJECT IS A COLLABORATION between seven cities or municipalities from four countries around the North Sea and the Channel, all of which face more or less similar hydrodynamic and climatic conditions. That said, there are major differences between the countries and pilot cities, in terms of both their natural, urban and economic context and of their planning and administrative organization. Since cooperation and cross-border perspectives are essential to gain knowledge and implement solutions, it is important to make sense of these differences.

① BELGIUM/FLANDERS

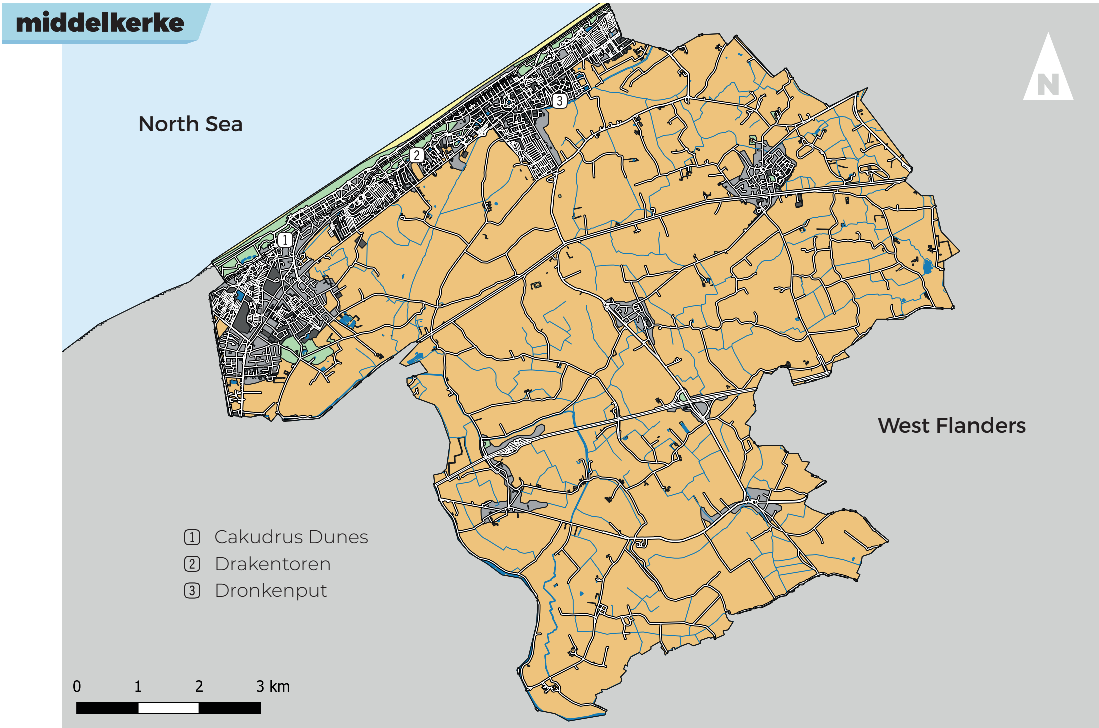
Sandy beaches

The Flemish coast consists of a more or less straight stretch 67 km long. Along almost its entire length, sandy beaches slope gently into the sea. The historic belt of dunes that naturally protected the hinterland from the forces of the sea have since been opened up in many places and have often been built on. The towns and seaside resorts are generally protected by the beach and a hard sea wall or promenade. Due to urbanization, only one third of the original dune belt is still recognizable as actual dunes. Most of these fragmented dunes are protected as nature reserves (Natura 2000) and safeguarded from further development by the 1993 Dune Decree.

Major economic interests

The Flemish coast is one of the most densely built-up and most densely populated coastal areas in Europe. Today, the ten coastal municipalities (excluding the city of Bruges) have a combined population of more than 220,000. The vast beaches with their fine sand are very popular with domestic and foreign tourists. Overnight tourism could count on 5.5 million visitors to the coast in 2019, the year before the outbreak of the Covid pandemic, accounting for a total of 27.7 million overnight stays. On top of that, the coast sometimes attracts more than 140,000 day trippers on peak days. Besides tourism, other major economic interests play a role on the coast, such as the industrial seaports of Zeebrugge and Ostend, offshore wind energy, the marinas of Nieuwpoort and Blankenberge, Ostend airport, and agriculture in the polders.

The Flemish coast and hinterland are very vulnerable to coastal flooding. Most of the polders behind the sea defences are below the level of an annual storm surge (+5.5 m TAW). The building density of this area ranges from 30 to 50 per cent. Flooding can therefore cause a lot of material damage and even cost human lives.



LAND USE / LAND COVER

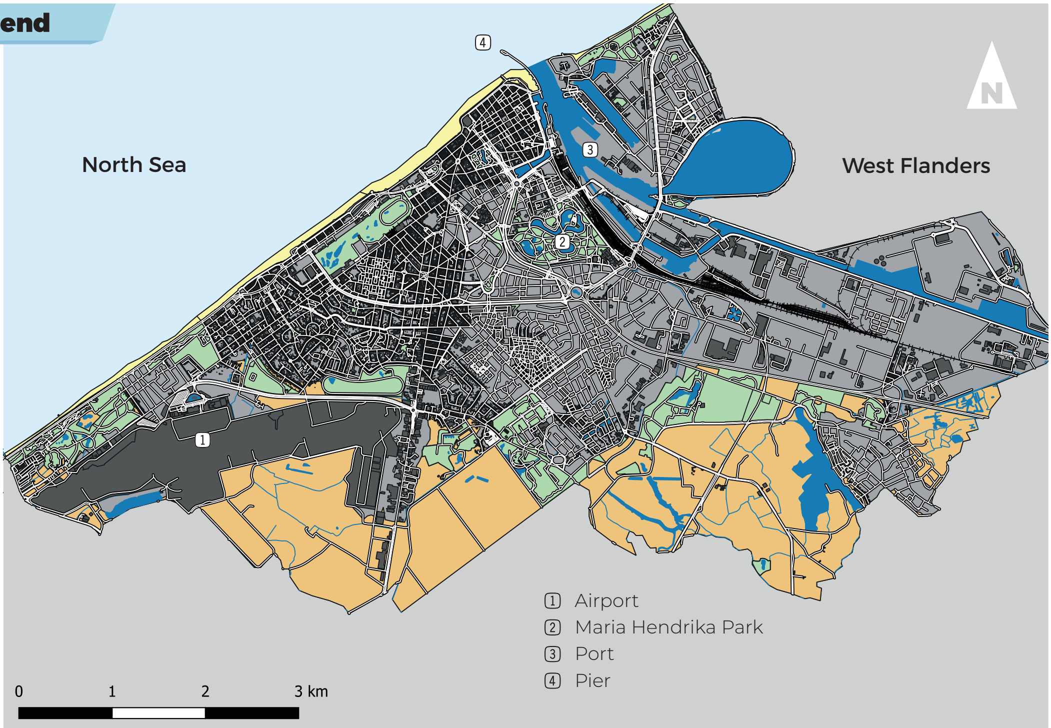
agricultural urban green space surface water beach

Coastal Safety Master Plan

In the coastal region and at sea, the Federal and Flemish Governments have different responsabilities. For activities between the low-water mark and international waters, the Federal Government is competent. The Flemish Region – more specifically the Agency for Maritime and Coastal Services (MDK), which comes under the Mobility and Public Works policy area – is responsible for sea defences and coastal protection. In 2011 the Flemish Government approved the Coastal Safety Master Plan. This plan is based on the principle 'soft where possible, hard where necessary'. It provides for measures to protect the Flemish coast against a 1000-year storm surge until at least 2050. The Master Plan envisages a sea level rise of 30 cm by 2050. Some structures, such as the storm surge barrier, have a higher protection status and longer lifespan and are designed to resist a sea level rise of 80 cm by 2100. Meanwhile, in 2022, implementation of the Coastal Safety Master Plan is well advanced. Both 'soft' (e.g. beach and dune replenishment) and 'hard' (e.g. dykes, sea walls and flood defences) sea-defence measures have been realized or are planned in the near future.

Although the Region is responsible, local authorities such as cities, municipalities and the province have the possibility to help shape coastal protection interventions themselves, provided they fit within the framework of the Coastal Safety Master Plan. This gives local governments some say in the elaboration of coastal protection. The pilot projects running within SARCC in Blankenberge, Middelkerke and Ostend are a response to local needs in terms of tourism, ecology, health environment and public space, among other things, and fall within the outlines of the Master Plan.

ostend



Coastal Vision 2100

In December 2017, the Flemish Government decided to launch a Complex Project 'Coastal Vision'. Coastal Vision envisaged a long-term approach to coastal protection with 2100 as the time horizon. In June 2021, the complex project was discontinued and replaced by a new process. Together with many stakeholders within the coastal zone and experts, the Department of Mobility and Public Works is investigating within which space coastal protection should be shaped in the future.

Given the high degree of uncertainty regarding sea level rise and the major economic and social interests at stake along the Flemish coast, the Department is investigating the most desirable measures in the event of a sea level rise of up to 1, 2 and 3 m. This does not mean that dykes or sea walls 3 m high will eventually be built everywhere on the Flemish coast, but it does mean that future measures and interventions must be able to grow along with a further rise in the sea level. This is not just about hard coastal protection. Coastal Vision also pays due attention to using NbS wherever possible.

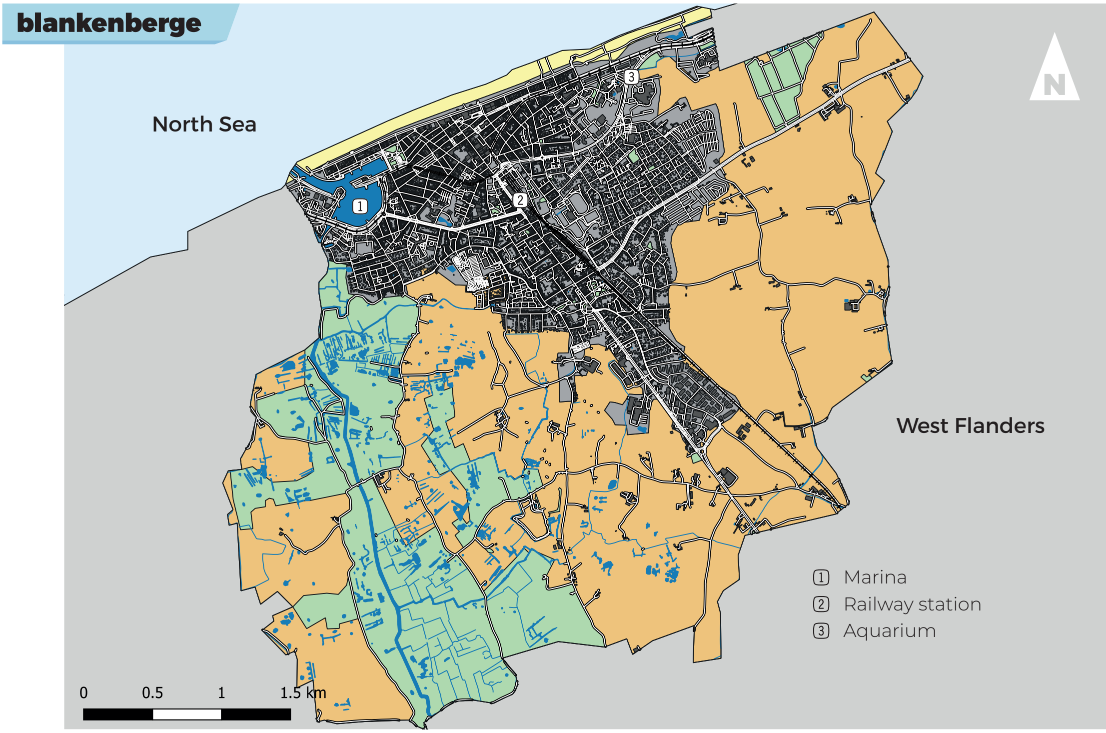
2 UNITED KINGDOM

A diverse coastline

The UK consists of several islands in the Atlantic Ocean and has a coastline more than 12,000 km long. This makes it the longest coastline of any country in the SARCC project. The pilot areas within the SARCC project are located along the North Sea and the Channel. The coastline is very diverse and is characterized by an alternation of beaches, dunes, cliffs, estuaries and tidal inlets. Open natural and agricultural areas with sometimes scattered buildings are interrupted here and there by very urban and densely built-up areas.

Alternate use

The varied coastal landscape has very diverse uses. In certain places along the coast, smaller



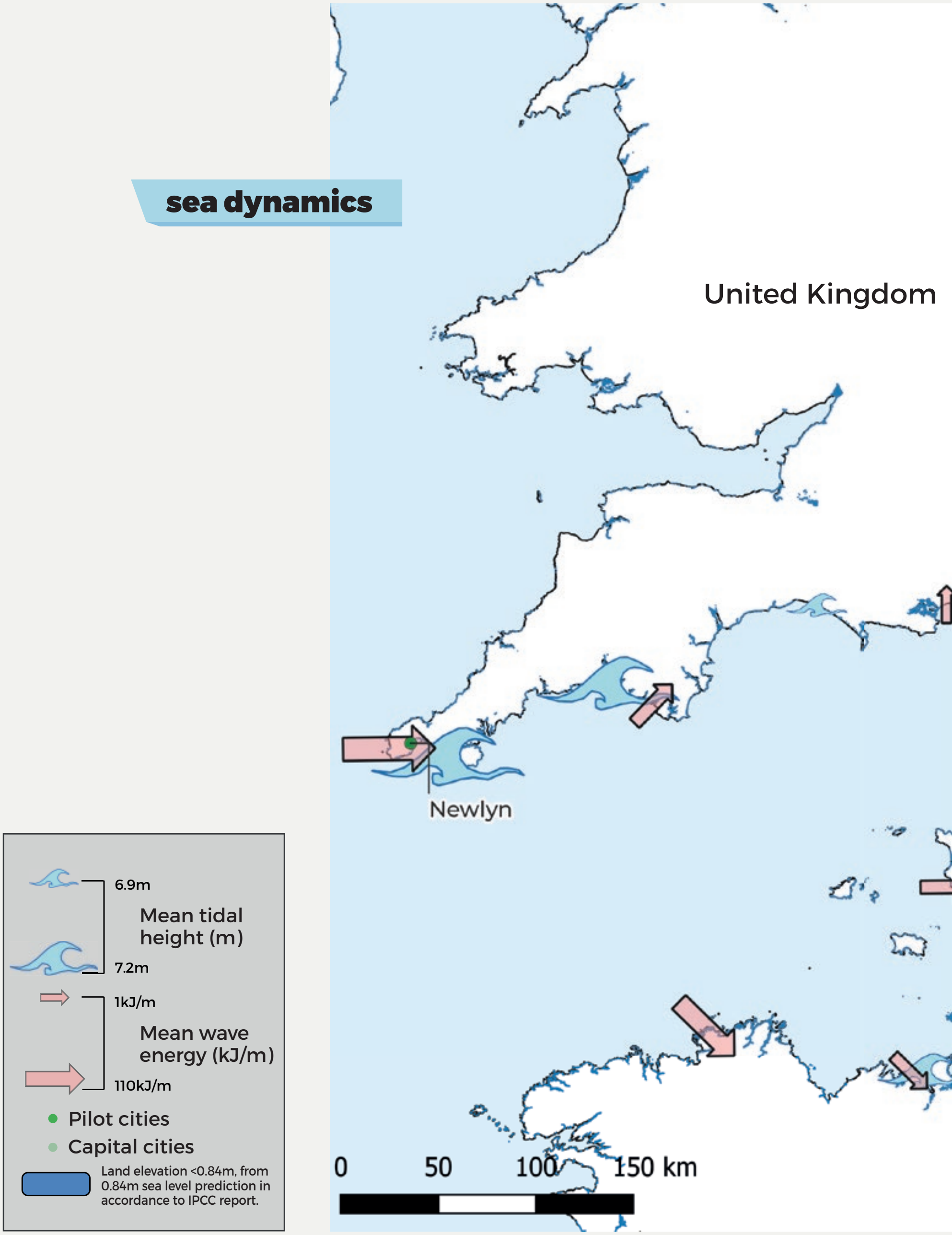
and larger towns developed. Besides housing, joint tourism and recreation use emerged in many places, but harbours also developed, which over time grew into important economic gateways. Within the '2 Seas' area, Southampton, Felixstowe and Dover are examples of this. Many of the built-up areas are highly vulnerable to sea level rise. This is not only the case along the coast, but also inland. Just think of the port of London, which is grappling with the consequences of rising sea levels.

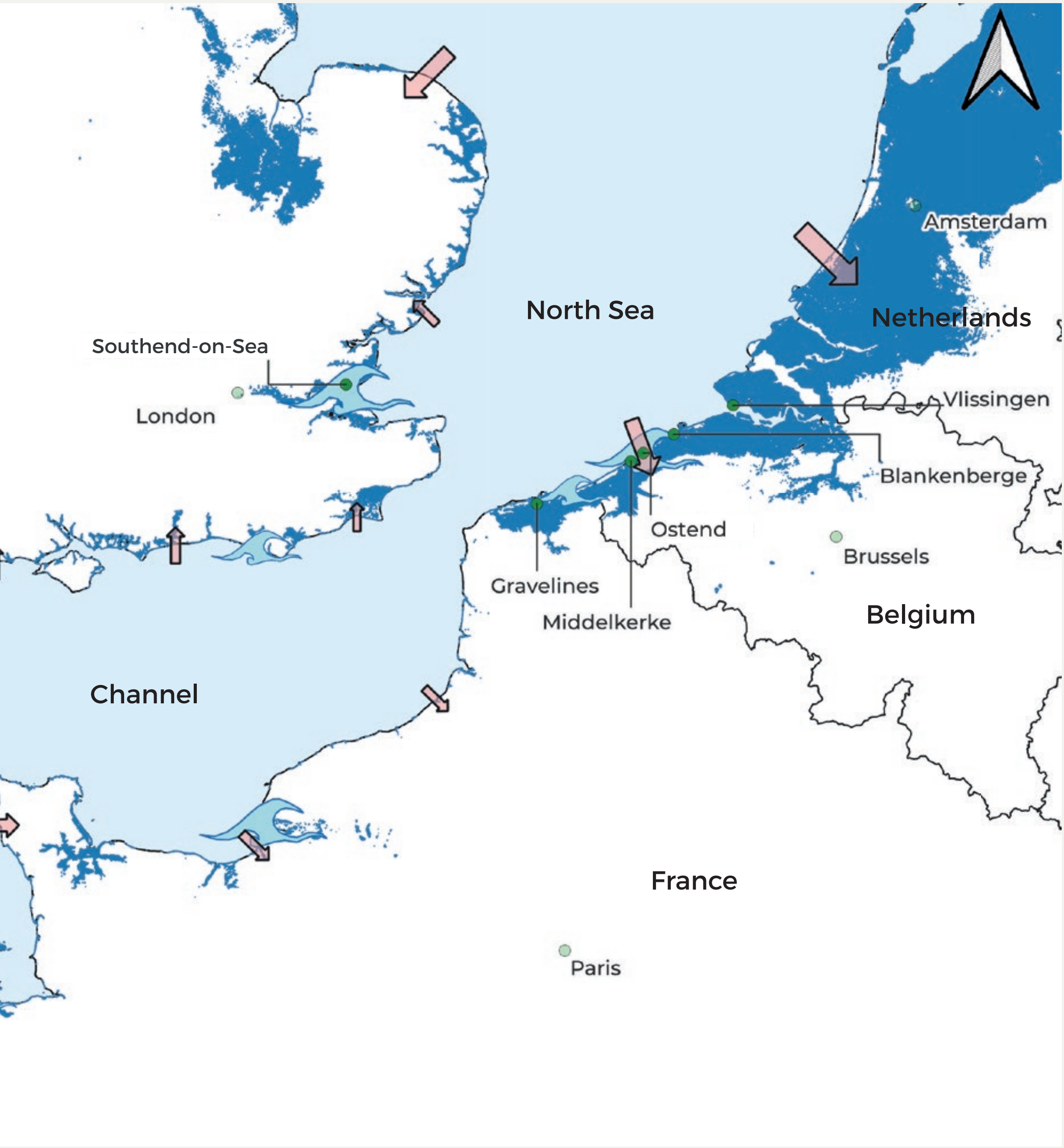
The diversity of coastal landscapes creates a difference in exposure to storms. Both SARCC pilots in the UK are examples of that diversity of contexts. Southend-on-Sea lies in the north-east of the highly urbanized Thames estuary, while Newlyn (near Penzance) is located in rural Cornwall, the most south-westerly corner of England.

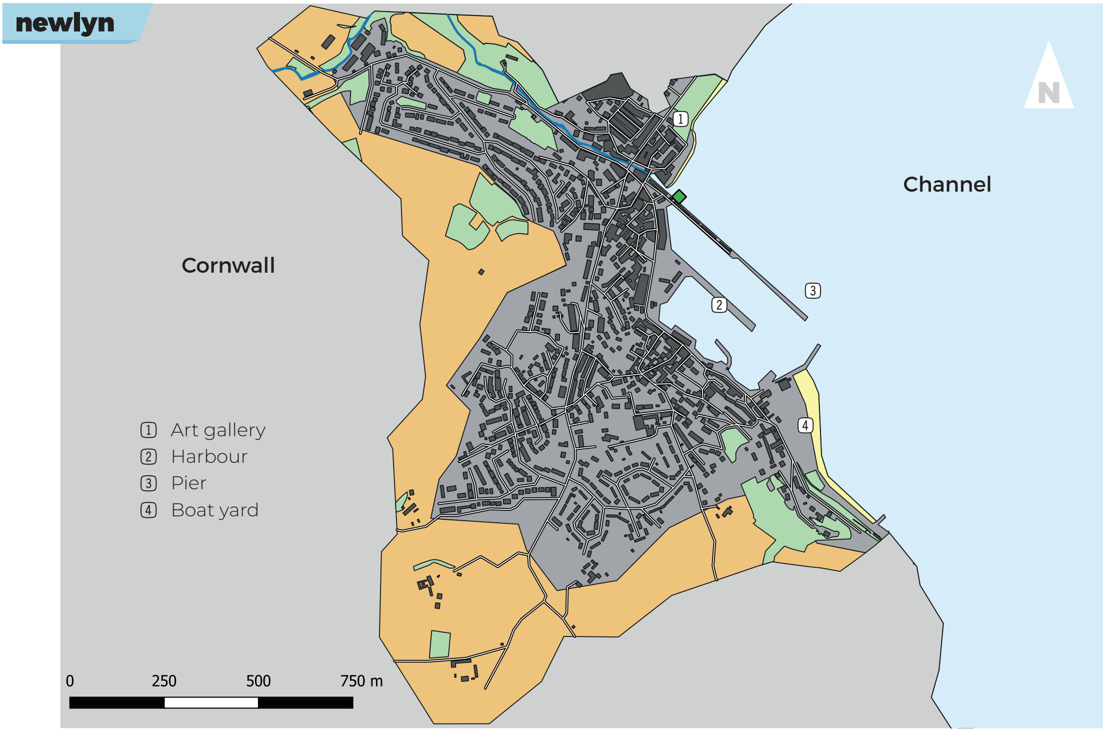
Cornwall's coast is dominated by high cliffs and is exposed to energetic waves, especially during powerful Atlantic storms. Further east, the coast is much gentler; there, there are low glacial rocks and estuarine areas where rising water levels can cause major problems. Urbanization in Newlyn developed along the low-lying coast and gradually extended further into the hilly areas further inland. Not only the powerful waves from the sea, but also the small, steep rivers upstream that react quickly to rainfall pose a major risk to this urban area and to the port. After all, water is difficult to drain off when sea levels are high. Moreover, there is little room for NbS as many developments are located on the waterfront. The pilot aims to manage the risk by introducing NbS into the intertidal zone.

Southend-on-Sea is a major tourist destination at the mouth of the Thames in the North Sea. The town lies on higher ridges with a firm soil composition and is relatively well protected from sea floods, but because most of the region is urbanized and paved, the town is highly vulnerable to flooding from the land

sea dynamics




North Sea
Amsterdam
Netherlands
Southend-on-Sea
London
Vlissingen
Blankenberge
Ostend
Brussels
Gravelines
Middelkerke
Belgium
Channel
France
Paris



due to the difficulty in draining surface water to the sea in the event of heavy rainfall.

Coastal management

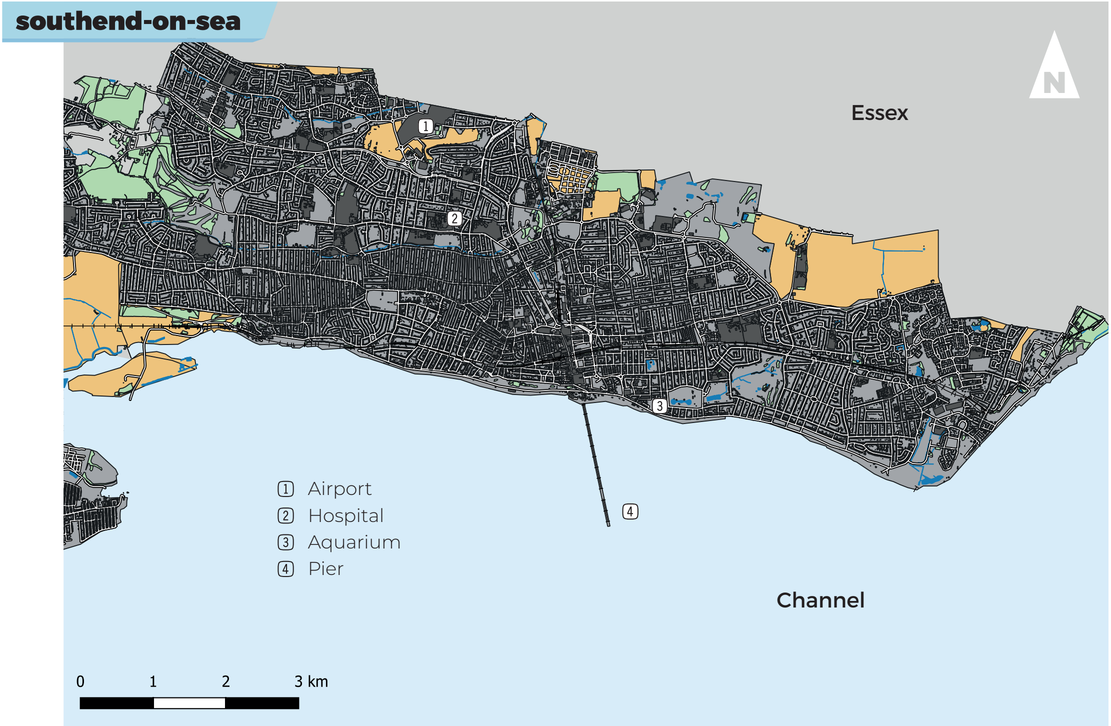
Flood risk management in England is highly diversified and responsibilities are spread across several organizations. Strategic and financial responsibilities for flood and coastal erosion risk management are centrally organized in the Department for Environment, Food and Rural Affairs (DEFRA). Flood risk management relies on, among other things, NbS.

In July 2020 the Flood and Coastal Erosion Risk Management policy statement was published. This policy statement describes the government's long-term ambition to create a country more resilient to flooding and coastal erosion. A key point in this is to use the power of nature to reduce the risk of flooding and coastal erosion. The 25 Year Environment Plan, published in 2018, also advocates the use of NbS for flood management.

In 2020 the Environment Agency – the main body responsible for flood protection – developed a National Flood and Coastal Erosion Risk Management (FCERM) strategy. The strategy describes a vision of a country ready for and resistant to flooding and coastal change until the year 2100.

The most important plans at the regional level are the Shoreline Management Plans (SMPs). These set out how the ambitions of the national strategy are to be achieved within local policies, provide a risk assessment of coastal flooding and erosion, and assess the impacts of future sea level rise. The current twenty SMPs for the coast of England provide a policy framework for coastal management for the twenty-first century.

In addition, Flood Risk Management Plans (FRMPs) have been produced across the UK. These include a national document setting out how organizations, stakeholders and communities will work together to manage flood



risk across England from 2021 to 2027. This document specifically states that NbS for flood risk management can make an important contribution to improving the environment for humans and animals by improving river and coastal waters and by creating and enhancing natural habitats.

③ THE NETHERLANDS

Delta of the Scheldt, Meuse and Rhine

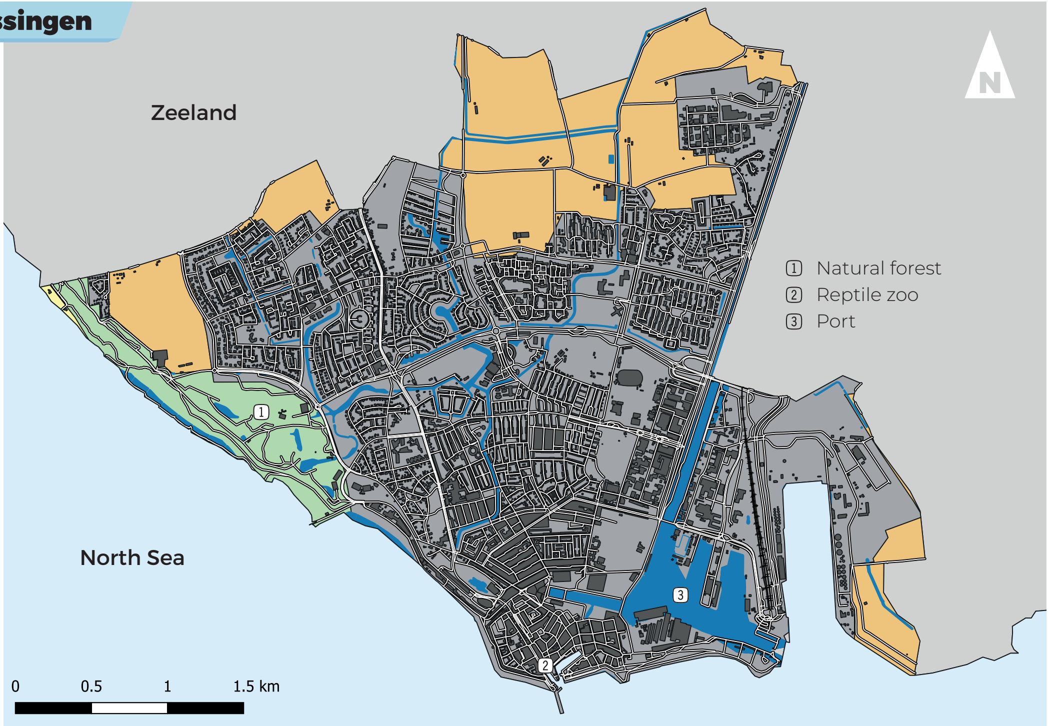
The Netherlands is located in the delta of the Scheldt, Meuse and Rhine rivers. Nearly one-fifth of the surface of the Netherlands consists of water, about one-fourth of the country is below sea level and just under one-third is prone to river flooding. The history of the Netherlands is therefore strongly intertwined with centuries of struggle against water. For instance, the 1953 North Sea flood, which claimed more than 1,800 lives in the Netherlands, is engraved in the collective memory.

The entire Dutch coastline has a length of about 523 km, 353 km of it bordering the North Sea, the rest the Wadden Sea and the Western Scheldt. Along the coast, 254 km of robust dunes as well as dykes and flood defences protect the country from coastal flooding. Besides many sandy beaches, open agricultural and natural areas are also present as are scattered built-up areas, interspersed with urban and densely built-up areas.

Diverse functions in a diverse landscape

The varied coastal landscape is used in very diverse ways. Smaller and larger towns developed in well-located places along the coast. Over time, joint tourism and recreation use developed here in many places in addition to housing. Ports also developed, becoming important economic gateways over time. Rotterdam is the largest port and is located at the mouth of the Rhine. It is followed closely by the port of Amsterdam.

vlissingen



Pilot city Vlissingen is a small port city at the mouth of the Western Scheldt estuary in the province of Zeeland. Zeeland has been particularly prone to flooding since time immemorial. Virtually the entire province lies at or below sea level and since the Middle Ages, the fight against water has been a common thread running through the province's history. Land reclamation and land loss alternated with one another and the geography of Zeeland changed radically throughout history. Many smaller islands gradually grew together to form the large peninsulas we know today.

Like most of the province, the town of Vlissingen lies below the level of an annual storm surge. The town is protected by a reinforced dyke to the south and sand dunes to the west. The inner polders are drained by the Canal through Walcheren, which connects to the sea via locks.

Powers and objectives

Since 1814, water protection in the Netherlands has been a national responsibility. Compared to other countries, the Dutch have a very low risk of storm surge with an average return period of 10,000 years. After the major floods of 1916 and 1953, the coastline of the Netherlands was made as short as possible to achieve the greatest possible control and reduce risks.

In the Netherlands, flood risk management responsibilities are set out in the Water Act (2010). The Ministry of Infrastructure and Water Management is responsible for national water policy, with the Directorate-General for Public Works and Water Management being the implementing organization for the management of large bodies of water (sea and rivers). The Water Boards in turn are responsible for regional waters (canals and polder waterways) and ensure the preservation of water quality and quantity. They are also responsible for protecting the country from flooding. Provinces have a coordinating function to monitor the condition of primary flood defences, potential flood risk and flood risk maps. Municipalities play an important role in flood warning and in the development of evacuation plans.

The National Water Plan (2016–21) sets Dutch policy for water safety and freshwater supply. Among other things, it examines how the abundance of water in the Netherlands can best be incorporated into spatial planning. In turn, the Delta Programme is an implementation programme for the National Water Plan. The Delta Plan outlines the course for the future: the government takes the initiative to protect the Netherlands now and in the future against flooding and ensures sufficient freshwater. Work is currently under way on the National Water Programme (2022–27), which combines the former National Water Plan (2016–21) and the Management and Development Plan for National Waters.

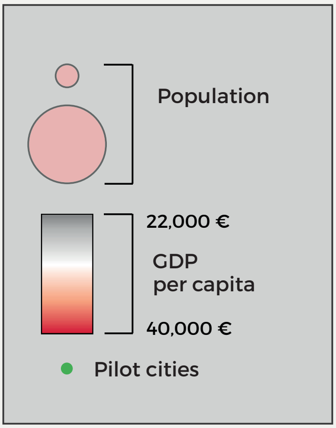
Delta Decisions have been elaborated around the various themes of water safety, fresh water and climate adaptation. One of these is the Delta Decision on Water Safety, in which the protection of humans and the economy against flooding from the sea, major rivers and lakes is paramount. The core of the decision is that the probability of death from flooding for everyone behind the dykes should not exceed 1 in 100,000 per year by 2050. To this end, efforts will be made to strengthen and maintain primary flood defences, dunes and storm surge barriers. This is elaborated, among other things, in the High Water Protection Programme (HWBP) in which the twenty-one Water Boards and the State work together on a major dyke reinforcement operation to be completed by 2050.

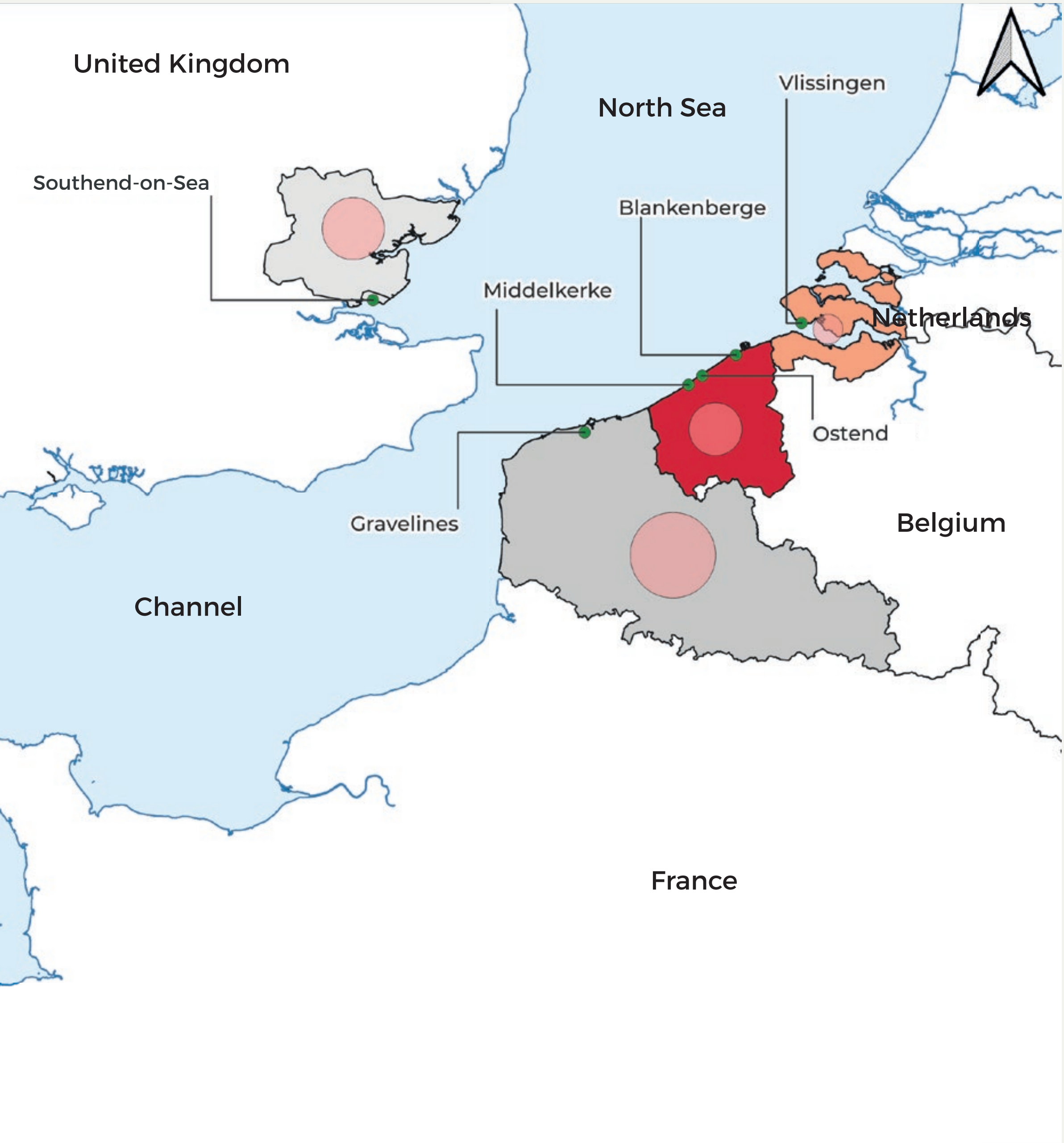
The Strategic Sand Decision was elaborated to complement the Delta Decisions. This sets out how the sand along the Dutch coast can protect the country naturally under the principle 'soft where possible, hard where necessary'. The Directorate-General for Public Works and Water Management maintains the coast with sand replenishment. This is necessary because wind, wave action and currents constantly cause sand to disappear into the sea and beaches and dunes to lose their natural protective function. The replenishments contribute not only to maintaining the coastline, but also to local and regional goals for an economically strong and attractive coast.

A natural and hybrid approach

Besides protection, coastal safety projects also take into account the spatial quality of the coastal zone. Examples can be found in the sea defences of Scheveningen, Vlissingen, Zeelandic Flanders, Hondsbossche and Pettermer. Traditional hard coastal defence has evolved into a hybrid form of coastal defence where NbS and hard infrastructure alternate where possible. The Netherlands is further committed to NbS. The National Water Programme stipulates that in terms of water safety, the central government promotes building with nature. In the coastal zone, much has already been done in recent years in terms of dynamic coast and dune management. The sand engine is a good example of this.

population and GDP




United Kingdom
North Sea
Vlissingen
Southend-on-Sea
Blankenberge
Middelkerke
Netherlands
Ostend
Gravelines
Belgium
Channel
France

④ FRANCE

Many seas

The French coastline is very diverse and, not counting the overseas territories, has a length of more than 5,800 km. The country borders the North Sea, the Channel, the Atlantic Ocean (Celtic Sea and Bay of Biscay) and the Mediterranean. There are sandy coasts, marshes and mudflats as well as rocky coasts, sometimes with cliffs. Scattered along the coast are cities and towns of various sizes. France also has many ports. The largest are those of Marseilles and Le Havre, but there are also important seaports in Brest, Calais, Dunkirk and Nantes. The SARCC project concentrates on the coasts along the North Sea and the Channel. That part of the coast runs from the Belgian border in the east to just past Roscoff in the west.

In France, floods are a major risk. Flood risks are mainly caused by flooding from the sea and flooding from rivers and watercourses. For floods from the sea specifically, 1.4 million inhabitants are exposed to the risk. In addition, most coastal municipalities have a high tourist capacity, the total share estimated at seven million beds.

Hauts de France

The coastal town of Gravelines is located in the Hauts de France region, between Dunkirk and Calais. The coast of this region is called the Opal Coast and consists mainly of sandy beaches. Further west, beyond Calais, the coast turns into a cliff coast. The Opal Coast has many seaside resorts but is not as intensively built-up as, for example, the Flemish coast. The hinterland of Gravelines consists of vast polder landscapes where an extensive network of canals, ditches and watercourses (the so-called *wateringues*) drain the lower-lying agricultural areas to the sea. So here too, the danger of flooding comes not only from the sea, but also from land.

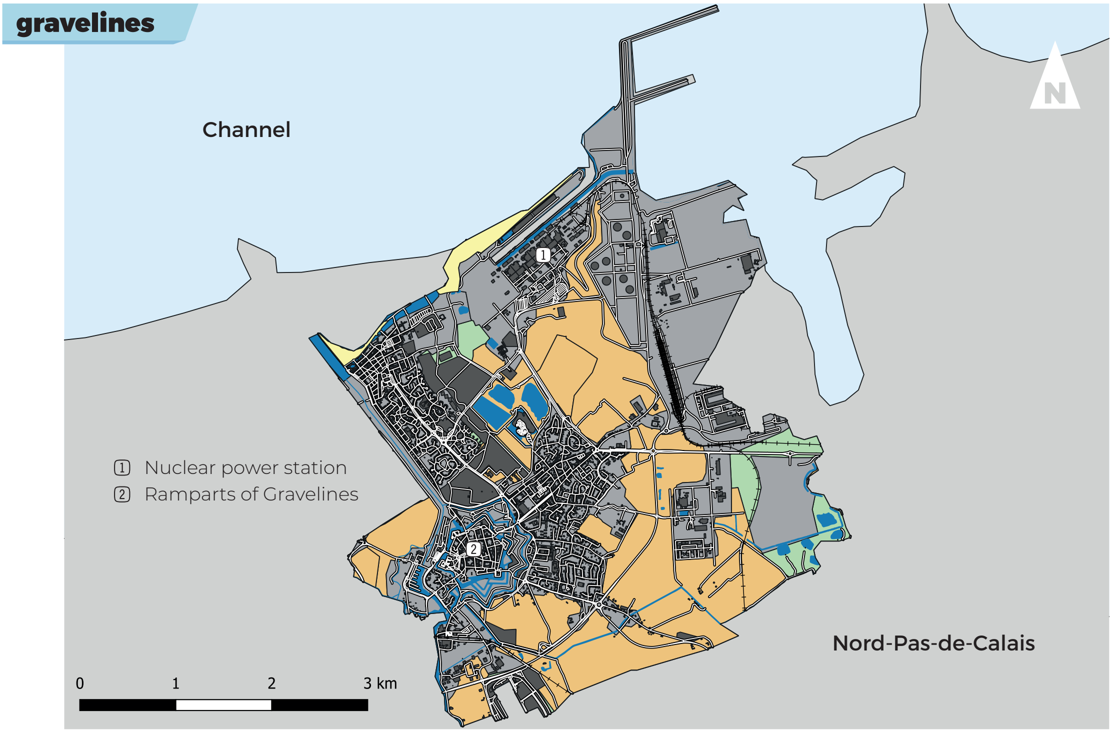
At Gravelines and Dunkirk, the coastline is heavily urbanized and altered by the construction of the port of Dunkirk, its many industries and fish farms. The Gravelines nuclear power plant, the sixth largest in the world and the largest in Western Europe, is under threat in case of flooding from the sea. Urbanization, the presence of heavy industry and the nuclear power plant mean that the economic, social, health and environmental risks of a flood are very high.

Powers and objectives

In France, in order to mitigate coastal risks, measures are being implemented such as assessing risks when developing areas, coastal protection actions and the development of warning systems. This is the responsibility not only of the French state but also of local authorities. For the most vulnerable municipalities, the state has drawn up risk prevention plans (PPR). These involve prohibitions or regulations in specific danger zones and precautionary zones. These plans have not been drawn up for all areas, but even if there is no plan in place, local authorities must take risks into account.

A national strategy

France is particularly exposed to natural flood risks. Given this fact and spurred by the Floods Directive, France drew up a national flood risk management strategy (SNGRI) in 2014. This strategy covers both risk management for floods from the sea, rivers and watercourses and risk management in the event of rising groundwater. An action plan was also linked to this strategy. For instance, the state worked with municipalities to develop natural disaster prevention plans (PPRN) and, more specifically



for floods (PPRI). The plans map out risk areas and link them to building conditions. Based on the national strategy, flood risk management plans (PGRI) have also been developed. These are based on the European Water Framework Directive (WFD).

In 2002 the PAPI system was created. These flood prevention action programmes are implemented by local authorities and provide the framework for flood prevention in close partnership with the state. Projects set up within this framework are financed partly by the state and partly by local authorities.

GEMAPI

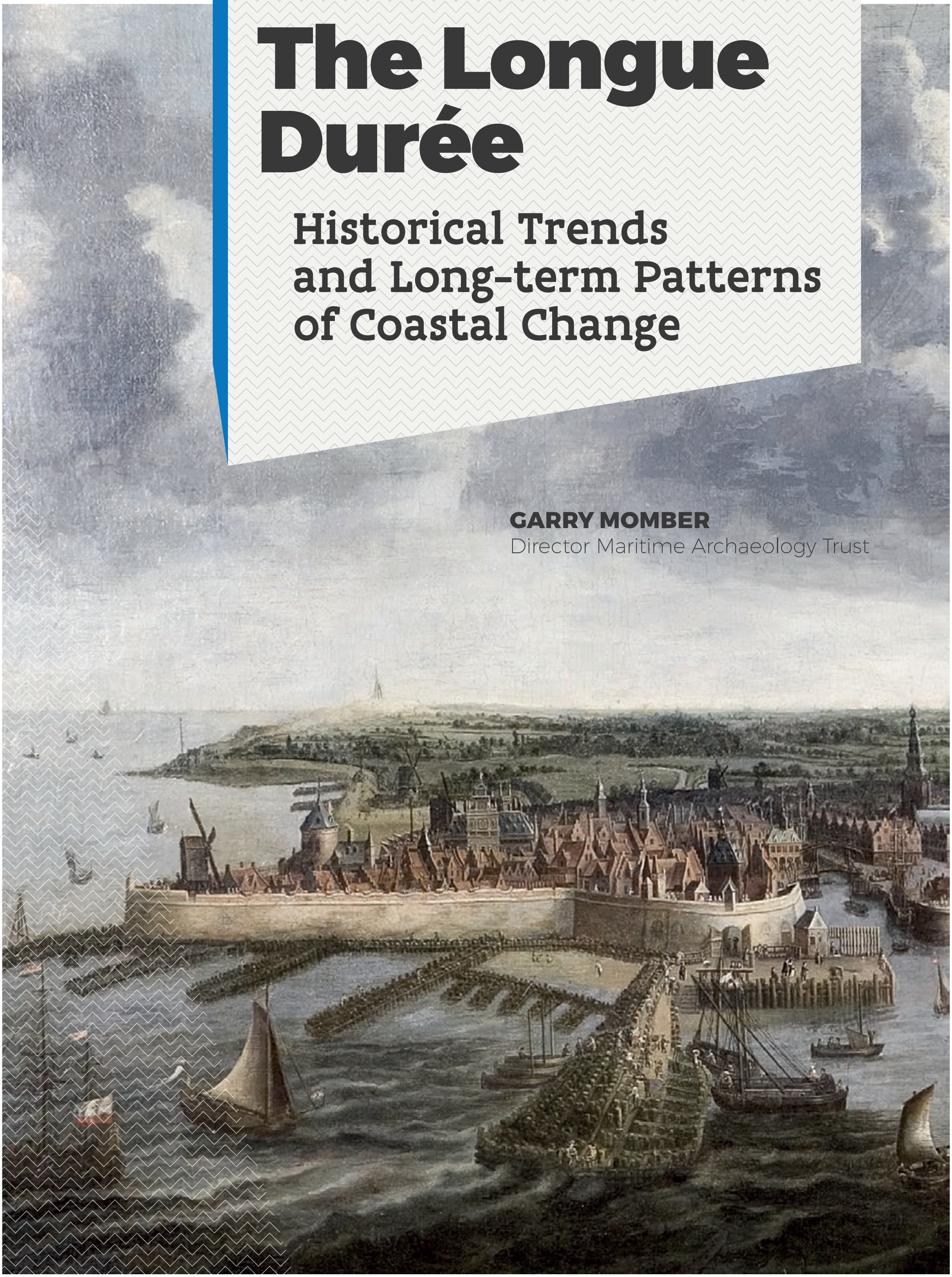
Since 2018, competence over the management of aquatic environments and flood prevention (GEMAPI) has been entrusted to intermunicipal agencies. Metropolises, cities, municipalities and agglomerations must team up to develop and defend river basins, including protection against floods from the sea. This transcends the municipal level, but funding is provided through municipal taxes.

French legislation currently has less room for NbS. The GEMAPI do offer opportunities here if the intercommunal agencies can work together on this, although it always remains their own choice. This is not always obvious and there is therefore a need for a more regional approach to highlight the benefits of NbS.

The Longue Durée

Historical Trends and Long-term Patterns of Coastal Change

GARRY MOMBER
Director Maritime Archaeology Trust



THE COASTLINE HAS BEEN SHAPED BY the long-term relationship between land and sea. Past coastal planning regimes have suffered from a poor understanding of these processes. Where grey infrastructure has been put in place to defend the landscape, it works in opposition to the established equilibrium, presenting a conflict that is hard to sustain. Archaeological, art and historical data can highlight this paradox, helping to calibrate impacts on the coastline and the coastal plain. Where ongoing processes are understood, it can inform stakeholders and coastal managers, and contribute to the decision-making process.

The long-term context

An acceleration in the pace of climate change, with an increase in the frequency of coastal erosion, flooding and instability is placing pressure on urban coastal settlements. Many defensive structures built in past centuries were not designed to withstand the magnitude of these fluctuations. This is because the long-term variability of coastal change largely went unnoticed as it operated at a timescale that transcended many generations and was therefore not anticipated.

At the end of the last Ice Age, 11,500 years ago, the global oceans were about 40 m lower than today. When the climate warmed, the ice sheets melted and sea level rose rapidly.

Fig. 1 Solent. Exposed intertidal landscape at low water dated to 2571–2347 BC. The remains of tree routes can be seen in the foreground and a line of fallen tree trunks extends towards the water. These are eroding from the peat.

Fig. 2 Solent. Bronze Age fish trap dated to 1502–1401 BC. It had been covered and protected for millennia, but now it is exposed and is eroding quickly.

Within 6,000 years there was a rise of around 35 m. This had three significant consequences for the SARCC area under study. First, as the ice caps shrank, the weight on the Earth's crust was redistributed, initiating an adjustment, causing some of the land and associated coastline in the south to fall relative to the sea and some areas to the north to rise. This continues today. Secondly, fast-flowing rivers carried the glacial meltwater to the sea and with it vast quantities of eroded soils; terrestrial, windblown sands were also introduced into the maritime system. Thirdly, coastlines were and still are being reshaped. Soft cliffs have been worn away and new marine waterways opened up, and currents are continuing to evolve as they transport the eroded marine sediments around the shallow seas and coastlines. These processes act at different timescales and many have yet to reach a conclusion. Today, however, with the threat of increased global warming, the impacts could change rapidly. An awareness of past human and natural impacts along the coast and their consequences can provide wisdom from hindsight and inform future mitigation.

Long-term influences on change along the coastline

To demonstrate the long-term influences on the coastline, a case study was examined in the Solent. This waterway running between the British mainland and the Isle of Wight is undergoing changes that are analogous to many of the pilot sites in the SARCC project. It was once a river valley that was turned into a marine channel when the sea level rose. The process has preserved and now exposed a great deal of archaeological and palaeo-environmental data that has been analysed.

On the north side of the Solent, an intertidal beach that was recorded as being covered by extensive mudflats on historical charts has been steadily stripped of sediment. Today the salt marsh has mostly gone. At one location, an ancient channel, now silted up, has a sequence of organic and mineral sediments that were deposited as the sea level rose up the beach at 2571–2347 BC (Fig. 1). In addition, features dating to the Neolithic (3346–3090 BC), Bronze Age (1502–1401 BC) and Roman (255–418 AD) periods have been uncovered.

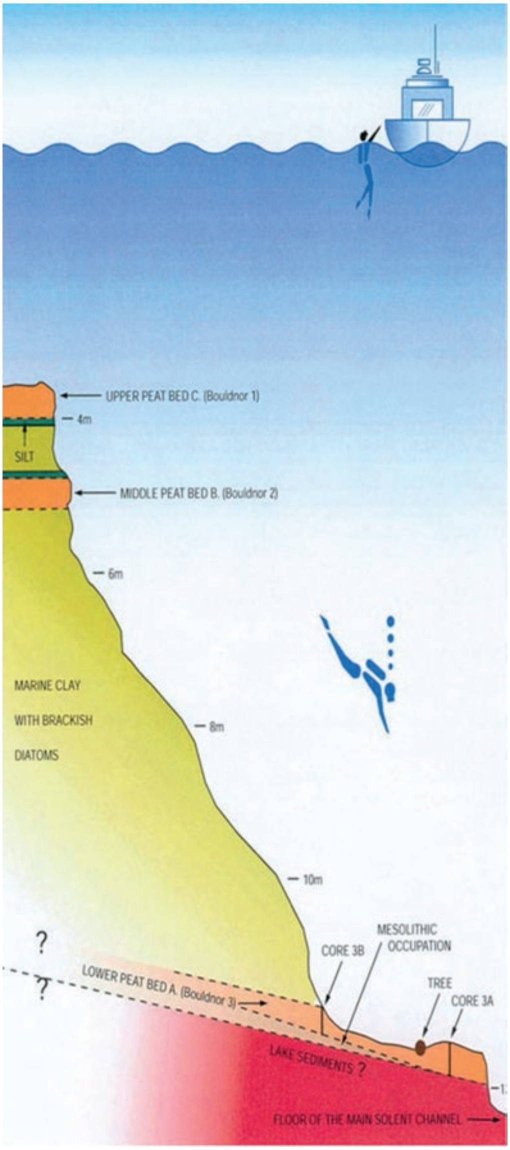


Fig. 3 Schematic of underwater section cutting through peat at Bouldnor Cliff.

The structures are all wood and they are eroding rapidly. When they were first exposed, they were all in very good condition, some even with tool marks, demonstrating that this was the first time they had been revealed since being covered and protected. Each structure is datable, provides a reference point for the past sea level and evidence for a sheltered shoreline at the time they were constructed. The archaeology now shows that the beach is dropping after being stable for thousands of years (Fig. 2). The onset of erosion is a relatively modern phenomenon that coincides with the development of coastal infrastructure and the restrictions of sediment-rich watercourses.

Like many rivers in the ria (a submerged river valley) coastlines around the North Sea and Channel, the Solent contains postglacial infill deposits. At the underwater site of Bouldnor Cliff, along the south side of the western Solent, a 7 m thick accumulation of alluvial sediments, interwoven with layers of peat, had built up above a valley floor as sea level rose. Then, around 5,000 years ago, the valley was overtopped and a channel was created. This transformed the sheltered environment into one of erosion which removed a section of the deposited sediment to reveal a cliff within which laminated layers of clayey silt and peat have become exposed (Fig. 3). Dates have been taken from the tops of the peat horizons within the cliff to provide index points relative to the sea level at 8.7 m, 3.1 m and 2.1 m below the lowest tides. The depths dated

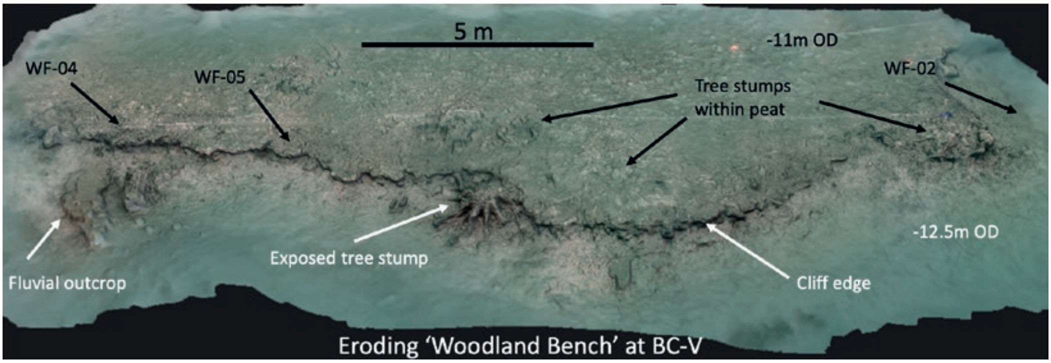


Fig. 4 3D photogrammetric image of the woodland bench with trees and archaeological features at Bouldnor Cliff.

to 6000–5920 BC, 4820–4435 BC and 4425–4230 BC, respectively. Erosion of the covering material has revealed archaeology that shows us how people adapted to sea level change and that they communicated with people on mainland Europe in the east. This site holds a resource that provides a dateable, detailed sequence of events that shows how long-term processes, lasting 8,000 years, directly impacted the coastline today and how past occupation sites were unavoidably submerged due to sea level rise (Fig. 4).

The SARCC research has recorded how the process of erosion is continuing. It has shown how the system has yet to reach an equilibrium as it has quantified the loss of seabed. As the seabed erodes, the water depth increases, adding to the wave energy that accelerates erosive forces along the shoreline. As a result, coastal cliffs along the Solent shoreline are eroding rapidly and castles, built to last to survive attack, are now falling into the sea. Unfortunately, the submarine zone is not, as yet, taken into account when planning coastal defences in the UK.

PILOT DEVELOPMENTS

Newlyn

The survival of a 5,000-year-old intertidal prehistoric landscape, similar to that seen on the north side of the Solent, shows that this part of Mounts Bay was protected from the ravages of an open sea when the water rose during the last stages of postglacial sea level rise. The sheltered conditions at the time enabled sediment to settle, cover and protect the ancient land surface, being a feature that can remain for millennia if undisturbed. However, when it becomes exposed, palaeo-environmental material and any associated archaeological features can degrade within years, although large sections can be lost in a single storm. These deposits are particularly important, as outlined in the Solent case study, as they provide evidence of coastal and climatic evolution when the sea rose, the climate changed and the shoreline was realigned. Significantly, the exposure of the submerged landscapes off Newlyn Harbour over the last century indicates a new phase of erosion.

Fig. 5 Map of north pier. Extract from Cornwall LXXIV. NW, revised 1906, published 1908.
(reproduced with the permission of the National Library of Scotland)

Fig. 6 Above. Old Tolcarne Bridge, Newlyn Henry Pendarves Tremenheere 1804.
(image courtesy of Penlee House Gallery and Museum, Penzance)

Below. Today, the Old Tolcarne Bridge is now squeezed by development and prone to flooding.
(November 2020 MAT)

The historical and artistic record has documented changes to the landscape, the beach and coastline. They show that erosive processes have increased over the last two centuries due to construction around the bay. The factors that have caused the greatest impacts are the development of the port in the late nineteenth century where the North Pier channels the water directly into the mouth of the Coombe river (Fig. 5). This is compounded by restrictions of the Coombe river channel and by building on the flood plain (Fig. 6). The result is a lowering of beach levels and flooding of Tolcarne village during high-tide storm events.

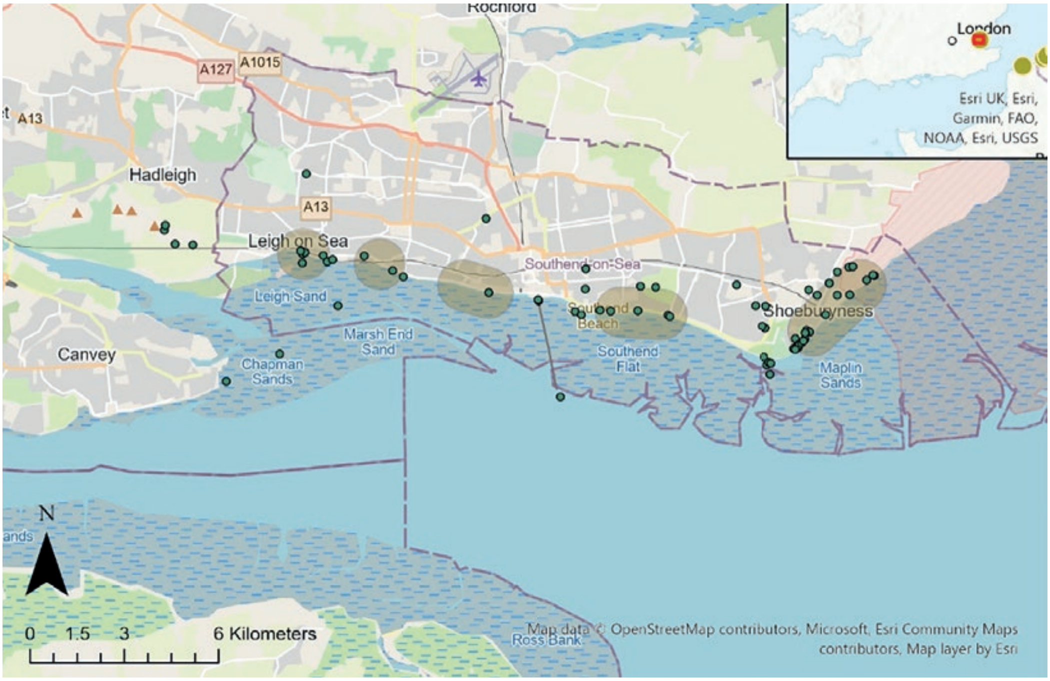


Fig. 7 Distribution of archaeological features along the Southend-on-Sea foreshore that were used to monitor change. (from the SACC maritime Atlas)

Fig. 8 The Chapman and André 1777 map. When compared to current maps, erosion is evident along the shoreline of the Great Wakering Marsh and East Beach, where the Iron Age hill fort, located by the recorded 'Pigs Farm', has been truncated.

Fig. 9 East Beach in the late nineteenth century, where it appears to be eroding quickly.

Southend-on-Sea

Around 4,000 years ago, the sea had risen to current levels and the river Thames flood plain was lined with salt marsh that was covered with each rising tide. The marshes formed a protective buffer against flooding inland but, from the thirteenth century, as populations grew, the Thames saw progressive reclamation and dyke building. This created new land but it also narrowed the river channel, inadvertently increasing the height of the incoming tide and, with it, an increased risk of overtopping the riverbanks.

Southend-on-Sea lies on the northern shores at the outer Thames Estuary. Archaeological features, historical markers and charts have shown where the coastline is eroding (Fig. 7). The south-facing shoreline is now fixed. This has removed the adaptive capacity of the beach and resulted in drawdown and scour along some of the hard frontage. The study also identified where the sediment flow had been interrupted by human actions and construction along the east-facing coast off Shoeburyness. As a result, erosion has accelerated along East Beach, which now needs to be protected. The truncation of an Iron Age hill fort by coastal erosion in the last 200 years indicates the scale of recent erosion (Fig. 8). This feature, along with other historical structures, can be used as markers to monitor rates of loss (Fig. 9). Accelerating erosion along a coastline can have implications for property insurance and impact of the cultural value of a landscape.

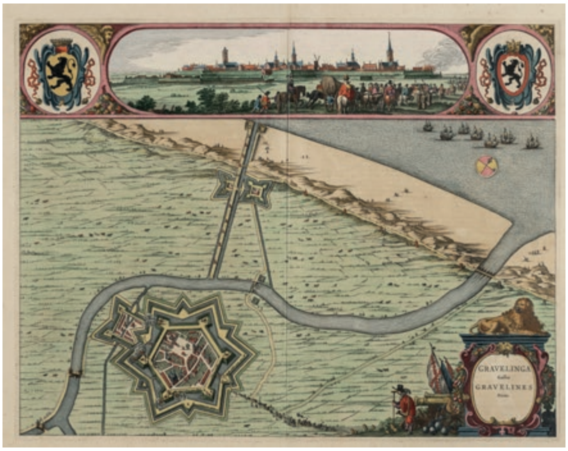


Fig. 10 Johannes Blaeu, Gravelines, 1649.
(source: Rijksmuseum, CC0, via Wikimedia Commons)

Gravelines

Gravelines grew within a small sheltered estuary. Historical evidence demonstrated how long-term sediment transport then restricted navigation within the river mouth (Fig. 10). A channel excavated across the dune system and beach now, inadvertently, acts as a groyne allowing the dunes to develop in the west while funnelling the sea towards the town on the east where, on this side of the channel, it is putting a much thinner line of dunes under threat and causing flooding (Fig. 11). Building on the coastal dunes along the east beach has also weakened the adaptive capability of the coastline. An awareness of the long-term

Fig. 11 The left image shows where sand dunes have built up on the west of the canal and the location of historical records, accessible within the maritime atlas, that have been used for the analysis to reference past change. The image on the right looks east along the beach, showing the reduced dune complex. The whole beach is covered by water at high tide.

movements of the foreshore sediments would have helped earlier societies to predict patterns of change along the coastline. This wisdom from hindsight is still accessible today for coastal managers and it can be used to help design natural defences that respond to the evolving threats.

Middelkerke, Ostend and Blankenberge

As sea level began to slow during the post-glacial thaw around 5,000 years ago, the coastline off Flanders advanced. High levels of sediment that derived from cliffs and wind-blown tundra deposition were carried down rivers to supply estuaries, extending the land seaward. Salt marsh evolved around the Rhine, Meuse and Scheldt estuarine complexes and barrier dune systems built up along the coastline. By the middle of the second millennium BC, the land at the mouth of the Ostend Valley extended a further 10 km out to sea when compared with the contemporary coastline while coastal peat marsh stretched almost 20 km inland.

Sea level began to stabilize by the first millennia BC. The coastline became relatively stable until the status quo was undermined by human influence. Peat extraction, primarily by the Romans, removed the surface deposits, drained the land, compacted the soil and lowered ground levels to reverse the earlier depositional processes (Fig. 12). Subsequently, dykes were built that contained the water but caused funnelling, increasing water height and making flooding more devastating when it occurred. In the fourteenth to sixteenth centuries, flooding was a relatively common occurrence. However, engineering solutions advanced and larger dykes were built, giving people more confidence to move to the places with increased protection, making flood events even more catastrophic.

Fig. 12 Exposure of the peat deposits that now lie seaward of the sea wall between Ostend and Middelkerke. The shapes in the peat were a result of cutting during the Roman period.

In more recent times, the whole coastline has been delineated by fixed dykes and the estuarine drainage system has been infilled/poldered. These changes can be charted on historic maps, which, when compared with contemporary flood risk maps, show that the areas at greatest risk of flooding inland are the old, poldered estuarine channels.

Along the coastline, the historical record shows how the building of coastal dykes, promenades, roads and tramlines has interrupted the natural system by stopping the interplay between beach and dunes and restricting the ability of the coastline to adapt (Figs. 13 and 14). Hard defences deflect the swash, increasing the strength of the backwash, contributing to the erosion and the stripping of the beaches (Fig. 15). The defences are then being undermined, compromising their ability to mitigate the impact of storm surges as the climate changes (Fig. 16).

Within the SARCC project, nature-based solutions are being reintroduced by coastal authorities at the pilot sites to recreate dunes systems in front of the new sea defences and coastal roads. This is returning the coastline to a more resilient state and closer to that seen in the past. The historical records can be used to justify the need for change and help advocate the most appropriate solution.

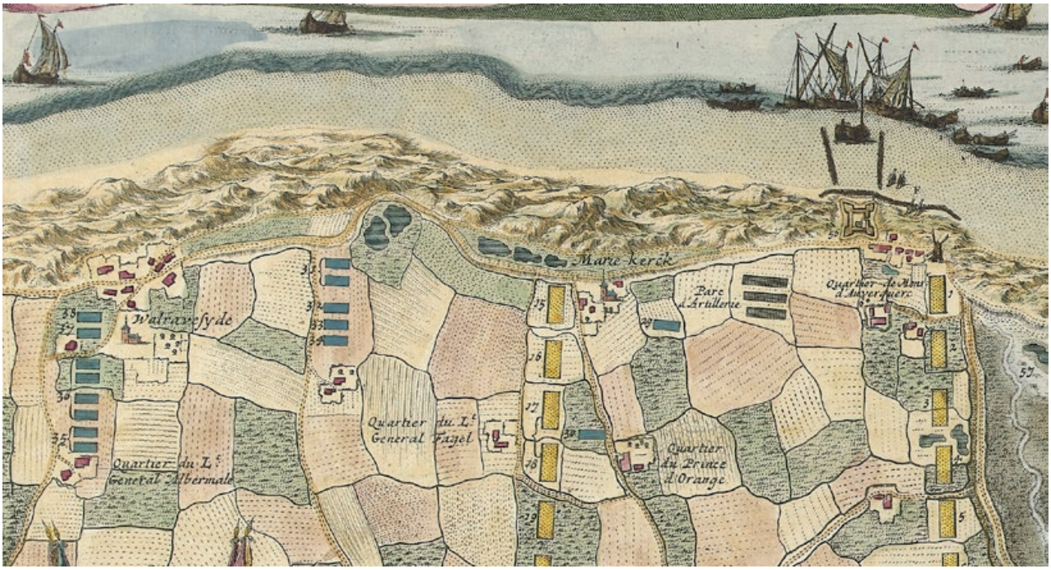


Fig. 13 A plan to the west of Ostend, 1706. The natural dunes system, before the building of coastal dykes and roads, was a substantial natural defence.

(Jacobus Harrewijn, Rijksmuseum, CC0, via Wikimedia Commons CC0 1.0 Universal Public Domain Dedication)

Fig. 14 Early-seventeenth-century engraving of Blankenberge protected by dunes.

(courtesy of Stadsarchief – De Benne, Blankenberge ID 454)

Fig. 15 Mariakerke Beach hotels taken around 1900 (left) shows the low beach level before replenishment. The modern image on the right was taken from the same area in November 2021. Beach recharge is ongoing to keep pace with erosion.

(Geneanet, Creative Commons [BY-NC-SA 2.0], https://nl.geneanet.org/prentbriefkaarten/view/7699848#0)

Fig. 16 Storms in Ostend, 1924. The impact on the hard defences can be dramatic and devastating.

(credit: https://www.deplate.be/nl/postkaart-stormweer-1)

Fig. 17 Johannes Blaeu, Vlissingen, 1649.
(public domain, via Wikimedia Commons 1645, https://commons.wikimedia.org/wiki/File:Vlissingen_1649_Blaeu.JPG)

Fig. 18 Petrus Segaers, Bird's-eye View of Vlissingen, 1669.
(public domain, WikiMedia Commons).

Vlissingen

Vlissingen was constructed at the mouth of the Scheldt river for commercial and defensive reasons rather than by merit of being a sheltered anchorage. As it developed, the harbour infrastructure was extended seaward. Consequently, it became more exposed to the impact of the long-term natural processes within the estuary mouth (Figs. 17 and 18).

This was not fully appreciated at the time and the relentless abrasion from the sea caused damage to the city walls. As the strategic location could not be compromised, the civic authorities built bigger and better defences rather than adapt. The town is now many metres below the high water mark, so any overtopping would be very destructive to the residents and the urban centre while also

Fig. 19 Vlissingen. The remaining city tower on the sea wall. The other half was damaged by storm action and was demolished.

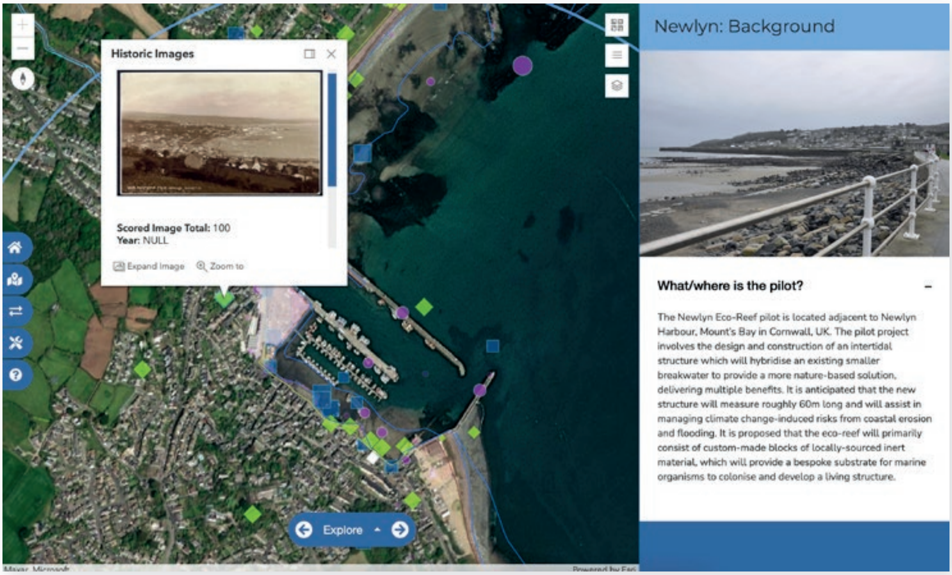
Fig. 20 Vlissingen. Boulevard de Ruyter with the lighthouse and statue.

having a significant impact on the cultural value of Vlissingen (Figs 19 and 20).

The municipality now requires extensive defences to protect against sea level rise and climate change, while adjacent areas along the foreshore to the east have been allowed to respond more naturally and they retain the protection of the natural dune system. The juxtaposition demonstrates how natural defences, with the ability to respond and adapt to variable weather events, can provide nature-based solutions without the need for extensive human intervention. In areas where the natural processes can be harnessed and incorporated into the design of coastal protection initiatives, more economic solutions can be created.

Conclusion and outcomes

The SARCC project has assessed the historic trends and long-term patterns of change within a case-study area and seven pilot sites. The analysis has used a suite of tools including archaeology, palaeo-environmental deposits, art, photographs, maps and charts to provide both qualitative and quantitative information on coastal evolution. This review of historical data sets has presented us with information to understand past, current and long-term patterns of change that indicate areas of erosion, deposition or stability, where the evidence presents datable markers that can help to calibrate the pace and scale of change. Historic evidence can show how changes made by humans have interfered with natural processes, resulting in increased impacts on the coastline and the coastal plain.
Where the shoreline is now artificially fixed, it has been argued that nothing can be done, thereby suggesting that studying the past is of limited benefit. To the contrary, the SARCC project has demonstrated the value of looking at historical data sets. By showing how an assessment of the longue durée can provide insight into the mechanisms that have shaped the coastline, it enables the creation of an evidence-based narrative of coastal change. This story of past change is a valuable tool to help inform stakeholders and the public when considering future coastal adaptations and the introduction of nature-based solutions.



Maritime Atlas

The longue durée is examined to explain how human and natural influences contributed to the evolution of the coastline. This knowledge provides long-term evidence upon which to place baseline assessments. This is achieved by the creation of a historical maritime atlas that enables sites to be identified that can inform on the long-term process of coastal change, sea level rise and, in some cases, climate change. To do so, data is gathered from historical tools including art, archaeology, maps, charts, photographs and the palaeo-environment. The evidence is described, scored and interpreted to qualify past events and patterns of change. The results are viewed and queried through an online portal where the highest scoring sites are used to help determine the long-term impacts and influences on the coastline in the pilot-area case studies. The most significant results are accessible via a Maritime Atlas viewer. These provide a valuable data source to be used by coastal authorities to inform the design phase of a development and disseminate the need for coastal protection initiatives to the public.

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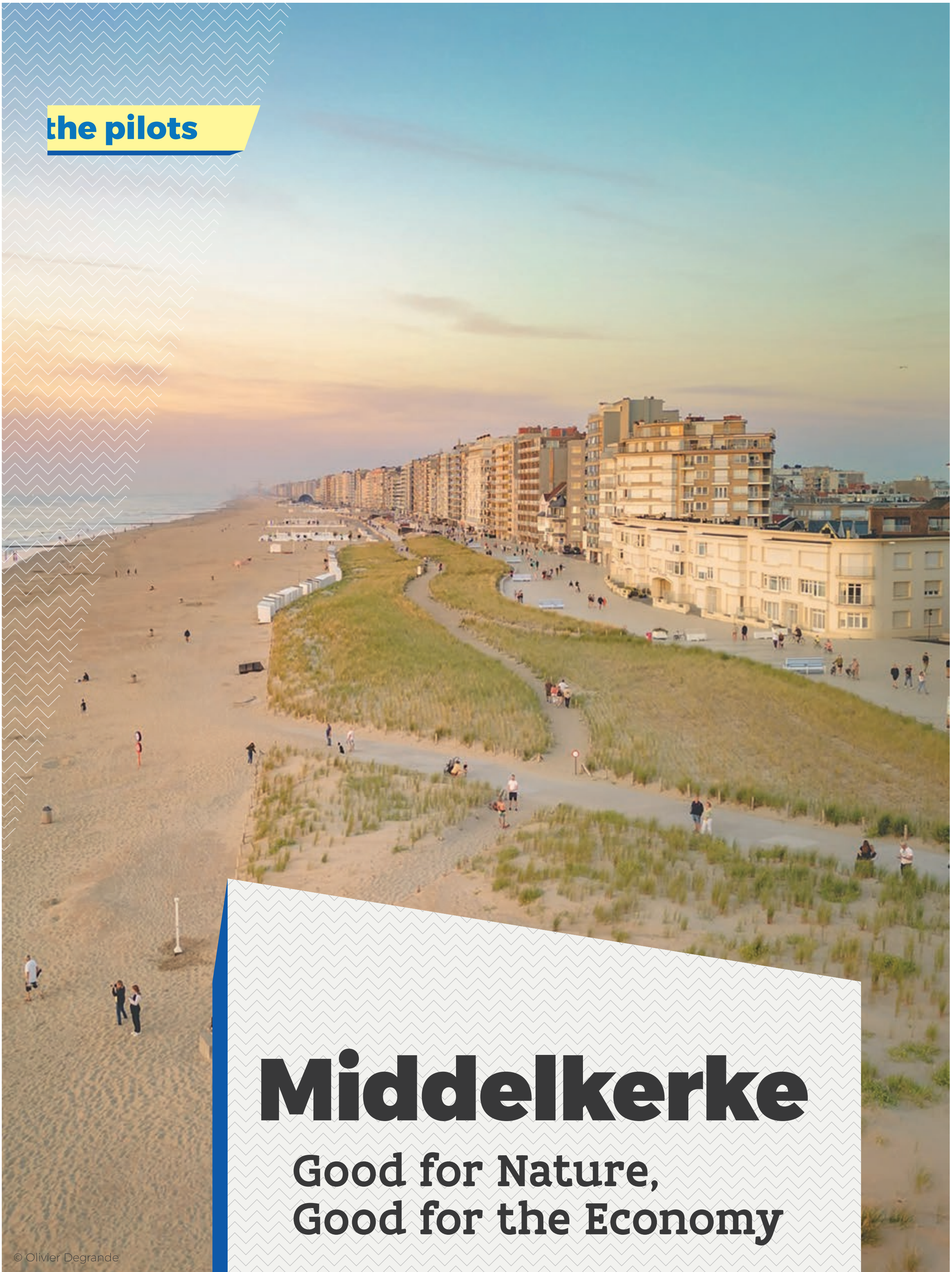
PART 2

The Pilots

Seven pilot cities along along the North Sea and Channel are experimenting with innovative nature-based coastal protection solutions.

the pilots



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Middelkerke

Good for Nature, Good for the Economy

Middelkerke is protecting itself from a 1000-year storm with materials that are naturally abundant on the Flemish coast: sand and marram grass. Together, they form a green 'dune-before-dyke'. The innovative pilot project is not only more cost-effective than a hard, concrete dyke construction, but also a lot better for the environment. Moreover, the 'grass dyke' provides increased experiential value and gives tourism a boost.

SOMEWHAT IRREVERENTLY, one could say that all Flemish coastal municipalities are somewhat similar. The Flemish coast is a generic 'line town' stretching from De Panne to Knokke and that was built to suit tourism. Large parts of the coastline consist of a high wall of apartment buildings overlooking the sea. Here and there between the seaside resorts, there are still strips of dunes and nature.

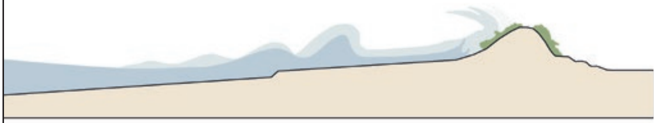
Sea level rise is forcing the Flemish authorities to take additional measures. In most places, beach nourishment is sufficient to protect against a 1000-year storm, but in Middelkerke – one of the weak spots in terms of coastal safety – it is also necessary to strengthen the dyke. Maarten Van Nieuwenhove, project manager for the SARCC project at the municipality of Middelkerke, explains: 'A few years ago, we forged plans for an additional hard infrastructure in concrete, a so-called stilling wave basin or SWB construction. This is a "dyke-before-dyke", with the front dyke somewhat lower than the current dyke, which breaks the waves in the event of a storm so that they lose their destructive power before they reach the city. But it soon became clear that the cost was very high, and that the negative impact on the environment and climate would be significant.'

Hybrid coastal defence

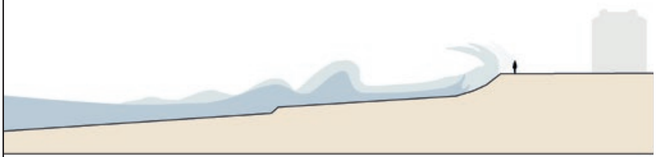
The municipality of Middelkerke and the Flemish Government started looking for alternatives and enlisted the urban planners and landscape architects of MOP Urban Design and CLUSTER landschap & stedenbouw. In collaboration with engineering firms Plantec and SBE, they designed a hybrid coastal defence with both hard and soft infrastructure. Van Nieuwenhove: 'In the more urban zones, where most of the shops and businesses are clustered, there will be an SWB. This will take

Evolution

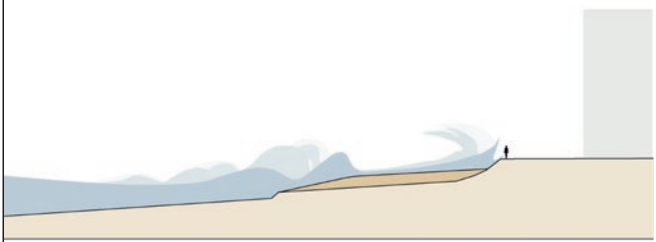
Evolution of the coastal profile
from 1800 until today.



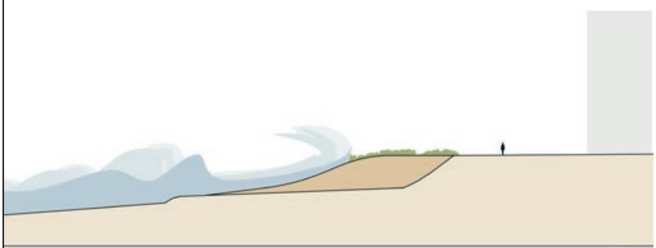
Dunes (1800)



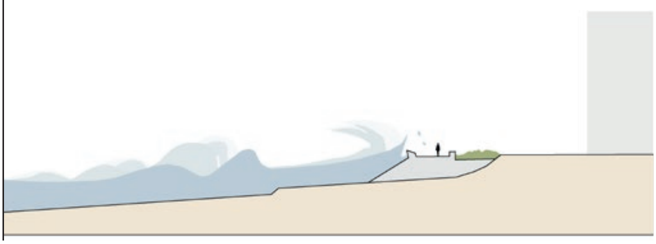
Dyke (1900)



Sand replenishments (2000)



Dune-before-dyke (2022)



Wave-mitigating extension (2022)

Dune-before-dyke principle

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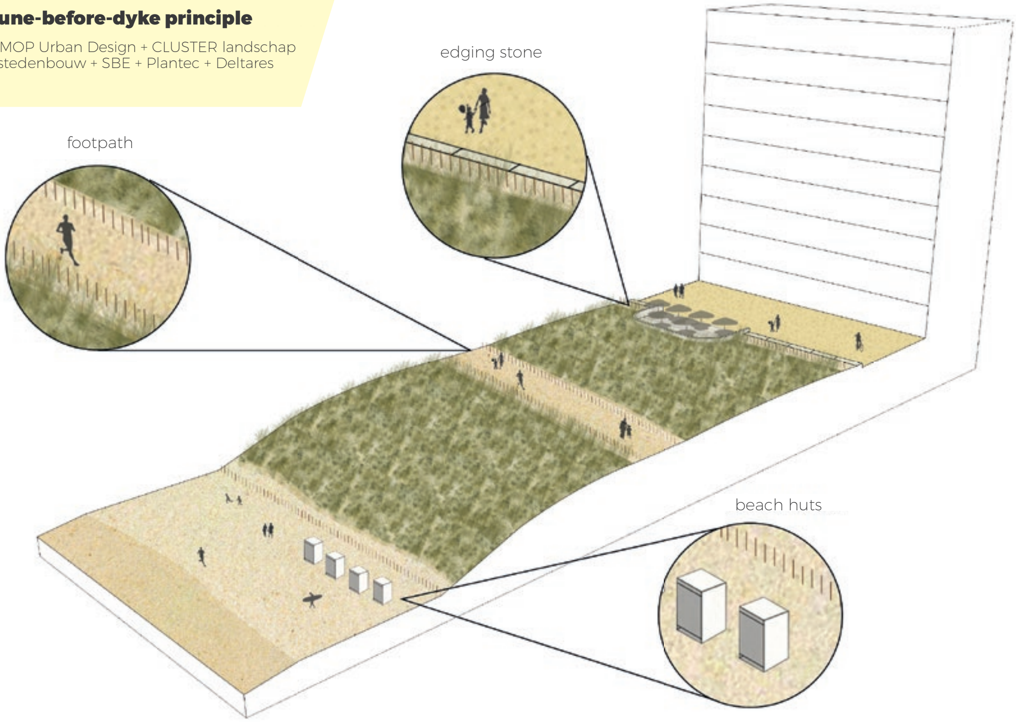

the form of a lowered promenade between the existing sea wall and the beach. On the beach side, the lowered boardwalk has a wide breaking element that also serves as a parapet. When the water breaks during storm surges, it is collected in the lowered zone and flows back to the sea through openings at the bottom of the breaking element. In the more residential zones, by contrast, we realized the so-called grass dyke. In total, we laid out 500 m of grass dyke.' It is this grass dyke that has been included as a pilot project within SARCC.

'The grass dyke is a natural but controlled system of low dunes in front of the existing dyke. The dune is an artificial dune, very different from the pilot projects in Gravelines or Ostend, where the dune arises and grows naturally. In Middelkerke, the dune has been "modelled": the engineers calculated that the dune is most stable and effective thanks to a parabolic foot. Marram grass and other dune vegetation fix the dune and prevent the sand from blowing away.'

Unique for Flemish coastal towns

During the design process, Middelkerke organized a participation process with residents and merchants. This process was necessary because the idea of a dune-before-dyke is unique for Flemish coastal towns. Van Nieuwenhove: 'There were a lot of concerns. Many people, especially the residents of the ground-floor flats, feared that the

Wave-mitigating extension principle

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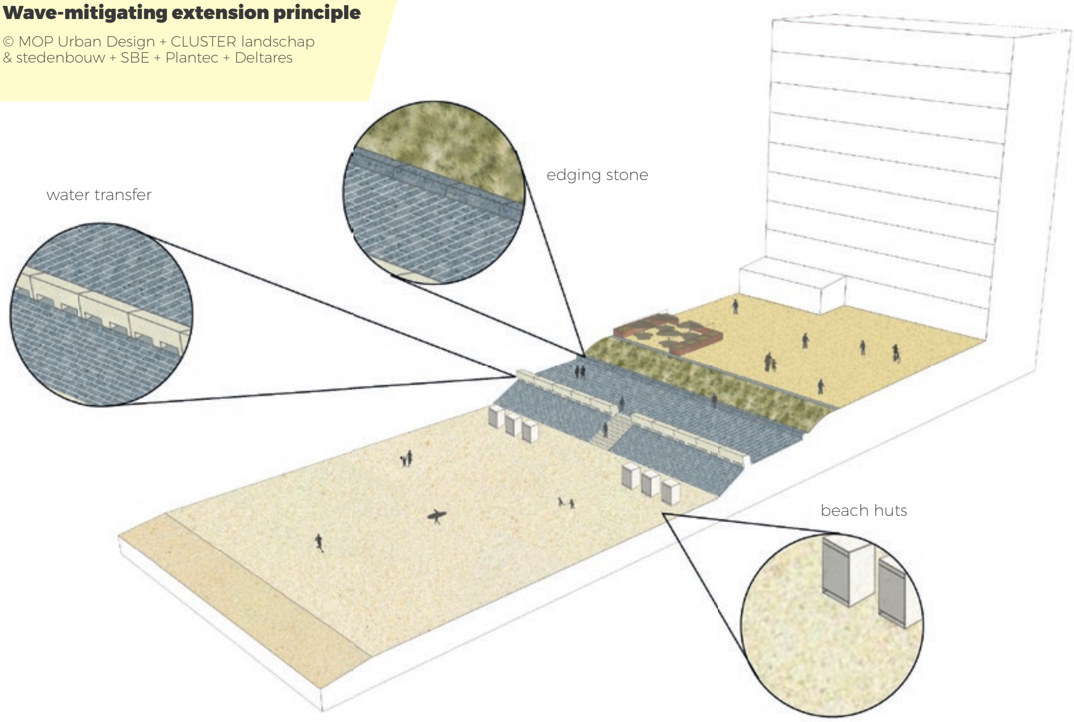
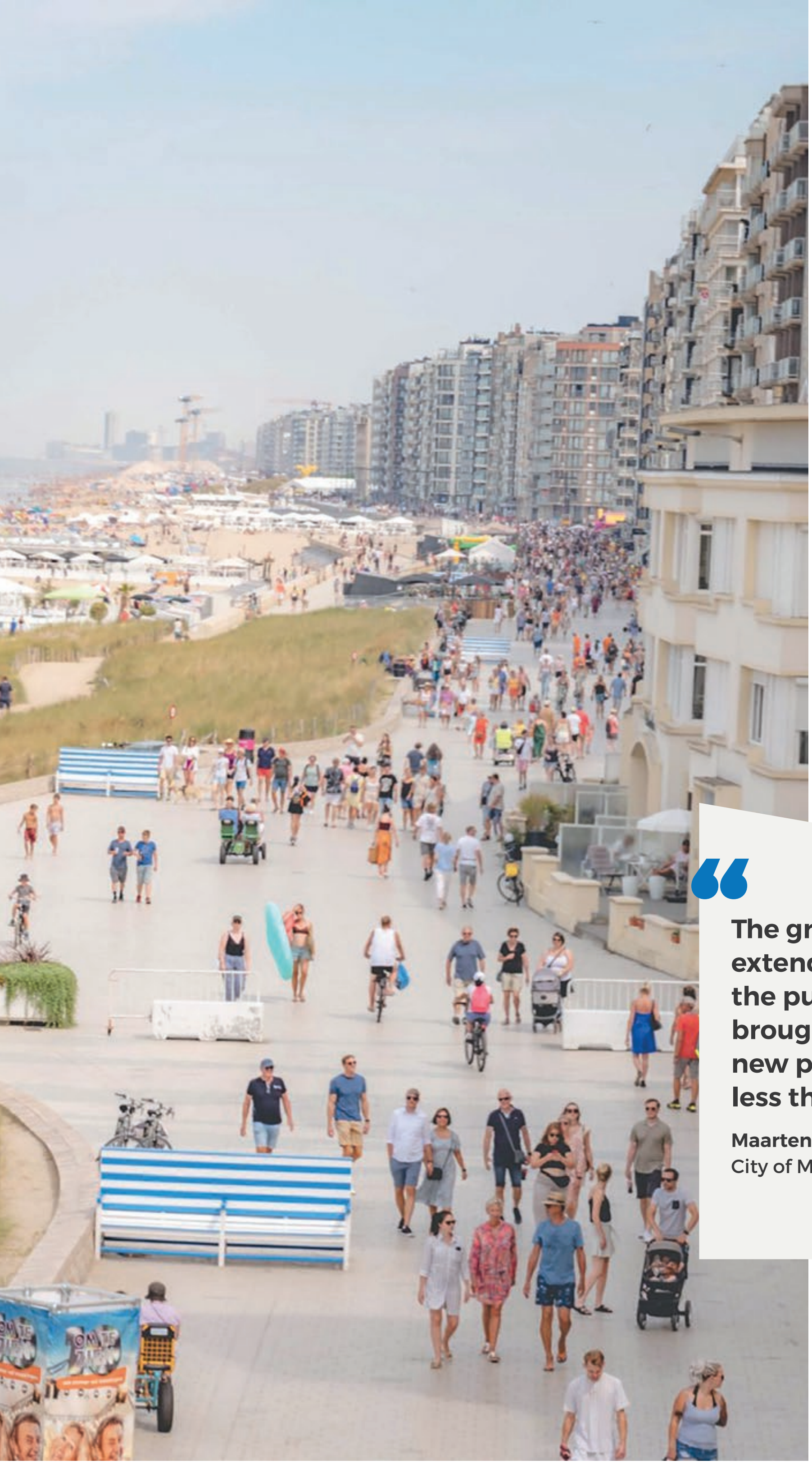


construction of the dune would cause them to lose their beloved sea view. Some feared that the beach would be harder to reach, because you would have to cross the barrier of the dune first.'

The city took those concerns into account in the design and was able to convince residents of the added value of the project. In the final design, the dune is barely higher than the embankment, and the sea view from the sea wall and ground-level floors has been preserved. In the dune, clay shell paths – paved walkways based on natural materials – were constructed, which are also accessible to wheelchair users. In addition, the entire dyke was redesigned, which represents enormous added value for residents and traders. Van Nieuwenhove: 'The participation process really did prove useful. Although we spent a bit more time and energy in the design phase, there were no protests during the public enquiry, so implementation went extremely smoothly.'

Flexible sea wall

The benefits of this nature-based solution are numerous. 'The dunes restore contact between nature and the sea. They are cheaper to construct and more flexible to manage than hard sea-wall structures which require large investments and have only limited durability because of unpredictable sea level rises. Thanks to the grass dyke, Middelkerke is protected against a 1000-year storm until



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> The grass dyke both extends and enhances the public space. It has brought into existence a new park measuring no less than 100,000 m².

Maarten Van Nieuwenhove
City of Middelkerke

2050. But if the sea level rises more, thanks to its natural structure, the dune can simply be raised.'

The experiential value has also increased. The grass dyke widens and upgrades the public space. Van Nieuwenhove: 'A new park of no less than 100,000 m^2 has been created. Before, most of the dyke, especially in the morning and afternoon, was in the cast shadow of the flats. Now, residents and tourists can enjoy the sun at any time of the day.'

Nothing but benefits, then. Still, Van Nieuwenhove adds a reservation: 'Although the soft coastal protection is cheaper than a hard sea wall, it does require regular maintenance. We have had to retrain our technical staff and draw up a maintenance plan to manage the vegetation. In addition, precisely because it is a pilot project, we will have to constantly monitor the dune during storm surges and repair it if necessary.'

"The grass dyke is a natural but controlled system of low dunes in front of an existing dyke.

Maarten Van Nieuwenhove
City of Middelkerke

Twofold turnover

It is not an obvious project, and yet it appeals to residents and tourists. Van Nieuwenhove: 'We see that merchants are benefitting. The owner of a café told me that his turnover had doubled since the construction of the grass dyke. The grass dyke has become a tourist attraction. The pilot project protects our municipality from storm surge, it has a favourable impact on finances and the environment, and it is also good for the local economy. Therefore, we will continue to implement this concept in the coming years for a complete renovation of our sea wall. We have plans to realize this model further west and east along a full length of 1,500 metres.'

Mayor's Statement

Jean-Marie Dedecker

'In a world where we are constantly reminded to reduce our ecological footprint, this "nature-based design" is a great way to protect the coast. Simply put, we are protecting our city from a 1000-year storm with the materials already present on our coast: sand and implanted marram grasses. This forms a green dune in front of our dyke, carried out with as few polluting effects as possible.'

'We based our multi-year plan for renovating the sea dyke on this. Our dyke will undergo a renovation in the coming years where "nature-based solutions" will form part of the solution, along with a "stilling wave basin" (SWB). So in the future, our sea dyke will be dynamically protected by living dunes, which also allows us to evolve along with nature.'

© Olivier Degrande

Ostend

And Nature Takes Care of the Rest ...

the pilots

A dune-before-dyke ensures that the wind no longer blows the sand onto the tram tracks. The natural solution also offers other advantages: it creates valuable nature and the dune provides additional protection against sea level rise.

'SOFT WHEREVER POSSIBLE, hard wherever necessary' is the adage of coastal defence in Flanders. Things were once different. Less than fifteen years ago, dykes, breakwaters and quay walls were still the main ingredients of any coastal defence. The Flemish Government changed its tactics. To protect the coast from a 1000-year storm, beach nourishment was carried out in many places. This greatly changed the appearance of many seaside resorts. Ten years ago in Ostend, when there was a heavy storm, the waves used to crash violently over the dyke, a spectacle that always attracted many spectators. Beach nourishment widened the strand considerably, so the waves no longer reach the dyke during storm tides.

Nourishment of the beach and subtidal zone is a very simple and effective way of protecting the coast. They break the wave force, they are easy to repair after a storm and they have the advantage of being able to grow with sea level rise. But they also have some drawbacks. Beach nourishment can seriously disrupt marine life. Moreover, sand reserves off the Belgian coast are not inexhaustible.

Sand nuisance

There are also 'minor inconveniences'. Beach nourishments have made the beaches wider, making it much easier for the wind to blow the sand over the dyke, causing considerable sand-related nuisance. Particularly in Raversijde-Mariakerke, just west of Ostend's city centre, this causes problems. Here, the Koninklijke Baan, the Coast Tram and the cycle path run on the dyke, right up against the beach. Car and tram traffic regularly have to be diverted or interrupted because the sand prevents the flow of traffic. Karel Vanackere, project manager for SARCC at the city of Ostend, explains: 'The costs related to the obstructed traffic and the clearance work can run up quickly. On top of that, the cleared sand cannot simply be thrown back onto the

The beach was raised with sand and then planted with brushwood fences and marram grass. Nature then took care of the rest. Maritime sedimentation (sand supplied by the tide and waves), aeolian sedimentation (sand supplied by the wind) and the spreading of the marram grass helped the dune to grow by itself.

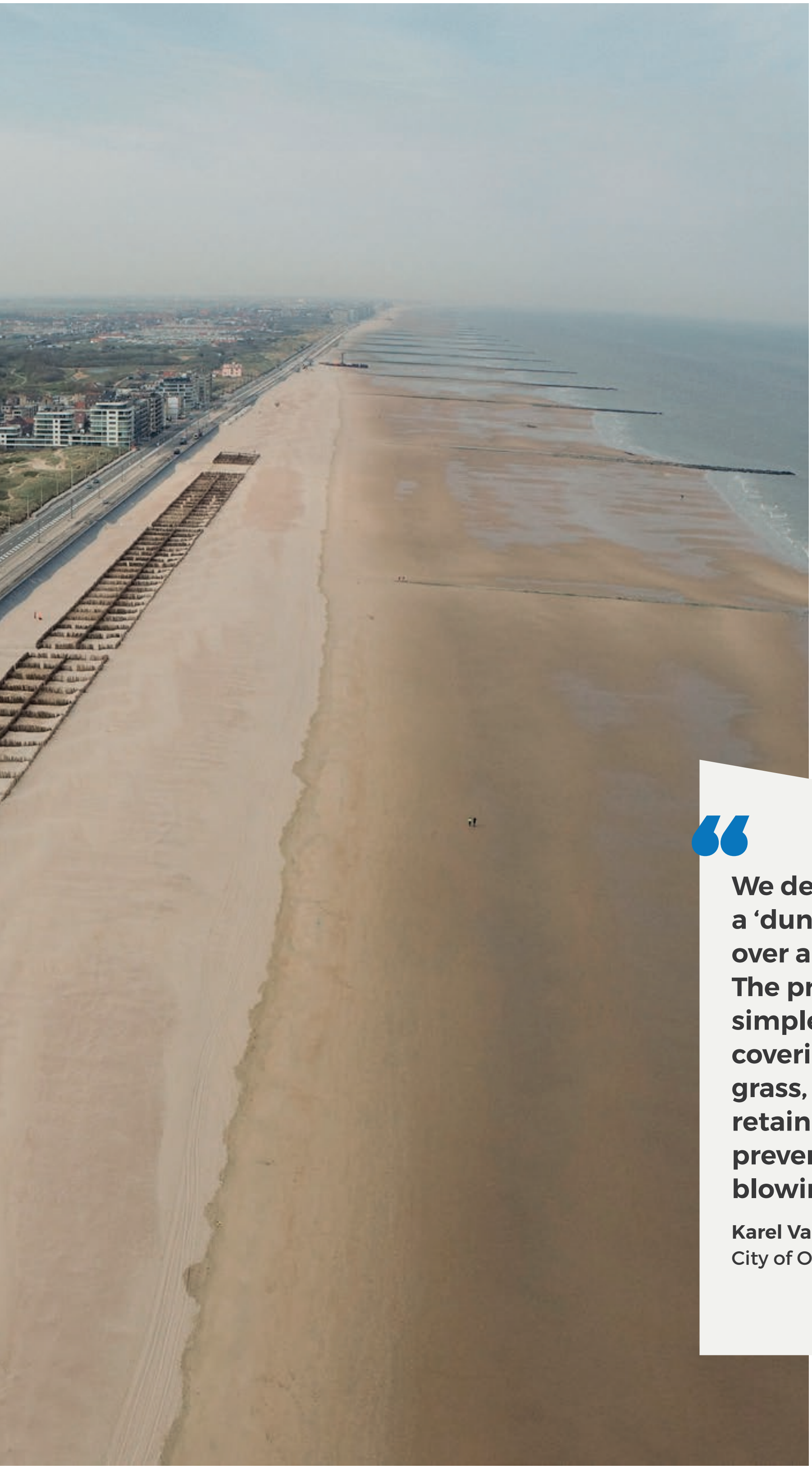



beach because it might be contaminated by traffic. It will be disposed of as "waste" and processed.'

Initially, Ostend conceived the plan to build a 'sand trap', a concrete wall to hold back the windblown sand. However, that is an expensive and not very elegant solution. The SARCC project offered new perspectives. Vanackere: 'We decided to build a "dune-before-dyke" over a length of 700 m. The principle is very simple: thanks to the covering of marram grass, the dune will retain the sand, preventing it from blowing inland.' No sooner said than done. The beach was raised with sand and then planted with rows of osier and marram grass. The test area was divided into several zones, each with different planting patterns of osier and marram grass. This will make it possible to tell which configuration is most future-proof.

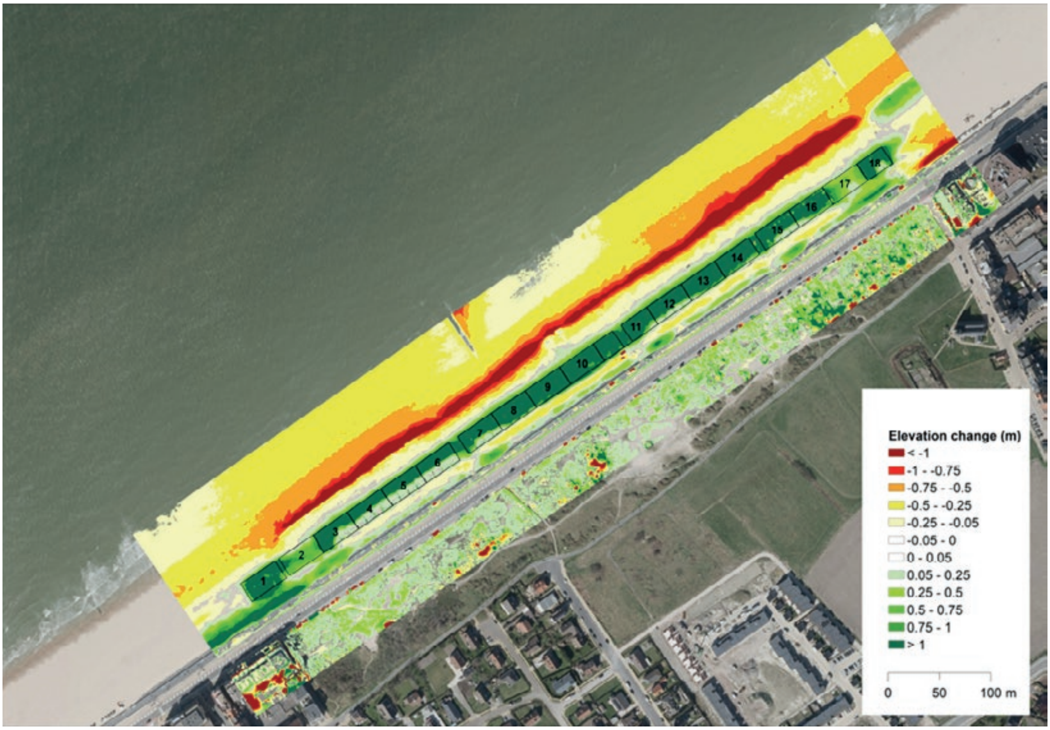
Building with nature

What is special about this pilot project is that it is not only a 'nature-based solution' but also a form of 'building with nature'. The dune is not constructed as such, as in the pilot project in Middelkerke, but young dune formation is initiated, after which natural processes take over. Thanks to marine sedimentation (sand supplied by tides and waves), aeolian sedimentation (sand supplied by the wind) and the planting of marram grass (which retains the sand), the dune should grow by itself. Indeed, dunes are 'living dunes'. In a natural situation, dunes can emerge, grow and recover by themselves. Marram grass plays a crucial role in this: marram grass has a densely branched and deep system of rhizomes with which it can keep up with an annual sand growth of 1 m. In other words, marram grass is able to grow with the shifting of sand.



We decided to build a 'dune-before-dyke' over a length of 700 m. The principle is very simple: thanks to the covering of marram grass, the dune will retain the sand, preventing it from blowing inland.

Karel Vanackere
City of Ostend



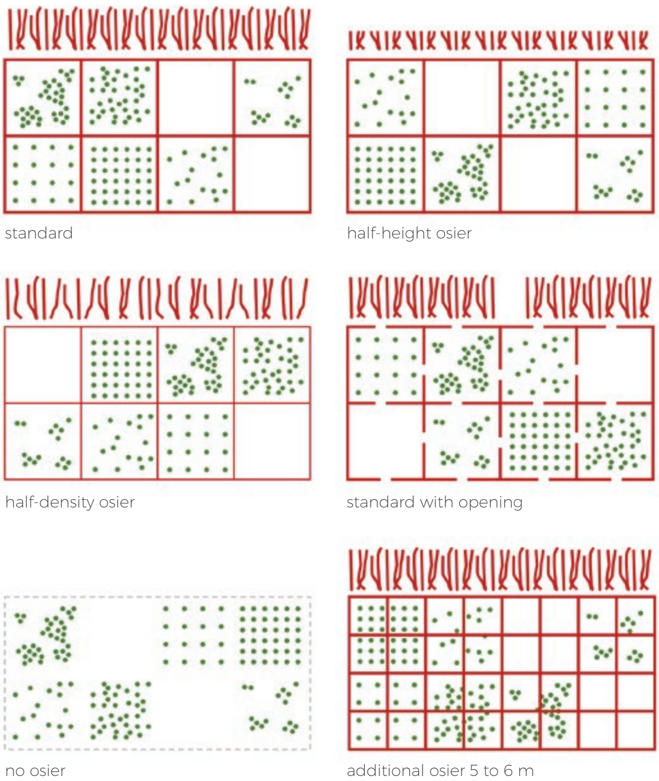
Monitoring

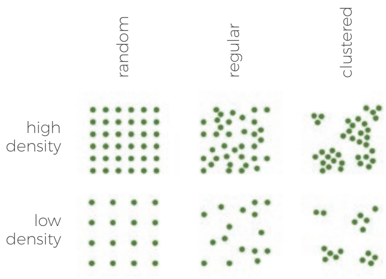
What is interesting about this pilot project is the close monitoring carried out by the Flemish Government and researchers from the universities of Leuven and Ghent. At regular intervals, they conduct drone flights to map the evolution of dune formation in detail. Based on accurate elevation levels, they calculate how much sand is retained on site and which planting configuration is most effective.

Vanackere: 'The results soon exceeded expectations. The works started in the spring of 2021 and already in the first winter season it became clear that the dune had grown faster than predicted. The tram tracks and the roadway remained virtually free of sand accumulation. If we compare building a concrete sand trap with the natural dune, the latter is clearly much more interesting in terms of cost, ecological value and aesthetics. For the time being, it has also proven to be more than efficient enough.'

Open sea view

One of the potential stumbling blocks of this pilot project was that the changing landscape would generate resistance from the population, as the open sea view from the dyke would disappear. The city of Ostend therefore organized a participation process with residents beforehand. Vanackere: 'There was support for the idea of creating a dune-before-dyke as a soft measure, but there was also scepticism as regards the view from the dyke. There was a lot of concern in relation to the sea view. On the other hand, working





with nature creates a living landscape that people can adapt to. This is in contrast to a hard measure, which gets realized overnight. The process of creating the dune becomes an experience in itself and, in time, will more than compensate for the changing view.'

Drone flights

What is interesting about this pilot project is the close monitoring carried out by the Flemish Government and researchers from the universities of Leuven and Ghent. At regular intervals, they conduct drone flights to map the evolution of dune formation in detail. Vanackere: 'Based on accurate elevation levels, they calculate how much sand is kept on site and which planting configuration is most effective.' The monitoring should also reveal whether the presence of a dune has an impact on the need for nourishment of the beach and subtidal zone. Vanackere: 'Beach nourishment is an effective form of coastal defence, but the beach needs to be nourished over and over again. There is a possibility that, thanks to the new dune, we won't have to replenish sand as often. That could have a beneficial effect on the cost of coastal defence.'

Today Ostend is applying the dune-before-dyke principle in other places, more specifically on Oosteroever. Vanackere: 'The principle is not applicable everywhere, however. Large parts of the beach are very valuable to tourists. A dune can only develop and grow if the area is temporarily closed off from access. Only when the dune is "mature" and has reached a certain robustness is access possible again.'

Existing situation. At this spot in Ostend, the Koninklijke Baan with its tram tracks runs right along the beach, so the wind blows the sand onto the road and tram rails. Car and tram traffic regularly have to be diverted or interrupted because the sand prevents the flow of traffic.

© Ostend

Mayor's Statement

Bart Tommelein

'We have learned that if we want to make Ostend a sustainable and robust city, this cannot be done with hard infrastructural measures alone. On the contrary, nature is an ally we must mobilize to realize this ambition. The project in Mariakerke-Raversijde is promising and has already proven its soundness. Simultaneously, we are conducting similar experiments in Oosteroever where we are working with the Flemish Government and knowledge institutions on integrated coastal defence.'

'The SARCC project contributes to a change in mentality where nature-based solutions are seen as the preferred alternative when making policy choices.'

the pilots

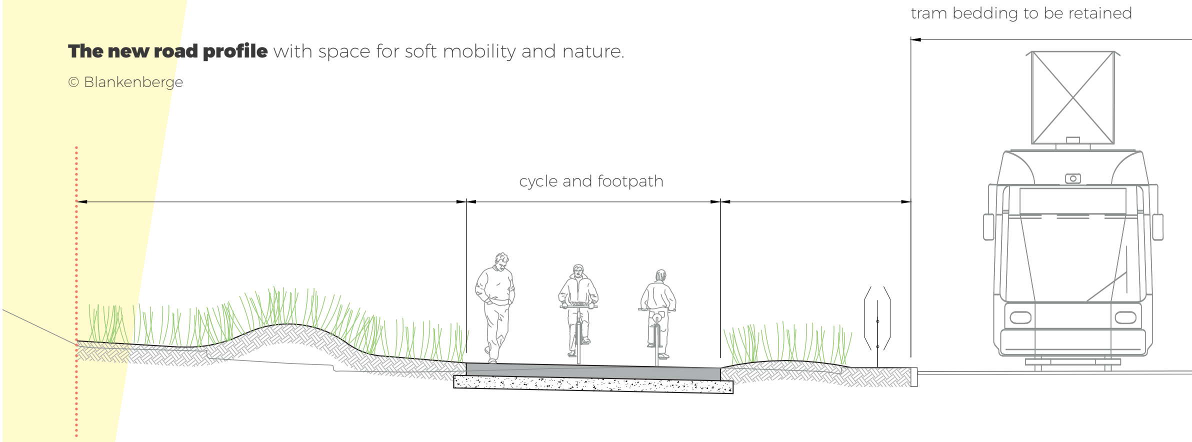
Blankenberge

Depaving and Duning

In Blankenberge, too, the basic ingredients for the nature-based solutions consist of little more than sand, marram grass and other dune vegetation. But unlike in Ostend or Middelkerke, the new dune here is not growing towards the sea, but inland. To make this possible, Blankenberge has depaved a section of the oversized Koninklijke Baan.

The new road profile with space for soft mobility and nature.

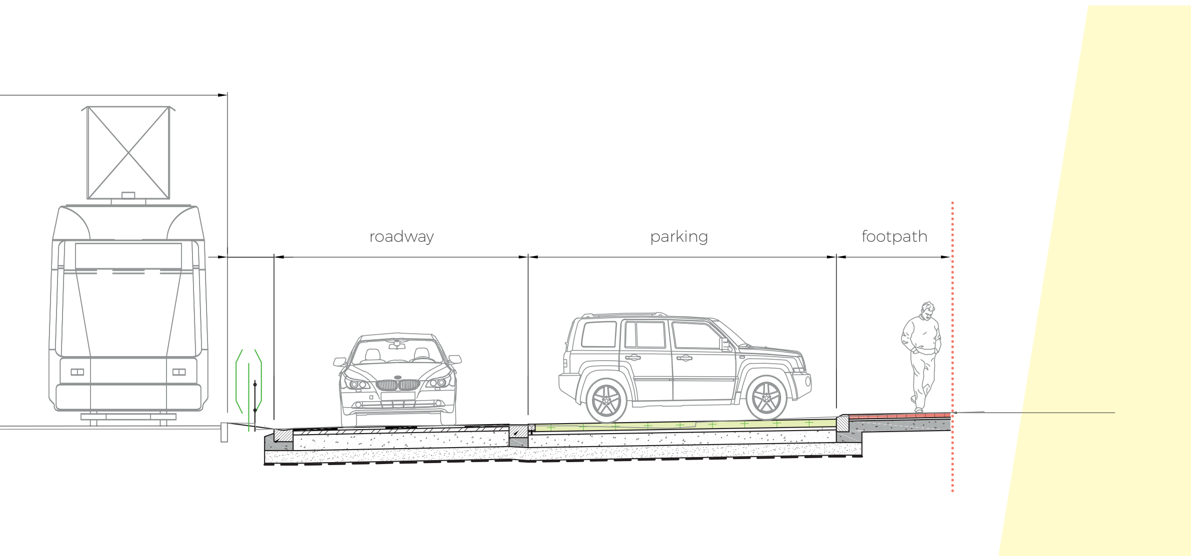
© Blankenberge



THE KONINKLIJKE BAAN is a relic from a distant past. The road covers the entire length of the Belgian coast, from De Panne to Knokke, and was built from the end of the nineteenth century on the initiative of King Leopold I, with the aim of opening up the coast to burgeoning tourism, but also to allow smooth military troop movements along the maritime border of the still young nation. In the 1950s, the road grew into a motorway with two lanes in each direction and a breakdown lane on either side. The 1990s also saw the addition of the Coast Tram. To this day, the Koninklijke Baan is a busy and oversized barrier that cuts off the coastline from the polders behind.

Blankenberge conceived the plan to dismantle, just east of the city centre, one lane of the Koninklijke Baan over a length of 700 m and return it to nature. At that spot, between the Koninklijke Baan and the beach, there is an elongated and valuable dune area with dune lakes and wet dune grasslands that turns into the Fonteintjes nature reserve further east. An 11 m wide strip – successively the footpath, cycle path, parking lane, two driving lanes and another parking lane – was broken up. All that remains is a recreational cycle path, surrounded by embryonic dune formation. Alain Mengé, project manager of the SARCC project at the city of Blankenberge, explains: 'In September 2022, we started depaving no less than 6,700 m² of road surface. It is an excellent opportunity to realize a "nature-based solution" at that location. In fact, we have decided to "dune" that area, significantly widening the existing dune and creating a "dune-behind-dune", providing additional protection against sea level rise. By enlarging the dune foot over a distance of 700 m, we are giving a strong boost to nature and biodiversity.'

There are other benefits. 'In Blankenberge, we have invested heavily in recent years in so-called depaving projects. These are needed to bring more nature into the city, but mainly



Mayor's Statement

Björn Prasse

'The Flemish Government's Coastal Safety Master Plan proposes several measures to protect our coast from significant sea level rise. In Blankenberge, among other things, a wall was built around the marina as additional protection against a possible rise in surface water levels. Such hard infrastructural measures are not always that sustainable, which is why it is important to also deploy nature-based solutions against the effects of climate warming. Several small-scale nature-based solutions have already been provided in Blankenberge, such as the creation of façade gardens and green roofs and the depaving of front gardens. It is my wish that the dune-behind-dune project, which is being realized in the A. Ruzettelaan, can be the impetus for implementing more nature-based solutions and especially on a larger scale.'

to allow rainwater to seep into the soil better. On the coast, we suffer from a groundwater table that is far too low. This can lead to problems for the drinking water supply and for agriculture, especially in the dry but busy summer months. In addition, the fresh groundwater in the dunes raises a wall against the salt water from the sea. Wide dunes provide a buffer against the salinization of the polders behind.'

Downsizing infrastructure also gives an impetus to the transfer to softer and more sustainable mobility. Mengé: 'The halved road is an important access road to the city centre, both for residents, the provision of merchants, and tourist traffic towards the Zeedijk and beach. We submitted the project to local residents and local entrepreneurs beforehand. Unfortunately, due to Covid restrictions at the time, this could only be done on a limited scale. Nevertheless, we incorporated a lot of feedback from, among others, the managers of the nearby shops into the traffic measures. Among other things, we decided that people can only enter Blankenberge via the Koninklijke Baan. The other direction of travel will be cancelled.'

The works started in early September 2022, after the busy tourist season. Beforehand, the Flemish Agency for Nature and Forests had tackled the existing dune. 'A lot of exotics were growing like beach rose, which were suppressing original dune vegetation like marram grass', says Mengé. 'And marram grass is just as important now to retain the sand and keep the dune growing. Now that the road has

Existing situation
The Koninklijke Baan is a busy and oversized barrier that cuts the coastline off from the polders.
© Blankenberge

Depaving
Blankenberge decided to dismantle one traffic lane over a length of 700 m and to restore it to nature.
© Blankenberge

New cycle lane
All that remains is a leisure cycle path bordered by embryonic dune formation.
© Blankenberge

Dune
The dune has the opportunity to grow further inland.
© Blankenberge

been depaved, we will have to see how the dune evolves further. Will the dune grow by itself thanks to the wind, sand and vegetation, or will we have to give it a hand? We don't know yet. There are still many unknowns, but that's what makes it so interesting. Our intervention strengthens biodiversity in the nature reserve. Moreover, the pilot project in Blankenberge will be a test for other cities and towns. If the project is successful, it could provide an impetus for further duning the Flemish coast and making it more sustainable.'

the pilots

© Gravelines

Gravelines

Great Results with Limited Means

In the north of France, between Calais and Dunkirk, lies the ancient fortified town of Gravelines. Due to heavy urbanization and industrialization combined with sea level rise, the need for enhanced protection against maritime incursion has become crucial. The pilot in Gravelines is achieving great results with limited means. It consists of little more than placing wooden piles in strategic places. This in turn enables the dune to thicken and enhance its height. From then on, nature does its work.

WITH ITS GENTLY sloping sandy beaches, the coastline of northern France is similar to that of Flanders: sand, dunes, dykes and, behind them, the polders. And yet the coastal landscape looks very different. Tourism is much less developed than in Flanders. Here, you do not (yet) find rows of towering apartment buildings offering sea views. But there is a lot of industry. The region around Dunkirk is one of the main industrial regions in France. Dunkirk is the third largest port in France and Gravelines is home to Western Europe's largest nuclear power plant, which relies on seawater for cooling. Many heavy industries,

The pilot project in Gravelines has achieved great results with limited means. It consists of little more than the planting of wooden posts at strategic locations. Nature took care of the rest.

© Gravelines

which benefit from the proximity of the port and from cheap electricity, are located here: an aluminium smelter, petrochemical companies, a data centre and a fish farm. The presence of industrial infrastructure makes the area very risk-sensitive.

The sea wall consists of dykes, quay walls and dunes. Pierre-Philippe Richard, adviser to the mayor of Gravelines, explains: 'Gravelines, like the Flemish polders, lies below sea level. So we are very vulnerable to flooding. The danger comes not only from the sea, but also from the land. The polders are an artificial landscape. It is an area that has been reclaimed from the sea by man over the centuries. To drain off the rainwater to the sea, a finely branched network of canals and ditches was constructed, the so-called *wateringues*. Through these watering ways, the excess rainwater is pumped out to the sea.'

Gravelines has one big natural advantage. Richard: 'Fortunately, and unlike many other towns on the Opal Coast, which are constantly losing sand on their beaches, the sand tends to accumulate on our coastline, a phenomenon called "accretion" or "sand washing".' The pilot in Gravelines is taking advantage of the natural supply of sand deposited by the sea currents on the beach and the subtidal zone, which the wind then blows further towards the coastline. Richard: 'To create a natural sea wall that is high enough to protect us from rising sea levels, we have developed a simple system of wooden fences that stop the sand from being blown in. The sand accumulates around the fences,

The sand accumulates around the hedges, after which vegetation such as marram grass takes over. Marram grass stabilizes the sand and reinforces the stability of the dune area.
© Gravelines

© Gravelines

> Fortunately, and unlike many other towns on the Opal Coast, which are constantly losing sand on their beaches, the sand tends to accumulate on our coastline, a phenomenon called 'accretion' or 'sand washing'.
>
> **Pierre-Philippe Richard**
> City of Gravelines

Mayor's Statement

Bertrand Ringot

'This innovative project has allowed us to implement a highly cost-effective solution to better protect the inhabitants of Gravelines while preserving the outstanding natural beauty of the beach. Tourism being one of the main activities of Gravelines, the nature-based solutions instead of grey structure seemed more adapted to our territory from this point of view. I believe it also helps biodiversity since the vegetation in the dune is now thicker. Economic actors, decision makers and local residents are all satisfied with what the SARCC project has allowed us to do.'

after which vegetation such as marram grass takes over. Marram grass fixes the sand and increases the stability of the dune area. We have also constructed elevated, wooden paths to enable visitors to walk through the dune in a controlled manner. The paths face east to take into account the sand currents caused by the wind.'

Richard: 'Apart from better protection against flooding, there are other advantages to this pilot: a higher, wider dune looks better and is

To create a natural sea defence high enough to protect Gravelines against sea level rise, a simple system of wooden fences was developed that hold back the sand being blown in.

© Gravelines

good for biodiversity. Plants grow more easily in a thicker dune and animals come back to the beach and roam the pilot site. The project is also popular with residents and tourists. The pilot shows that we can tackle major challenges with simple, low-cost solutions and at the same time strengthen nature and biodiversity. Unlike hard concrete structures, this nature-based solution is cost-effective.'

Raised wooden paths were constructed to allow visitors to walk through the dunes unhindered. The paths face east so as to take into consideration the wind-driven sand currents.

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the pilots

Vlissingen

Should we Make Way for the Dykes?

© Vlissingen

The Netherlands protects itself from a 10,000-year storm surge by constantly maintaining, reinforcing and raising its dykes and dunes. Vlissingen, a centuries-old port city at the mouth of the Western Scheldt estuary, is investigating whether things can be done differently. The pilot project allows the sea to enter the country in a controlled way in emergencies.

WHILE BELGIUM, FRANCE AND THE UK protect their urbanized coastal regions up to a 1,000-year storm surge, the Netherlands sets the bar much higher. Here, the standard is a 10,000-year storm surge. Not incomprehensible when you know that most of the Netherlands is below sea level. The disastrous North Sea flood of 1953, still deeply engraved in the collective memory, demonstrates the need for robust sea defences.

The steady sea level rise constantly requires additional measures, including in Vlissingen, a centuries-old port city at the mouth of the Western Scheldt. However, additional measures require space, space that is not always readily available in the highly urbanized coastal area. Marije Verlinde of the municipality of Vlissingen explains: 'In the urban area of Vlissingen, a new raising of the sea wall would lead to a deep and undesirable intervention in the urban structure, requiring the disappearance of a large part of the buildings near the sea.'

Vlissingen started looking for alternatives. Verlinde: 'We have been asking ourselves the question for decades: Should we make way for the dykes? Should we keep building ever higher dykes and hide behind them?' The pilot project provided an opportunity to test a very different (and daring) strategy, partially abandoning the hold-the-line principle for the first time in the Netherlands. 'Instead of always raising the sea wall, our pilot is betting on moving with the sea and the natural height differences in the area. In the incidental situation of a 10,000-year storm surge, we let the water flow over the dyke in a controlled way, diverting it to a lower water storage area.

The redesign of the square and the street is not only a sea defence project but also an urban renewal project.
© Vlissingen

By doing so, we prevent the sea water from flowing into a heavily populated area and causing a lot of damage there.'

The square on the sea dyke at Coosje Buskenstraat has always been a weak spot in Vlissingen's coastal defences. That is because the Coosje Buskenstraat slopes sharply from the sea dyke towards the inner city, making it very vulnerable when waves hit the dykes. In the pilot project, the street will be redesigned as a river, making a left turn so that the water ends up in the 'scouring basin'. This is a former water basin that was used well into the nineteenth century to flush out the tidal harbour so as to keep it free of silt and waste. In the 1970s, the scouring basin was filled in. Part of the area was built on (with a cinema) and used as a car park. The remaining part remained undeveloped wasteland.

Scientifically underpinned

The risks of a possible flood are high. The pilot therefore played it safe. 'We had the concept extensively tested by researchers at TU Delft, another partner in the SARCC project. Among other things, they calculated how much seawater would potentially surge over the dyke and how much water the scouring basin can store. In the current project, the scouring basin can store up to 80,000 m^3 of water, but if necessary, the capacity can be increased to 270,000 m^3 with very simple interventions.'

Vlissingen drew a new design for the street together with TU Delft and the design firm Juust. On both sides of the street there will be a wide green strip, with plants that can withstand the salty sea air and strong winds. It is this green buffer that collects the water

> In the incidental situation of a 10,000-year storm surge, we let the water flow over the dyke in a controlled way, diverting it to a lower water storage area.
>
> **Marije Verlinde**
> City of Vlissingen

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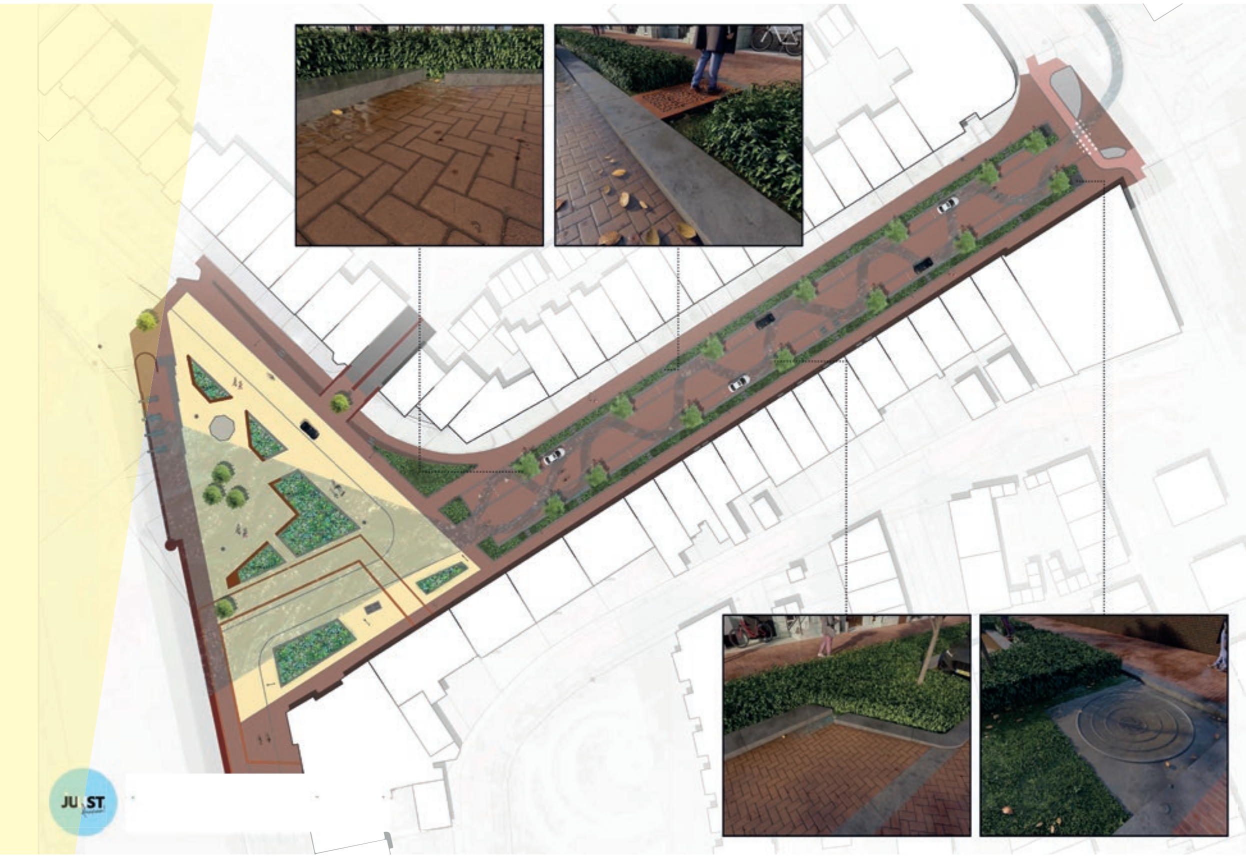


In the pilot project, the street is redesigned as a river that curves to the left so that the water reaches the scouring basin, a former water basin.

© Vlissingen

so that it can flow away to the scouring basin in a delayed manner. So the project is much more than a sea-defence project, it also gives ecological, tourist and spatial impulses to the city. Vlissingen also developed a vision for the scouring basin. The forgotten, inaccessible and rather unattractive wasteland will in future be transformed into an ecological water park and green lung in the city.

The nature-based solution offers the opportunity to tackle other climate-related problems, such as heavy precipitation. Thanks to the redesign of the public space, the amount of water in the sewers decreases at peak times, as the water is partly retained in the green spaces and enters the urban water system after a delay.

Mayor's Statement

A.R.B. (Bas) van den Tillaar

'Should we make way for the dykes? This is an issue that was raised during the development of Vlissingen in the early 1980s. With daring, creativity and a visionary outlook, governments, developers, architects and contractors at the time worked on a unique method of urban spatial development in the coastal zone. The task along the coast remains topical and is becoming urgent. As a result of climate change, urban coastal areas will sooner or later have to deal with rising sea levels and the threats or constraints this brings. The municipality is working with local, regional and (inter)national partners to respond to this situation. It is still our ambition to achieve and maintain an attractive coastal city in which to reside, do business, learn and live.'

'In Vlissingen, urban spatial development and (long-term) coastal defence go hand in hand. This involves looking at proven solutions and innovative concepts. Vlissingen can serve as an (inter)national testing ground in this respect due to its unique location and diverse coastal landscape and with commitment to the maritime, historical and morphological context. In the 1980s, the "Vlissingen model" was used to seek and find the solution for adjustments to new constructions on the coast. We will take the next step in the twenty-first century. Not only buildings, but the entire urban structure of coastal towns must be considered in the light of climate change. Here again, there will be room for innovation and flexibility, with opportunities for nature-based solutions.'

Verlinde: 'Apart from the theoretical exploration, we also carried out an on-site trial to test the street layout. We released 10,000 litres of water from a water tank in a short time. The trial showed that the drainage in the green strip can be removed in a buffered and delayed manner.'

The scale level of one's own street

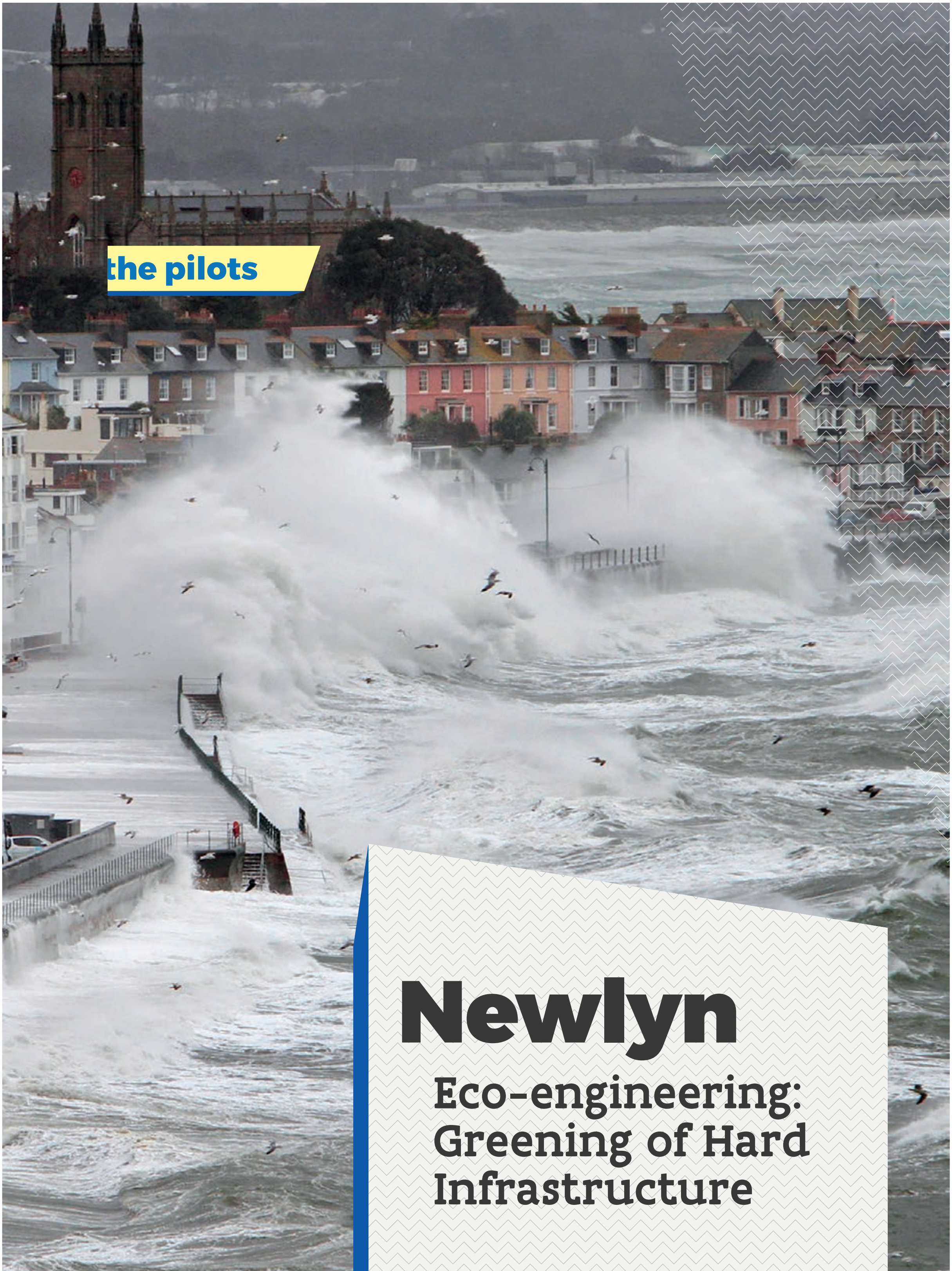
Verlinde: 'The Dutch are used to relying on the dunes and dykes that protect our country. It therefore requires a major shift in thinking on the part of citizens to accept that sea water is occasionally allowed into the city instead of being stopped by a hard sea wall. That also means accepting possible damage in a small part of the inhabited area to protect a larger area from the water.'

During the design process of the street, square and scouring basin, the city consulted its residents and entrepreneurs. A selection of citizens formed a focus group, which closely monitored the project. 'Initially, we feared there would be a lot of resistance to the plans. Sea level rise and its effects on the city are tasks that are far removed from citizens. The sense of urgency is not yet tangible. To make an abstract subject like rising sea level discussible, we linked it to very concrete tasks for the public space. If we reduce the project to the scale level of the individual street or neighbourhood, citizens are better able to participate and the climate target is made tangible and debatable. It was wonderful to see that many participants – thanks to their acquired knowledge of the future challenges – became "ambassadors" of nature-based solutions.'

Waterland Netherlands

The renewal of the square and Coosje Buskenstraat is scheduled for 2022. The vision for the scouring basin was delivered at the end of 2022 and will be realized in the coming years. In Waterland Netherlands, Vlissingen is a forerunner in innovative urban coastal development. And this is not the only project. Verlinde: 'The knowledge we gained from the SARCC project provided inspiration for other places on the Vlissingen coast. With the various stakeholders involved in coastal safety, such as the water boards and the Directorate-General for Public Works and Water Management, we will be discussing the possibilities of nature-based solutions.' But the pilot project is also getting attention beyond Vlissingen. Verlinde: 'Other coastal cities in the Netherlands regularly invite us to present our project. There is great interest. Perhaps it can also inspire other cities to think about nature-based solutions.'

Both sides of the street will have a wide green lane with plants that can resist saline water and strong winds.
© Vlissingen



the pilots

Newlyn

Eco-engineering: Greening of Hard Infrastructure

A small rock breakwater shelters seafront properties and infrastructure in Newlyn from waves. The pilot project is testing innovative 'eco-blocks' composed of low-carbon materials and textured to provide an ideal substrate for marine life. Adapting hard infrastructure to incorporate eco-engineering technology could create sustainability benefits for the surrounding ecosystem and coastal assets themselves.

NEWLYN IS A SMALL FISHING TOWN situated on the eastern side of the Penwith Peninsula in the county of Cornwall, a sparsely populated area with a rugged and often unspoilt landscape at the very western tip of England. The Coombe river flows through Newlyn into Mount's Bay. Because of its location at the 'entrance' to the English Channel, Newlyn's coastal zone is dominated by large Atlantic swell waves which refract around the Penwith Peninsula, on occasion producing nearshore wave heights exceeding 4 m. Sea level rise will therefore be felt hard at this tip of England.

Camilla Curry is a Flood and Coastal Erosion Risk Management (FCERM) officer working on the SARCC project. She works for the Environment Agency, the government body responsible for managing the risk of main river and sea flooding in England. She explains that the British approach to sea defences is very different from, say, the Flemish or Dutch approach. Curry: 'The UK coastline is thousands of kilometres long; it includes diverse characteristics and varying types of geology. The risks are not the same everywhere. Not all coastal areas are urbanized, as is the case in Flanders, for example. So, at the Environment Agency, we are working with the coastal protection authorities and other risk management authorities to transition from the narrow concept of "protection" to the broader concept of "resilience". This means, among other things, that we will have to accept that we are unable to protect the whole of the coastline using hard-engineered defences. We will manage the risks from climate change differently in some locations. This could include helping communities to better understand their risks and giving them more control to adapt and respond. However, there are inevitably vulnerable locations where seawalls and other

Flooding at Tolcarne Bridge during the St Valentine's Day storm, 14 February 2014.
Source: www.youtube.com/watch?v=CmRYAqhf-pk

types of hard-engineered defence will remain necessary to manage the risks of flooding and coastal erosion.'

Eco-blocks

Newlyn is one such vulnerable location. It has a highly developed and historic coastal frontage, with a fishing port, residential houses and numerous commercial businesses. The community has always been exposed to storms but has experienced increasingly frequent sea flooding and coastal erosion in recent decades. The town is built right on the water's edge and during heavy storms the waves overtop the breakwater, before propagating into the mouth of the Newlyn Coombe river. Houses, businesses and infrastructure situated at the mouth of the Newlyn Coombe are therefore particularly impacted by the resulting overtopping which occurs. To protect the town from the increasing risk of wave overtopping, this breakwater needs to be reinforced, raised and extended.

Curry: 'The current breakwater is made up of traditional granite rock. This smooth granite surface is difficult for marine life to settle on and does not attract a wide variety of species. That is why, in this pilot, we are exploring low-carbon concrete material that is specifically designed to attract marine life and where the CO_2 emissions from production and transport are as low as possible. We need to rethink the way we design and build traditional rock and concrete defences in some places. That's what this pilot project is all about.'

The Environment Agency is working with multiple eco-block suppliers to place a range of low-carbon concrete units – or eco-blocks – on and around the existing breakwater. They will be monitored both for their ability to encourage the growth of marine life and to

The existing breakwater in Newlyn. This is the test location where eco-blocks will be placed.

> In this pilot, we are exploring low-carbon concrete material that is specifically designed to attract marine life.

Camilla Curry
Environment Agency


A photo taken in July 2021 of a test eco-block by Exo-Environmental on the test location in Newlyn after the block had been on site for nine months. The dominant sort in the eco-block is *Enteromorpha sp.* (tube algae). *Fucus spiralis* (spiral wrack) is also present.

© Newlyn

withstand and absorb the high wave energy in the bay. The eco-blocks weigh around 4.8 t (4800 kg) and contain low-carbon concrete and some include by-product materials from a local quarry. The eco-blocks are being manufactured locally to minimize CO_2 emissions from transportation.

Curry: 'The marine life that grows on the eco-blocks – such as algae, seaweed and molluscs – may eventually increase the resilience of the whole structure, by creating a "bio-armouring" effect. We hope that using the eco-blocks will effectively create a living structure that could reduce the maintenance costs of the defence in the long run while also enhancing intertidal habitat and biodiversity. Monitoring a range of designs of eco-blocks from different suppliers will also help to maximize the learning from this project."

Community engagement

As part of the pilot, the Environment Agency has engaged with local residents to increase their awareness of the importance of embedding nature-based solutions in future coastal management where it is possible. The community's feedback for the pilot was collected and discussed during several engagement events. Curry: 'During the engagement phase, we learned that the intended construction site compound, which is located on a recreational green space (Newlyn Green), is highly valued by residents, especially during the summer season. One of the ways we addressed these concerns is by holding an art competition with local schools in order that the winner's artwork could be used to decorate the construction compound site fencing. We also changed the shape of the construction site compound to let the public access a popular local café close to the site compound. The community also expressed concern about the unnatural appearance of the eco-blocks. We have taken this feedback into account by placing the eco-blocks in a way that is visually consistent with the existing breakwater structure. Over time, it is hoped that as marine life colonizes the eco-blocks, the blocks will form an intertidal habitat that mimics the nearby natural rocky outcrops in form, function and appearance.'

Several manufacturers designed and produced different types of eco-blocks, each with different features which make them attractive habitats for marine life.

Innovative, ecological materials

The height and extent of Newlyn's present breakwater structure is not sufficient to provide effective protection from the most extreme storm conditions, which will become more frequent with rising sea levels. However, there are limited benefits that can be claimed through the UK Government's Flood Defence Grant in Aid (FDGiA) partnership funding model to protect homes in Newlyn from coastal flooding. This is due to its small population and the relatively modest economic benefits obtained from the large costs involved with upgrading costly coastal defences. For this reason, protecting a small seaside community such as Newlyn can be challenging. Exploring solutions like embedding eco-blocks into coastal structures can reduce future flood risks in addition to sustaining important intertidal habitats that can open extra environment-focused partnership funding opportunities.

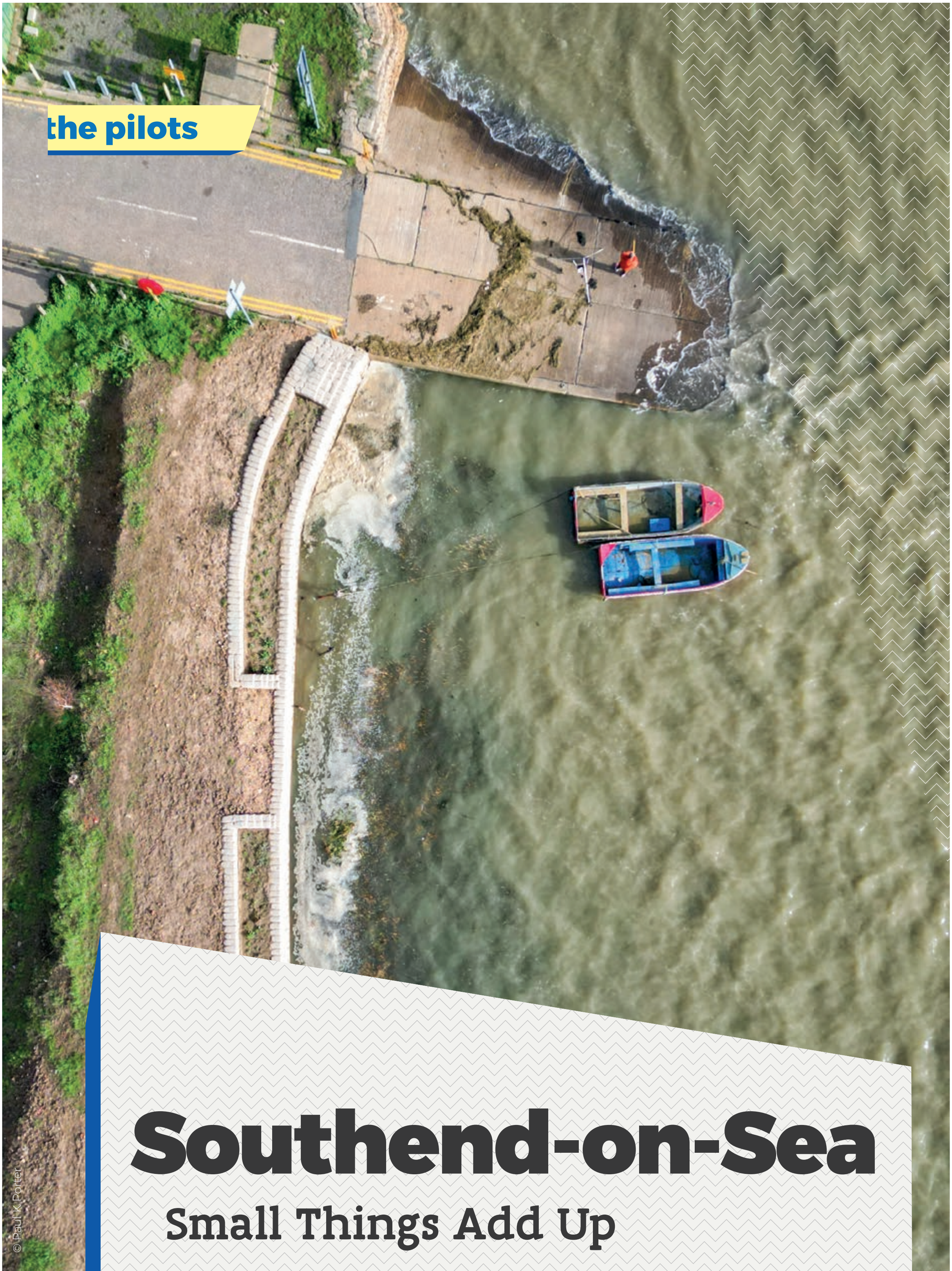
This pilot is an investigation of the use of innovative technology and an opportunity to monitor and gather evidence of their effectiveness for future coastal management schemes which 'green' traditional forms of hard coastal defence infrastructure. Curry: 'The eco-blocks will be continuously monitored and the knowledge gained will be shared with environmental and coastal managers from various organizations in the future. The intention is to develop proof of concept which can support deployment of the eco-blocks elsewhere on the UK coast, as a low-carbon and nature-inclusive alternative to traditional engineered defences.'

Mayor's Statement

Jonathan How

'Historically, Newlyn has always been vulnerable to flooding and damage from coastal storms. With climate change and the resulting sea level rise, both the frequency and consequences of these storm events will increase over the coming decades and beyond.
As such, I welcome the Newlyn coastal research and development project demonstrating an innovative and sustainable coastal management option for Mount's Bay. I look forward to observing how the innovative eco-blocks provide a low-carbon, hard-engineered coastal defence, but also how they act as a nature-based solution, helping to enhance intertidal habitats and improve biodiversity in future years.'

the pilots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Southend-on-Sea

Small Things Add Up

Compared to the other pilot cities, Southend-on-Sea is an outlier. The city chose not to roll out one big nature-based solution but to experiment in many different places. In total, no fewer than four pilots were realized, each with its own learnings and benefits.

NEAR SOUTHEND-ON-SEA, the Thames flows into the North Sea and the English Channel in a wide estuary. The city of Southend covers an area of 42 km^2 and has a population of just over 180,000. 'Every single inch is populated', says John Bennett, responsible in the city for the SARCC project. And indeed, a glance at Google Earth shows that the city is built right up to its banks. Those shores are very diverse in nature: hard dykes, narrow beaches, and here and there even dunes.

Pilot 1: Southchurch/Thorpe Bay Beaches

A large part of Southend's coastline consists of sand and shingle beaches. These beaches are getting smaller every year. The causes of beach erosion are not fully known, but it is suspected that sea level rise, urbanization and the intensive use by tourism have played a part in this. In this section of beach, the city decided to give back to nature an extensive shingle beach some 500 m long. 'It didn't take much', says Bennett. 'We normally rake our beaches every day during the summer months, which turns the sand and shingles and removes the rubbish. Embryonic vegetation doesn't get any chance to develop. On this stretch of the beach, we simply stopped the mechanical cleaning. The result was soon visible: different types of plants started to grow spontaneously.' A botanical study showed that twenty-two coastal species of halophytes or salt-tolerant plants thrive there, such as sea kale, sea holly, sea lavender, Sandhill Screw-moss and Sea Mayweed.

The project has not only given a boost to biodiversity, it is also hoped to protect the city against sea level rise. Bennett: 'It is great to see what the vegetation is capable of. We saw immediate results. The roots of the plants have stabilized the beach and slowed down erosion. Whereas in the past, when there was a storm, deep cliffs would form on the beach,

Southchurch/Thorpe Bay Beaches. Vegetation is given the opportunity to develop again on a large stretch of beach up to 500 m long, providing better protection against erosion.

now the beach remains flat and hardly any material disappears. The wind also has less influence on the sand. We can now see that the beach is not suffering as much from long shore drift. Less sand is getting blown over the sea wall onto the foot and cycle path.'

Of course, to make this project possible, we will need to share with tourists and local inhabitants the importance of this habitat. We will set up education boards and there is hope that the citizens and tourists will do their bit to protect this rare coastal habitat.

Pilot 2: East Beach

In the east of Southend, near the old garrison site, there is a remnant of the original dunes. These dunes are not very wide and are

East Beach. The existing dunes were restored, strengthened and replanted where necessary.

Vertipools and steel piling habitats. Small pools of low-carbon materials such as quarry waste provide an ideal substrate for marine life.

© John Bennett

subject to erosion by recreational users and tourists. Bennett: 'In our second pilot, we will restore the existing dunes. We will move some beach material to repair the gaps, reinstate fences and replant the bald dunes with native coastal plants. We also created several formal paths so that residents and tourists can still have access to the beach without damaging it.'

The project got off to a slow start. The dunes are around 200 m long, so a huge number of plants were needed. According to Nature England (the government's adviser for the natural environment), only native species grown in the UK could be used. Bennett: 'That didn't make it easy. There are only three companies in the UK that grow such plants. One was organized on too small a scale, another only grew marram grasses, and the third, which did meet the conditions, went bankrupt during the pandemic. There was nothing left for us to do but collect our own seeds and grow our own plants in our own parks department facilities.'

Pilot 3: Vertipools and steel piling habitats

The third pilot is located near the Old Leigh Port area. Bennett: 'A harbour infrastructure with its homogeneous surfaces of quay walls and steel sheet piles is often an ecological desert, as organisms have difficulty adhering to it. But in the Thames Estuary, where the sea moves up and down with the tide, a very particular marine life can develop.' On the quay walls and piles in the harbour are the so-called "piling habitats", a product developed by EXO Environment, one of the partners in the SARCC project. Like the Vertipools, the piling habitats consist of small pools made from low-carbon and circular materials such as quarry waste and dredged material. Bennett: 'The steel

Two Tree Island. A green wall is being built to protect the island's coast from erosion.

piling habitats provide an ideal substrate for marine life. In just a few months, it has been colonized by marine life such as algae, sea anemones, shellfish and so on. We have created an artificial intertidal habitat.'

Vertipools consist of triangular pools that are attached to the existing flood defence. Bennett: 'The Vertipools do several things at once. First, they break the force of the waves. If the waves collide into a flat and homogeneous surface they have much more force and can damage the sea wall and undermine the toe of any structure. The structure of the Vertipools, by contrast, deflects the energy from the waves so that the hard infrastructure of the sea wall is better protected. Furthermore, the Vertipools form a substrate for intertidal life. Marine life – such as algae, seaweed, sea anemones, shellfish, crabs and so on – can establish itself on and in the pools. This pilot is a "hybrid" nature-based solution: we are applying a green front to a hard structure. This pilot is a test-and-learn project of how we can reduce the maintenance costs of the existing hard sea wall.'

Pilot 4:
Two Tree Island

The fourth and final pilot is located on Two Tree Island, an island on the western edge of Southend. In the 1930s the island was used as a landfill for household waste. Thirty years later, in the 1970s, activities ceased, the landfill was capped, and the island was redesignated as a nature reserve. It has since become known for its wide variety of birds, wildfowl and waders. Bennett: 'Since humans do not use or inhabit the island – it is only in use by nature – there is hardly any budget to invest in protection against sea level rise. The rudimentary sea wall consists of stacked sandbags filled with concrete, but these were

> In our pilots we did not aim for massive change. We wanted to test and learn, in different places at the same time. We work with what is already there: sand, shingle, flora and fauna.

John Bennett
City of Southend-on-Sea

highly susceptible to erosion by wind and sea. Therefore, we will replace the sandbags and plant the new area with coastal plants grown by our parks team. This will create a green wall to link the landward area of the car park to the salt marsh and estuary.'

Seven miles of coastline

Southend opted for a fragmented approach. Every site is different: a beach, a dune, a sea wall and an island. Bennett: 'In our pilot we did not aim for massive change. We wanted to test and learn, in different places at the same time. We work with what is already there: sand, shingle, flora, fauna. We are investigating whether it is cheaper and more sustainable in the long term than building large-scale, hard infrastructure. But all these smaller experiments add up, we have increased the level of protection in the city by using nature-based solutions.'

Statement by Jo Gay,

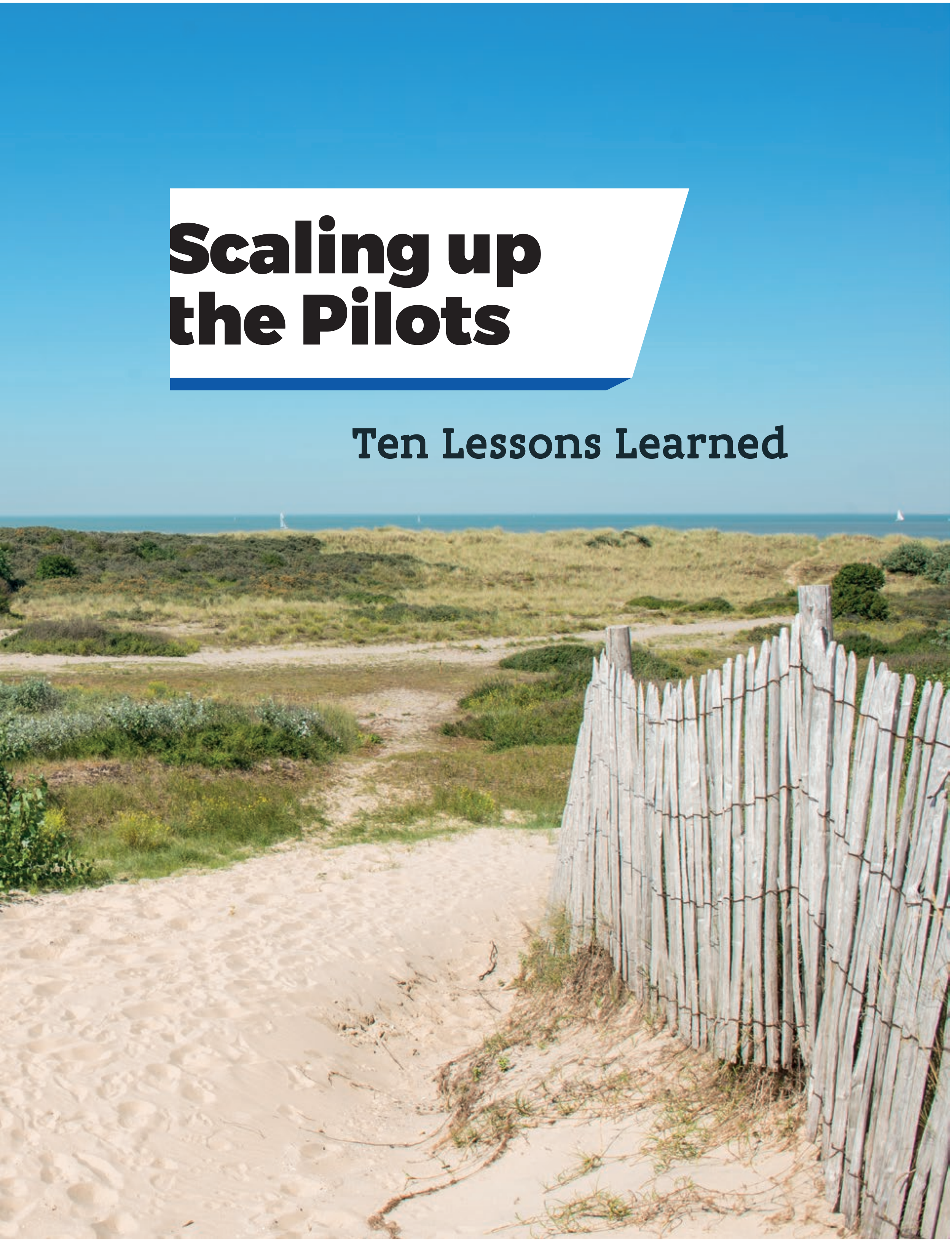
Head of Climate Change, Southend

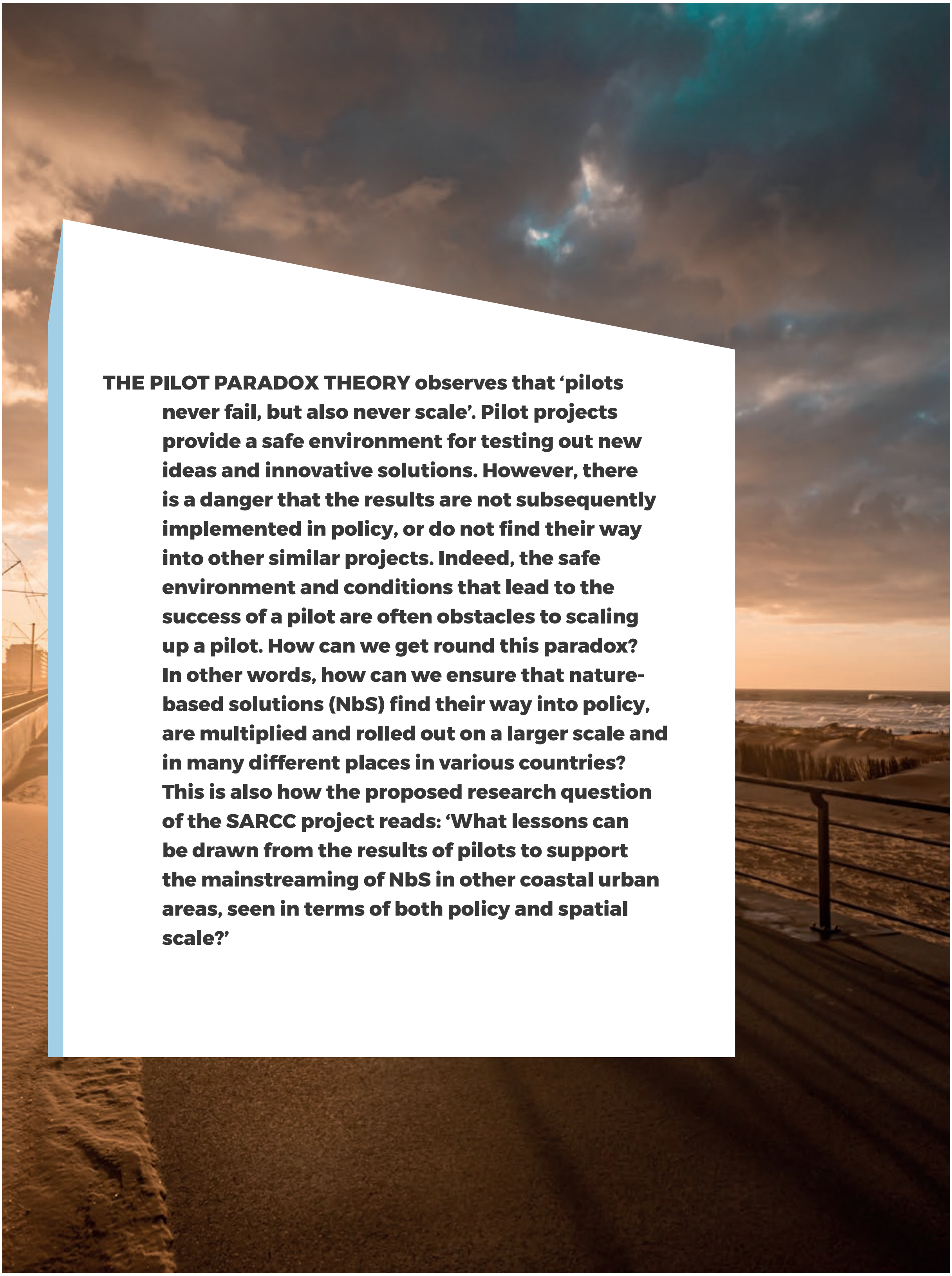
'The SARCC project has been very important for Southend City Council. As lead partner we have worked closely with all the project partners to develop a cohesive set of outcomes for both the project and each individual region. Through the SARCC project we are maximizing the integration of nature-based solutions in our coastal defences that were grown here in Southend. We are also happy to have partnered with the Environment Agency in this project and the data we have shared is feeding into a national strategy on nature-based solutions.'

PART 3

Scaling up the Pilots

Ten Lessons Learned





THE PILOT PARADOX THEORY observes that 'pilots never fail, but also never scale'. Pilot projects provide a safe environment for testing out new ideas and innovative solutions. However, there is a danger that the results are not subsequently implemented in policy, or do not find their way into other similar projects. Indeed, the safe environment and conditions that lead to the success of a pilot are often obstacles to scaling up a pilot. How can we get round this paradox? In other words, how can we ensure that nature-based solutions (NbS) find their way into policy, are multiplied and rolled out on a larger scale and in many different places in various countries? This is also how the proposed research question of the SARCC project reads: 'What lessons can be drawn from the results of pilots to support the mainstreaming of NbS in other coastal urban areas, seen in terms of both policy and spatial scale?'

Choose NbS where possible, grey infrastructure where necessary

When faced with an existential task like coastal safety, government authorities and the general public often tend toward a conservative reflex. Grey infrastructure is still valued higher and considered safer than NbS. Often wrongly so. Grey infrastructures such as dykes and storm walls have successfully protected us from the water for a long time, but today, due to rising sea levels, they do not always appear to be the most sustainable solution. Knowledge gained from the SARCC project shows that in many cases NbS are not only more effective, more resilient and cheaper (in the long run) to protect us from rising water and storm surge, but they also offer numerous benefits in terms of ecology and biodiversity, economy and tourism, health, prosperity and well-being. Therefore, we should reverse the ingrained reflex: instead of prioritizing grey infrastructure, we should first look at the possibilities of application of NbS. When NbS either do not appear feasible or less so, 'hybrid' solutions can be envisaged that combine hard infrastructure with NbS. The use of NbS obviously requires extensive knowledge of natural and geological processes, climate change impacts, ecosystem services and customization. Overcoming resistance to NbS also requires the proper monitoring of projects and empirical evidence on their long-term effectiveness.

Incorporate the 'ecosystem services' (ESS) approach in the design of coastal protection measures

The ESS concept is a view that identifies and valorizes the full set of services, products and benefits that nature provides to society. In any coastal protection project, make the trade-off between grey infrastructure and NbS and evaluate what benefits NbS can provide (in the short, medium and long term). Those ESS are very diverse: besides the necessary coastal protection, they include enhancement of biodiversity, preservation or enhancement of freshwater resources and carbon storage as well as opportunities for recreation, well-being, cooling and so on. The broad added value of NbS can be demonstrated through a comprehensive analysis of ESS. However, the ESS approach requires a sufficiently broad vision and integral involvement of a wide variety of sectors and stakeholders. In this way, the analysis can form the basis for an integrated assessment framework and act as a stepping stone to a transversal and integrated policy, where all relevant sectors, disciplines and stakeholders are gathered around the table. The ESS approach can result in a win-win for a multitude of parties and sectors: nature, economy, agriculture, fisheries, tourism, trade, coastal protection, people, society ... The valorization should be done in a language that is manageable and understandable for all (future) users. By mapping out (and calculating) the various advantages, we create the conditions for additional funding.

03 The design and implementation of NbS require co-creation and an integrated policy structure

Coastal protection projects are often enormously complex projects in which different interests interfere and even clash. While a metre-high dyke may protect a city from the water, it may also obstruct the functioning of that city, block access to the water or maritime views or else threaten natural values. In other words, priorities in flood risk policy must seek synergies and win-win strategies with other needs and sectors, such as urban and spatial planning, nature, tourism and the economy. Reconciling all these different interests requires an integrated or transversal approach. Policy (local, regional, national, international) needs to provide the flexibility to experiment, learn and adapt. This means that the classic organizational structure, at once compartmentalized and sectoral, must evolve into an integrated culture of co-creation across sectors and administrative levels.

04 Collaboration between government(s), industry, university and public (the Quadruple Helix) is an engine of innovation

Innovation and co-creation take place not only between governments or sectors, but also between government(s), industry and university. In drawing up plans for NbS, it is crucial to be guided by the relevant research and knowledge centres. The knowledge required is very diverse: engineers, designers, climatologists, geologists, hydrologists, economists, ecologists, sociologists, etc. A similar diversity of applied knowledge is found in industry: port companies, dredgers, farmers, fishers, tourism companies, etc. In this cooperative way, governments can implement actions based on knowledge, on the field know-how within a participatory framework. In the literature, cooperation between government, university and industry is described as the Triple Helix: the engine of innovation in society. The Triple Helix can be supplemented by a fourth party: the public (citizens and society at large). This is what is called the Quadruple Helix. Because the general public does not always trust NbS, it is important to properly inform citizens about the plans and about the multiple benefits NbS can deliver. Local authorities must inform the public and explain the dangers and uncertainties of climate change and ecological disruption, why NbS is the best option and what benefits are associated with it (ESS). This (minimal) form of participation is indispensable to gain support. Participation can also go a step further: actively involving citizens and local entrepreneurs in the design and realization will not only increase support, but a government can also build on local knowledge. The project may take a little longer during preparation or the start-up period, but after that it will not suffer from delays due to objections or legal challenges.

05 Find or be the agent of change

Experience shows that a complex transition project like coastal protection by NbS – in which many different actors from various sectors and an enormous amount of knowledge about different disciplines must be brought together – requires special 'booster' figures who can take the lead. Such 'agents of change' are connecting figures, not specialists but generalists, process managers who bring the right people together at the right times and thus get things moving and create momentum. The agents of change are also ambassadors of NbS: they spread the message to other regions, to higher authorities, a broader audience ... Agents of change are confident in NbS. They think outside the box and have a large network at their disposal through which to disseminate the knowledge and convince other actors about the added value of NbS. They defend their ideas even if it means challenging the current policies.

Look across borders and learn from other countries and regions

Sea level rise and other climate problems do not stop at the borders of a municipality, region or country. This is particularly the case in border regions. The SARCC project has shown that learning from each other's experiments and exchanging experiences lead to new insights and practices. So it is important to look across borders, exchange experiences and learn from each other. Nevertheless, it is not simply a matter of copying solutions from other cities on a one-to-one basis. After all, there are major differences between cities and regions. Every region faces different geographical, hydrological, natural, urban, cultural, social and economic parameters and therefore needs solutions adapted to the context. Also, the type of measures taken differ from country to country due to the country-specific conditions of safety precautions, the cultural and historical background, etc. Each situation is different and requires adequate knowledge of the local system. Customization is the key.

07

Remember the longue durée to recall the historical patterns of change

Although the climate has never changed as rapidly in the history of the Earth as it is changing today, climate change remains a slow process. A sea level rise of a few millimetres per year is, as it were, invisible to the naked eye. The same applies to geological processes such as erosion and sedimentation: these processes span hundreds, even thousands of years. That is why it is important to keep an eye on the longue durée in coastal protection works and NbS. Understanding past, present and long-term patterns of change that indicate the erosion, sedimentation or stability of areas can inform coastal managers and contribute to the decision-making process. Conversely, historical evidence can show how human-induced changes have disrupted natural processes, leading to harmful long-term effects on the shoreline and coastal plain. Archaeological data, historical information and information through artworks can contribute positively to building a fact-based narrative of coastal change. This can be used to help stakeholders visualize past changes and help coastal managers and policymakers propose solutions that work in tandem with, rather than against, long-term natural processes. The longue durée is also important for the design phase of NbS. In the design phase, the local conditions (past, present and future) need to be considered (morphological, climatic, historic, cultural) as well as the interests of the different sectors (spatial development, flood safety, recreation/tourism, etc.).

The end is the beginning: ongoing monitoring and evaluation of both project and process are necessary to scale up the pilots

Evidence of the effectiveness of NbS for coastal protection is currently limited due to the relatively recent use of these solutions. Within the SARCC project, pilots were considered as tools to provide empirical evidence of the effectiveness of NbS for coastal protection and its additional benefits. To do this, it is necessary to measure results accurately, not only throughout the SARCC project, but certainly also in the longer term. Numbers tell the tale. In this way, other cities and towns can also learn from the experiments as well as gain and grow confidence in the effectiveness of NbS approaches. Empirical data for the performance of innovative eco-products (like eco-blocks) should also be expanded through continuous monitoring. Growing confidence in such products can help to grow the market for eco-products and make them more affordable for larger-scale projects. It is not only important to properly monitor and measure NbS, but also to map and evaluate the processes needed to get there, so that other cities can learn, not only about what they can achieve but also about how they can get there. Last but not least, it is important to properly access and share that knowledge so that no one has to reinvent the wheel.

Establish an accessible platform or tool for knowledge sharing and capacity building

Pilot projects are experiments where learning by doing takes place. However, the success of a pilot project goes far beyond the success of the individual project: the ultimate goal is to scale up the pilots and get them implemented in many places simultaneously. This can only happen if the knowledge gained during the course of the SARCC project in general and the pilot projects specifically is also collected, accessed, shared and secured. Pool knowledge and make it accessible through an open-source knowledge sharing tool or platform. Such a 'learning environment' ensures that the knowledge and expertise gained are not lost, but that other actors can also build on it. Especially for smaller cities and towns, which do not always have the same capacity as larger players, such a learning environment is crucial. Setting up such a learning environment is a task of 'higher' authorities and ideally should occur on a regional, national or, even better, European level.

Seek co-financing and create new social business models

Cities and municipalities do not always have the necessary resources and know-how to implement NbS. For local governments, NbS are often still uncharted territory. As a result, these authorities often stick to classic recipes such as hard or, at best, hybrid infrastructure. Co-financing by higher authorities (regional, national and European) can convince local governments to opt for NbS after all. Cities and municipalities can cooperate for this purpose and look for investment opportunities on a larger scale. The higher authorities and partners in the alliance can also provide the necessary support and policy cross-fertilization in terms of knowledge and know-how. Secondly, it is important to provide a sufficient budget for long-term management, maintenance and monitoring from the outset, especially as early as the design of NbS. Although NbS measures may be cheaper than hard infrastructure in the long term, they require more (and more intensive) monitoring than hard infrastructure, given the dynamic nature of the realizations. Thirdly, it is important to prepare a comprehensive social cost-benefit analysis of the planned NbS project, including not only the costs of construction, maintenance and monitoring, but also taking into account and, where possible, quantifying the many external benefits (especially the diversity of ecosystem services).

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Climate change is undoubtedly one of the great challenges of the twenty-first century. The effects of warming are already being felt around the world today, with more intense heatwaves, droughts, floods, the melting of sea and land ice, and the issue at the centre of this publication: sea level rise. For the past century, we have mainly protected our coasts with ‘hard’ walls of defences such as concrete dykes, revetments and sea walls. This publication advocates changing tack and protecting ourselves from the sea with the means nature has given us.

Seven coastal cities in four countries around the North Sea and the Channel joined forces to investigate – and immediately test in pilot projects – how best to achieve this goal. From 2017 to 2023, a broad international and interdisciplinary coalition of public authorities, knowledge institutes and private partners conducted research into the possibilities, benefits and feasibility of so called Nature-based Solutions (NbS) for coastal protection as an alternative or addition to the usual grey infrastructures. They conclude that NbS are not only better for environment, climate and biodiversity, but are often more resilient in the long term and in some cases even much cheaper than traditional hard sea defences.