Europe's coastal erosion in a changing climate

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Coastal erosion in Europe

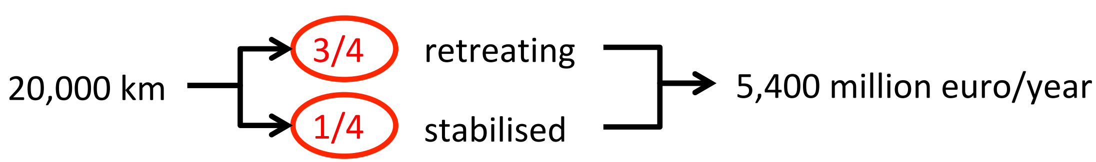
All European coastal states are to some extent affected by coastal erosion. About twenty thousand kilometres of coasts is eroding, of which three-quarters is actively retreating, and a quarter is artificially stabilised.

Coastal erosion results in

- loss of land with economical value
- destruction of natural sea defences (usually a dune system) as a result of storm events, which may result in flooding of the hinterland
- undermining of artificial sea defences as a result of chronic sediment shortage

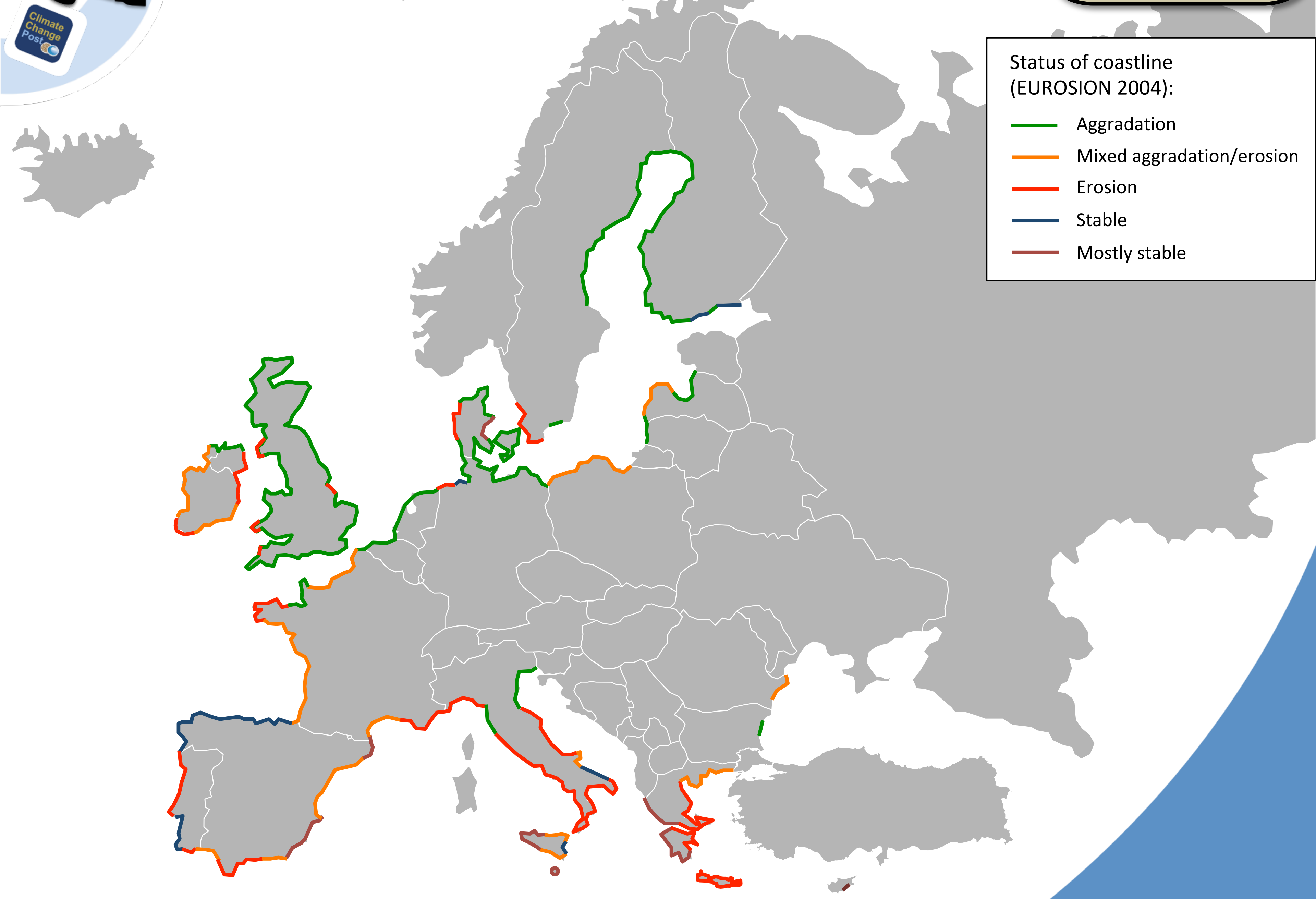
The cost of coastal erosion (coastline protection against the risk of erosion and flooding) has been estimated to average 5,400 million euro per year between 1990 and 2020.

Source: Salman et al. (2004); Pranzini and Williams (2013)



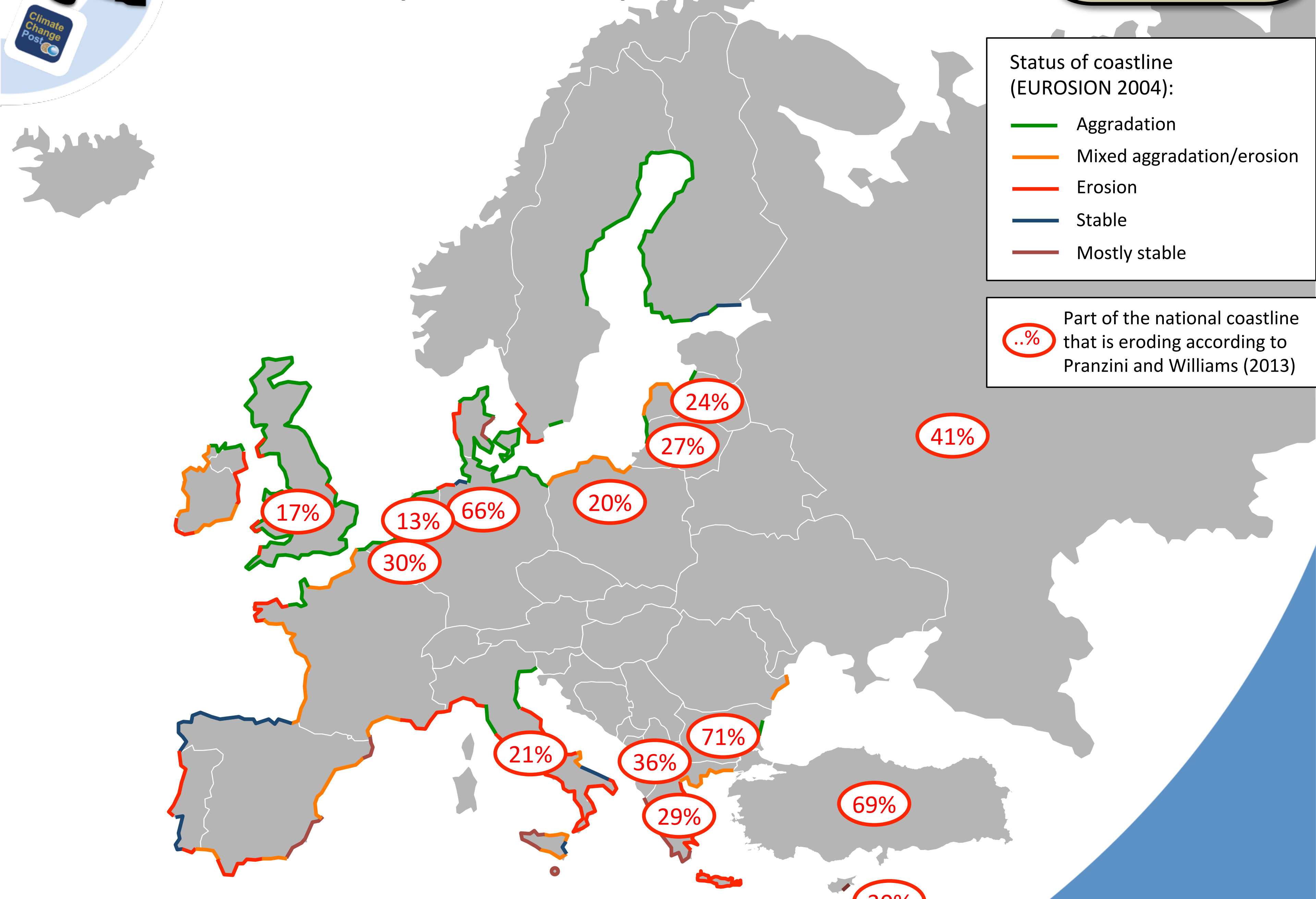
Coastal erosion patterns in Europe

Overview



Modified after EUROSION map (European Environment Agency, downloaded February 2019)

Coastal erosion patterns in Europe



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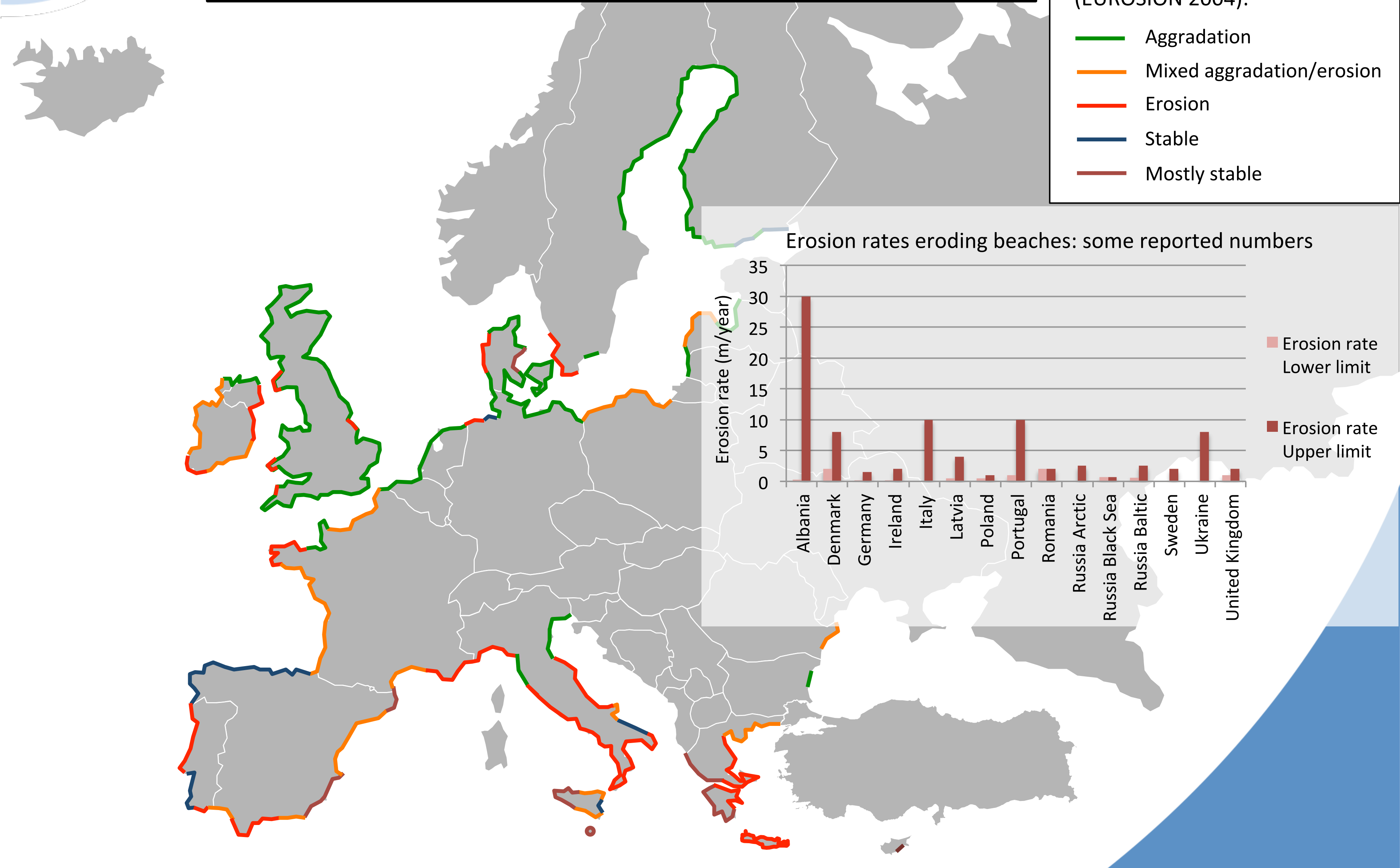
Overview

Beach erosion: Upper limit erosion rate is generally about 2 metres per year, with exceptions up to 10 metres. Locally, even higher erosion rates are observed.



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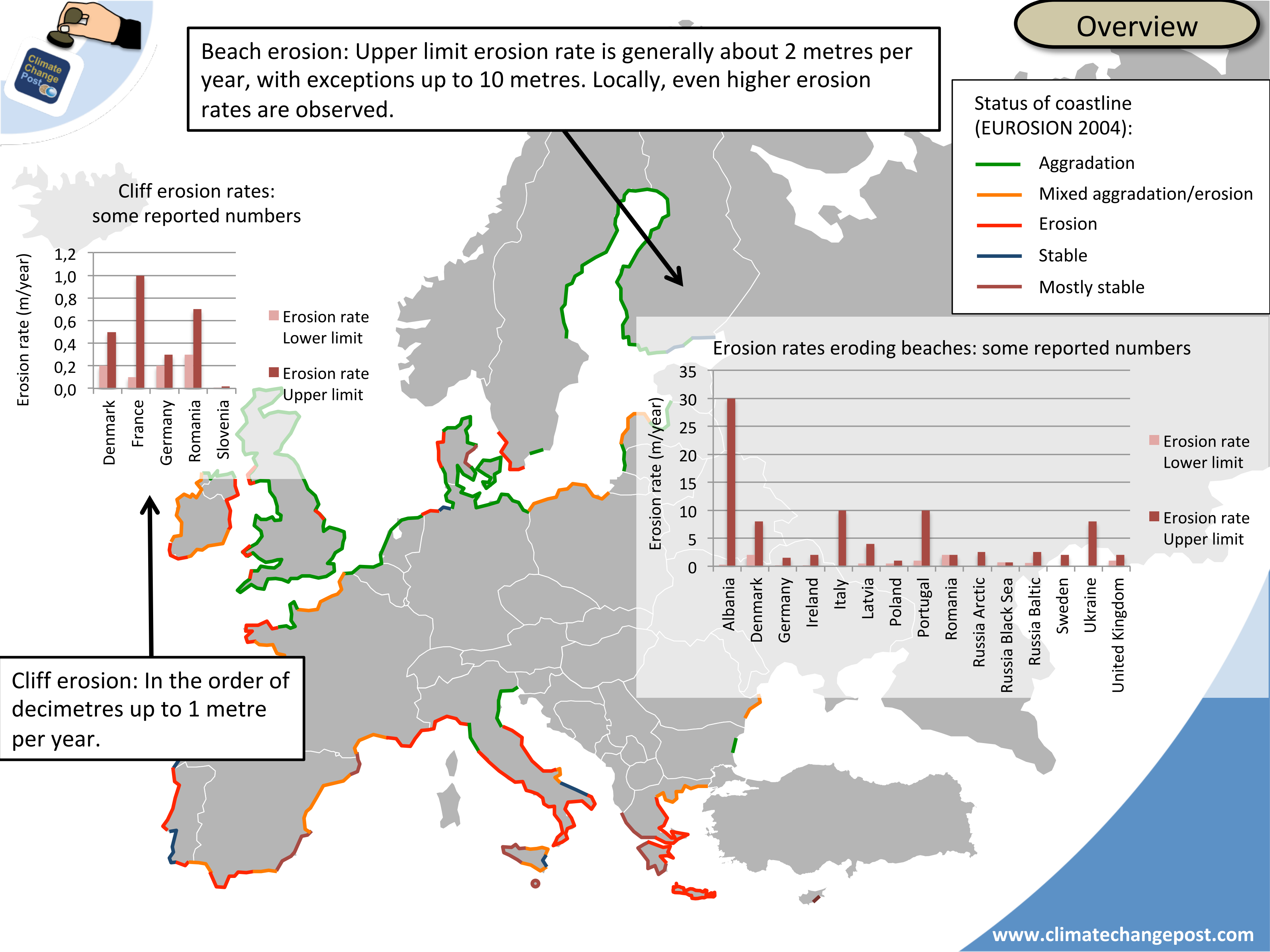
Cliff erosion: In the order of decimetres up to 1 metre per year.

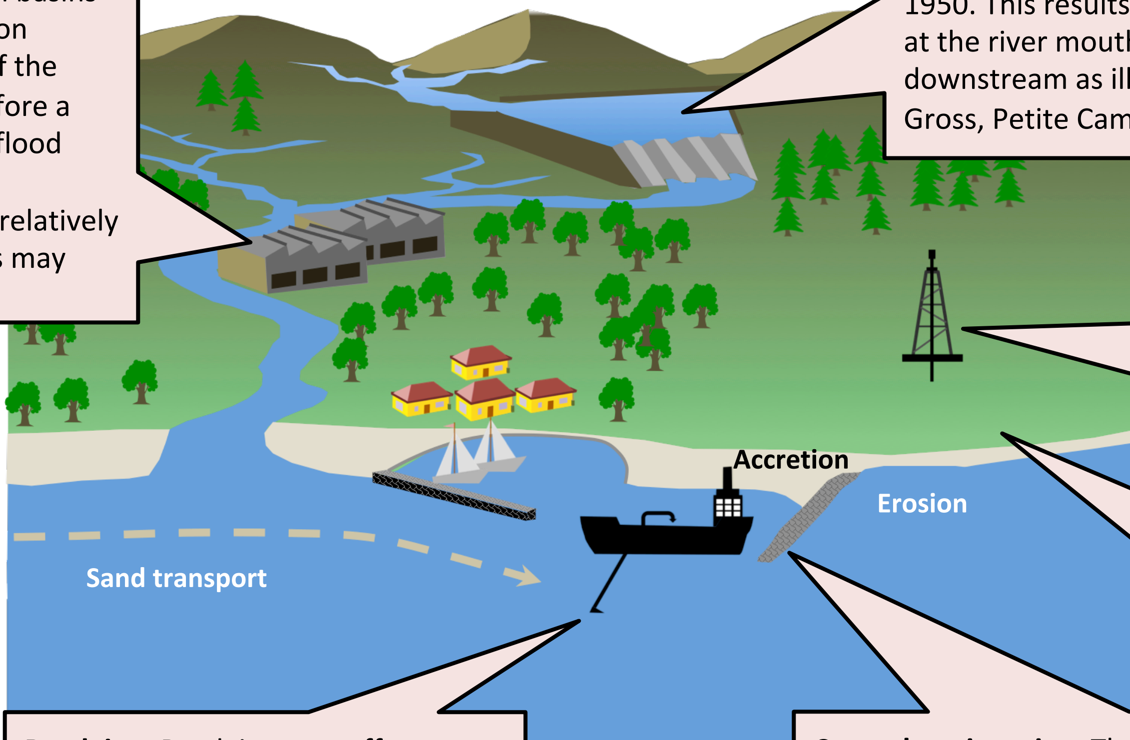


Coastal erosion is influenced by several human factors

Causes

River engineering. Damming has effectively sealed water catchments locking up millions of cubic metres of sediments per year. For some southern European rivers, the annual volume of sediment discharge represents less than 10% of their level of 1950. This results in a considerable sediment deficit at the river mouth, and subsequent erosion downstream as illustrated in Ebro delta, Playa Gross, Petite Camargue (Rhone delta) and Vagueira.

Land claim. Within tidal basins or bays, land reclamation results in a reduction of the tidal volume and therefore a change in the ebb and flood currents transporting sediments. As a result, relatively stable coastal stretches may begin to erode.



Gas mining or water extraction. Gas mining or water extraction may induce land subsidence, causing sediment deficit and a retreat of the coastline.

Vegetation clearing. A significant number of cases have highlighted the positive role of vegetation to increase the resistance to erosion.

Dredging. Dredging may affect coastal processes by removing from the foreshore materials (stones, pebbles) which protect the coast against erosion, and by contributing to the sediment deficit in the coastal sediment cell.

Coastal engineering. The waterfronts of urban, tourism or industrial zones have usually been engineered by way of seawalls, dykes, breakwaters, jetties, or any hard and rock-armoured structures. Such structures modify wave and flow patterns in the near shore zone and therefore cause a redistribution of sediment. The sediment redistribution can induce erosion in some places and accretion in others.

Coastal erosion is influenced by several human factors

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IPCC: the primary drivers of widespread observed coastal erosion are human drivers other than climate change

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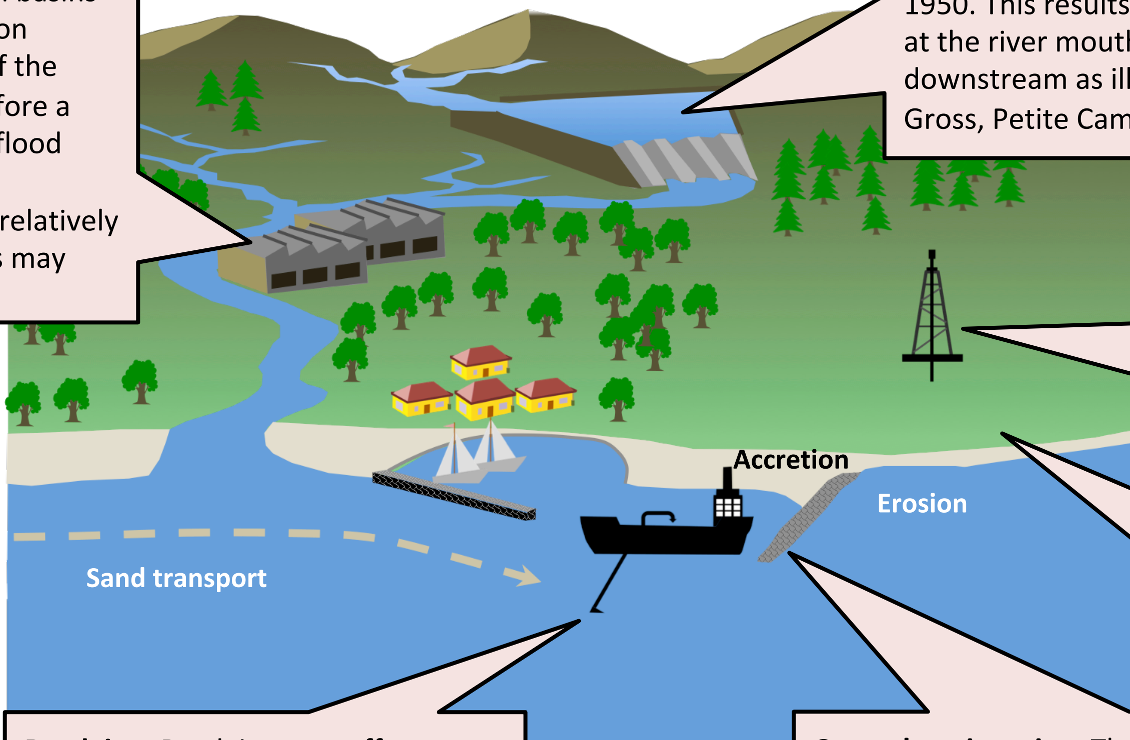

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↓

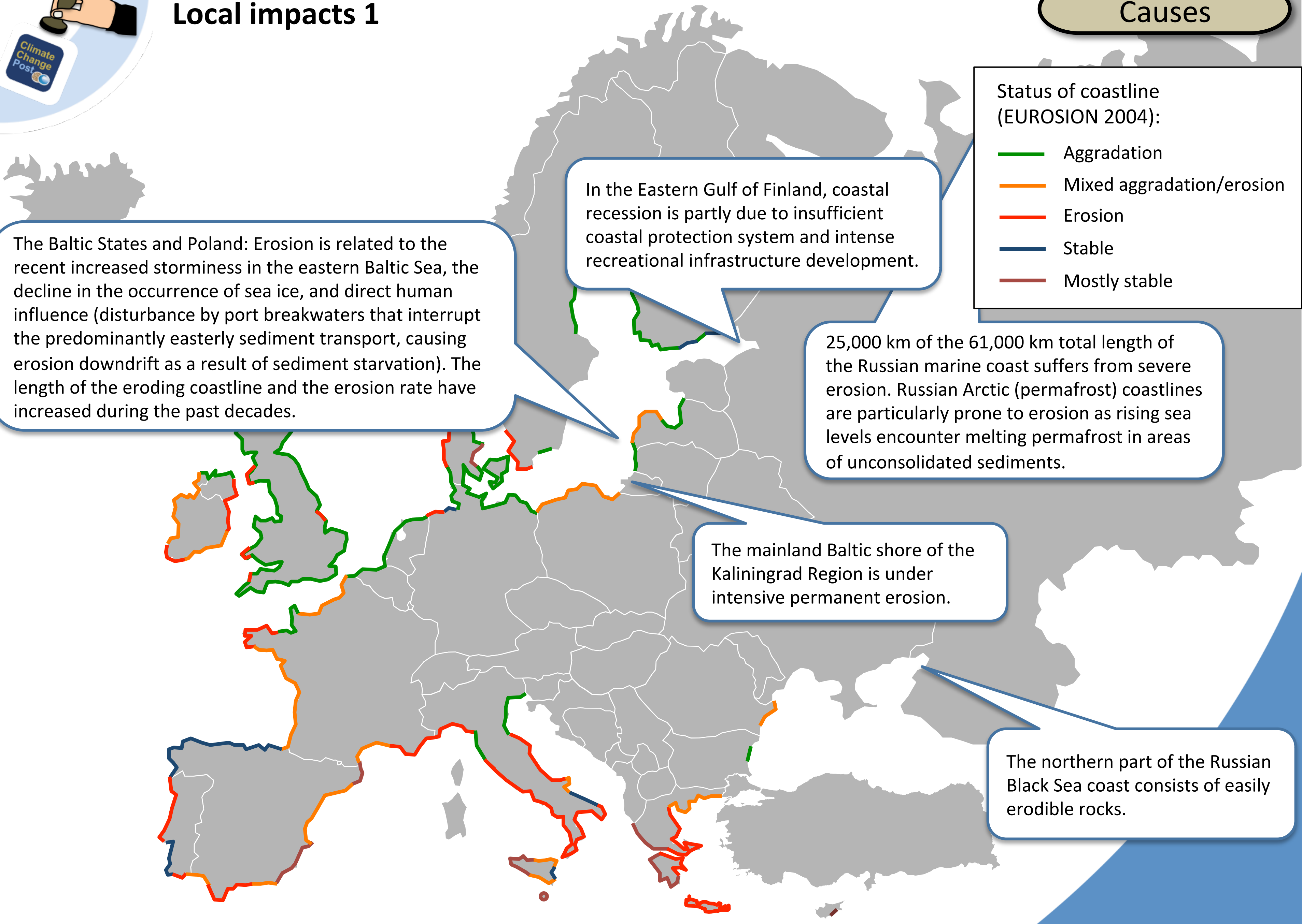
Reported climate change impacts:

→ **Less sea ice, more storms on the Baltic Sea**
Over the last decades, there has been a sharp reduction in sea ice duration time as a result of which ice is not acting as a natural 'protective barrier' during winter storms. In the past 20-30 years, the force of devastating autumn and winter storms over the Baltic Sea is increasing. As a result, erosion of the coast of the Baltic States increases.

→ **Melting permafrost**
Russian Arctic (permafrost) coastlines are particularly prone to erosion as rising sea levels encounter thermokarst areas. Thermal abrasion of areas of melting permafrost in areas of unconsolidated sediments results in rapid coastal recession, up to 2.5 m/year.

Local impacts 1

Causes



The Baltic States and Poland: Erosion is related to the recent increased storminess in the eastern Baltic Sea, the decline in the occurrence of sea ice, and direct human influence (disturbance by port breakwaters that interrupt the predominantly easterly sediment transport, causing erosion downdrift as a result of sediment starvation). The length of the eroding coastline and the erosion rate have increased during the past decades.

In the Eastern Gulf of Finland, coastal recession is partly due to insufficient coastal protection system and intense recreational infrastructure development.

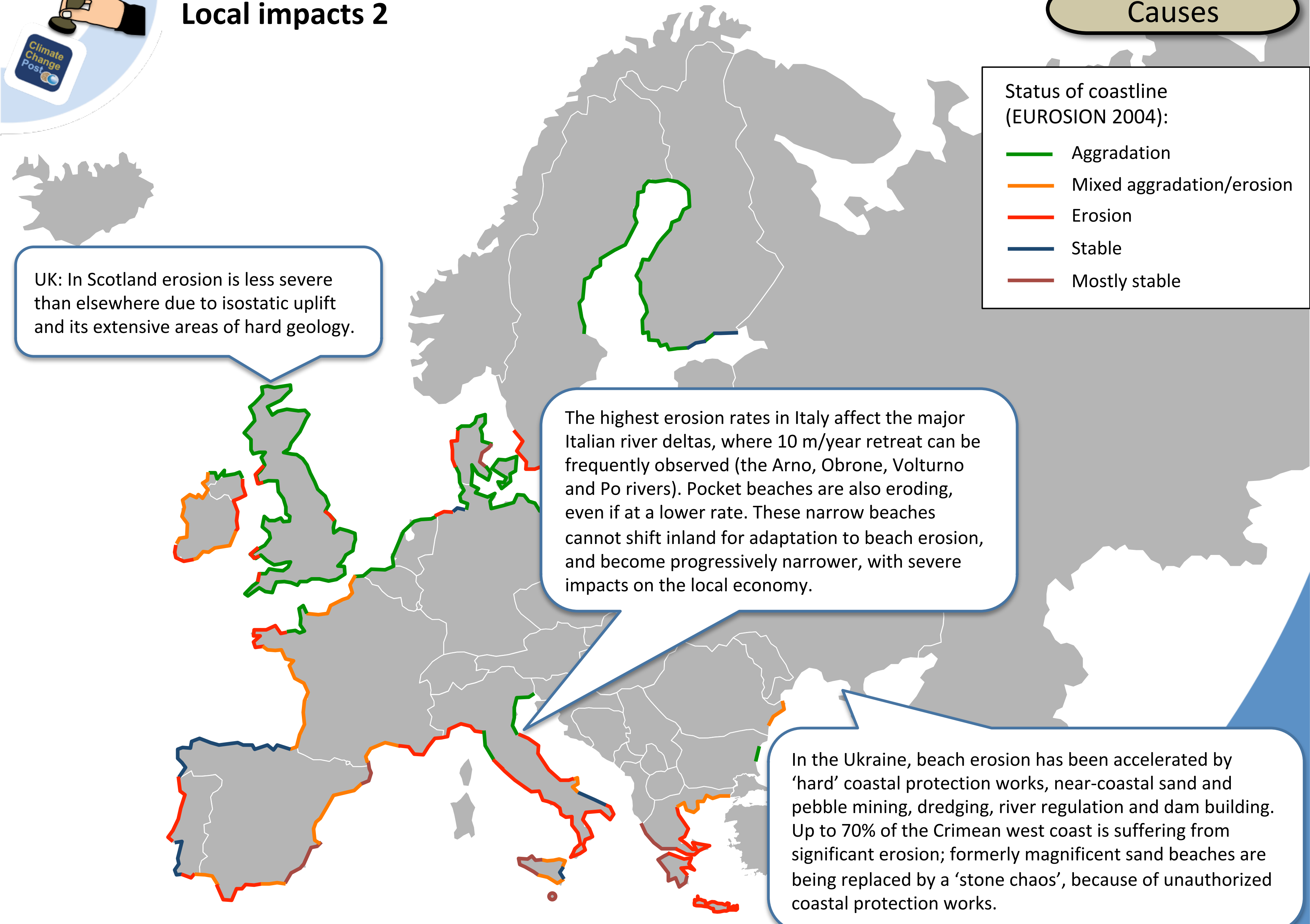
25,000 km of the 61,000 km total length of the Russian marine coast suffers from severe erosion. Russian Arctic (permafrost) coastlines are particularly prone to erosion as rising sea levels encounter melting permafrost in areas of unconsolidated sediments.

The mainland Baltic shore of the Kaliningrad Region is under intensive permanent erosion.

The northern part of the Russian Black Sea coast consists of easily erodible rocks.

Local impacts 2

Causes



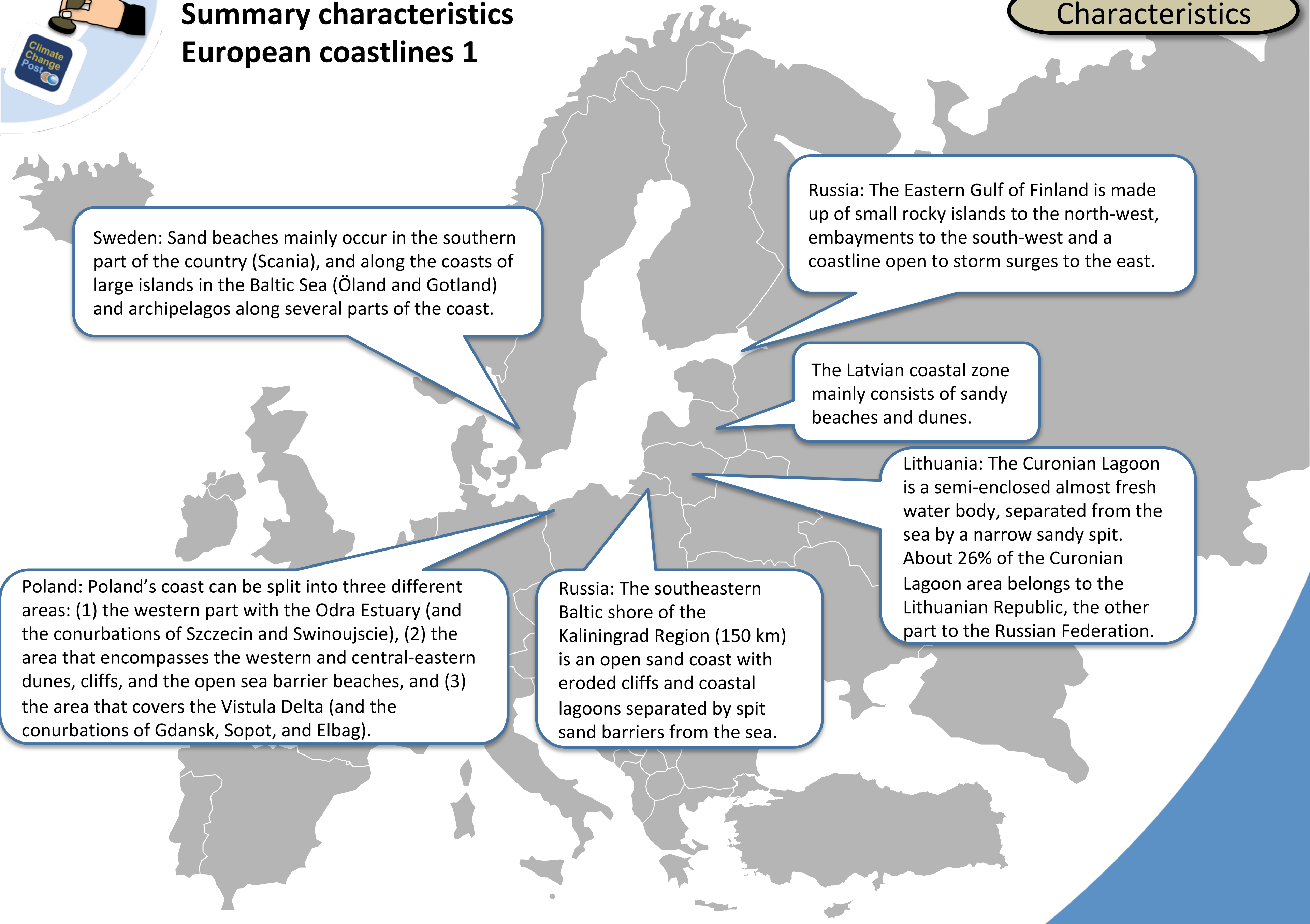
UK: In Scotland erosion is less severe than elsewhere due to isostatic uplift and its extensive areas of hard geology.

The highest erosion rates in Italy affect the major Italian river deltas, where 10 m/year retreat can be frequently observed (the Arno, Obrone, Volturno and Po rivers). Pocket beaches are also eroding, even if at a lower rate. These narrow beaches cannot shift inland for adaptation to beach erosion, and become progressively narrower, with severe impacts on the local economy.

In the Ukraine, beach erosion has been accelerated by 'hard' coastal protection works, near-coastal sand and pebble mining, dredging, river regulation and dam building. Up to 70% of the Crimean west coast is suffering from significant erosion; formerly magnificent sand beaches are being replaced by a 'stone chaos', because of unauthorized coastal protection works.

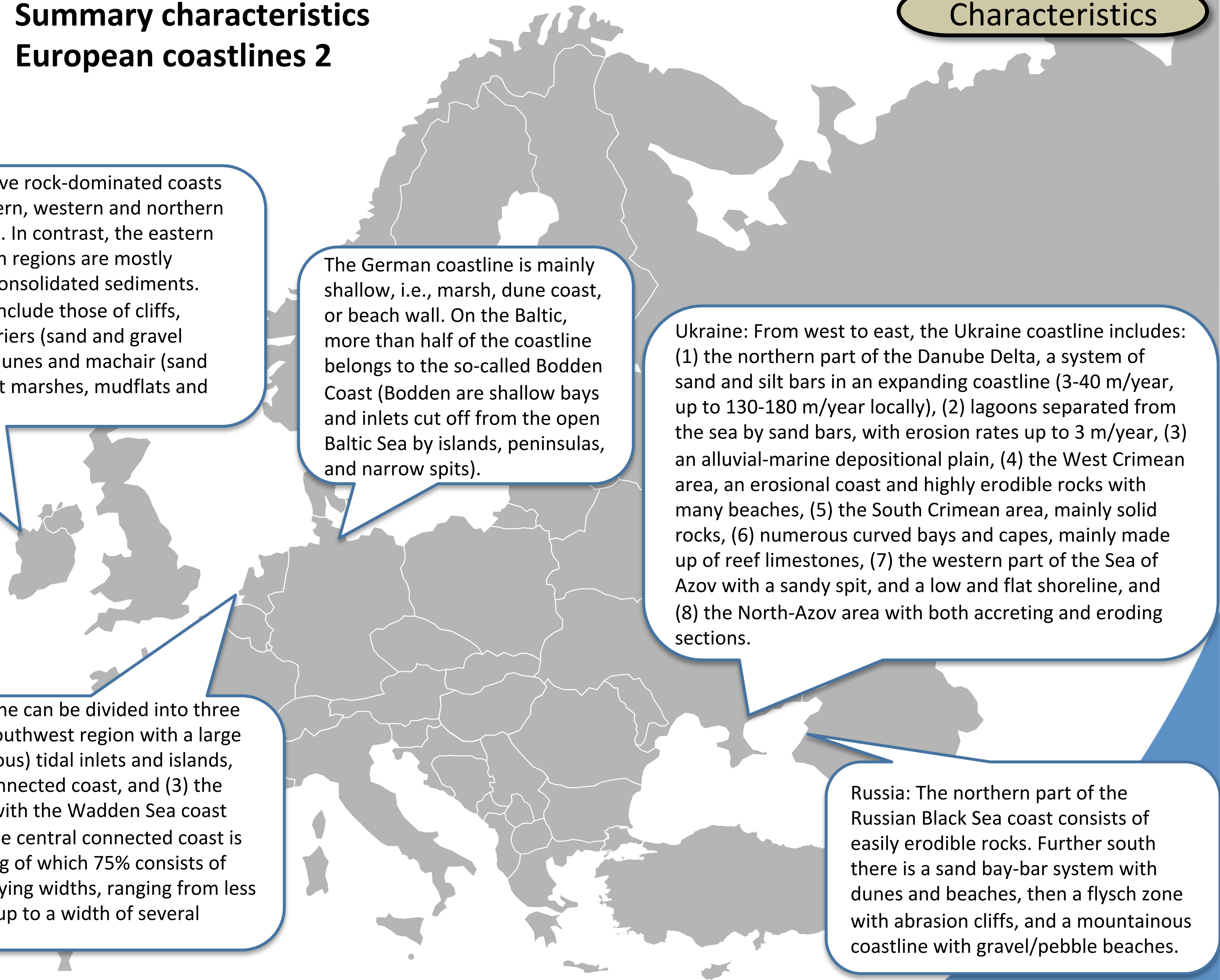
Summary characteristics European coastlines 1

Characteristics



Summary characteristics European coastlines 2

Characteristics



There are extensive rock-dominated coasts in the southwestern, western and northern regions of Ireland. In contrast, the eastern and south-eastern regions are mostly composed of unconsolidated sediments. Coastal systems include those of cliffs, beaches, and barriers (sand and gravel types); lagoons; dunes and machair (sand ''plains''); and salt marshes, mudflats and other wetlands.

The German coastline is mainly shallow, i.e., marsh, dune coast, or beach wall. On the Baltic, more than half of the coastline belongs to the so-called Bodden Coast (Bodden are shallow bays and inlets cut off from the open Baltic Sea by islands, peninsulas, and narrow spits).

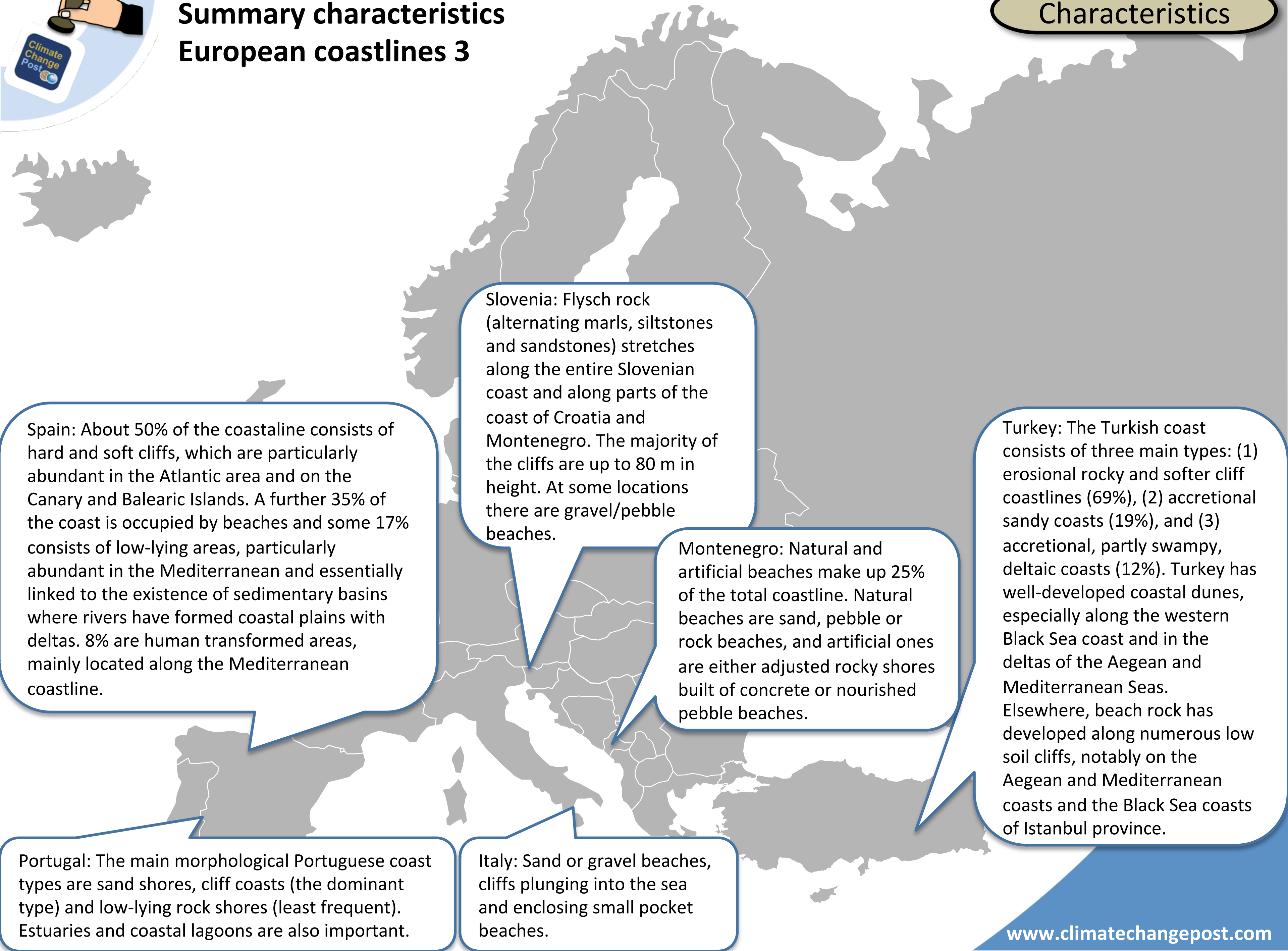
Ukraine: From west to east, the Ukraine coastline includes: (1) the northern part of the Danube Delta, a system of sand and silt bars in an expanding coastline (3-40 m/year, up to 130-180 m/year locally), (2) lagoons separated from the sea by sand bars, with erosion rates up to 3 m/year, (3) an alluvial-marine depositional plain, (4) the West Crimean area, an erosional coast and highly erodible rocks with many beaches, (5) the South Crimean area, mainly solid rocks, (6) numerous curved bays and capes, mainly made up of reef limestones, (7) the western part of the Sea of Azov with a sandy spit, and a low and flat shoreline, and (8) the North-Azov area with both accreting and eroding sections.

The Dutch coastline can be divided into three regions: (1) the southwest region with a large number of (previous) tidal inlets and islands, (2) the central connected coast, and (3) the northern region with the Wadden Sea coast and its islands. The central connected coast is about 350 km long of which 75% consists of dune areas of varying widths, ranging from less than 100 meters up to a width of several kilometers.

Russia: The northern part of the Russian Black Sea coast consists of easily erodible rocks. Further south there is a sand bay-bar system with dunes and beaches, then a flysch zone with abrasion cliffs, and a mountainous coastline with gravel/pebble beaches.

Summary characteristics European coastlines 3

Characteristics



Spain: About 50% of the coastaline consists of hard and soft cliffs, which are particularly abundant in the Atlantic area and on the Canary and Balearic Islands. A further 35% of the coast is occupied by beaches and some 17% consists of low-lying areas, particularly abundant in the Mediterranean and essentially linked to the existence of sedimentary basins where rivers have formed coastal plains with deltas. 8% are human transformed areas, mainly located along the Mediterranean coastline.

Slovenia: Flysch rock (alternating marls, siltstones and sandstones) stretches along the entire Slovenian coast and along parts of the coast of Croatia and Montenegro. The majority of the cliffs are up to 80 m in height. At some locations there are gravel/pebble beaches.

Montenegro: Natural and artificial beaches make up 25% of the total coastline. Natural beaches are sand, pebble or rock beaches, and artificial ones are either adjusted rocky shores built of concrete or nourished pebble beaches.

Turkey: The Turkish coast consists of three main types: (1) erosional rocky and softer cliff coastlines (69%), (2) accretional sandy coasts (19%), and (3) accretional, partly swampy, deltaic coasts (12%). Turkey has well-developed coastal dunes, especially along the western Black Sea coast and in the deltas of the Aegean and Mediterranean Seas. Elsewhere, beach rock has developed along numerous low soil cliffs, notably on the Aegean and Mediterranean coasts and the Black Sea coasts of Istanbul province.

Portugal: The main morphological Portuguese coast types are sand shores, cliff coasts (the dominant type) and low-lying rock shores (least frequent). Estuaries and coastal lagoons are also important.

Italy: Sand or gravel beaches, cliffs plunging into the sea and enclosing small pocket beaches.

A change from ‘hard’ to ‘soft’ defences

In the past decades, there has been a move away from the construction of new ‘hard’ defences; they cause more intensive erosion further downstream.

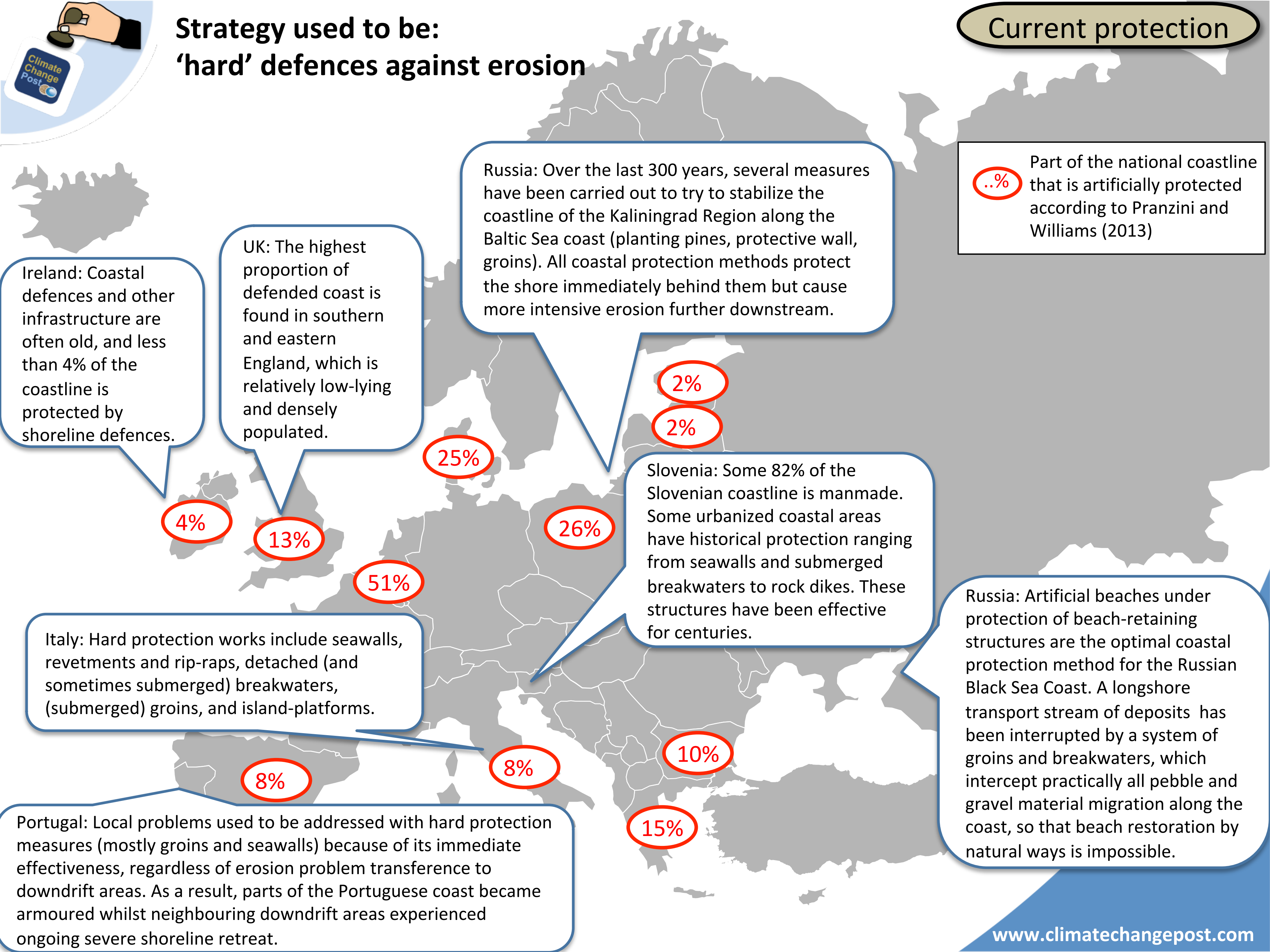
‘Hard’ coastal protection works include seawalls, groins, breakwaters, transverse dikes, revetments, flood embankments, placement of gabions and rock armouring.

‘soft’ engineering methods such as nourishments are increasingly being used.

The volumes of beach nourishments are especially large in Spain, Italy, Germany, France and the Netherlands.

Still, beach nourishments are often used in conjunction with ‘hard’ measures.

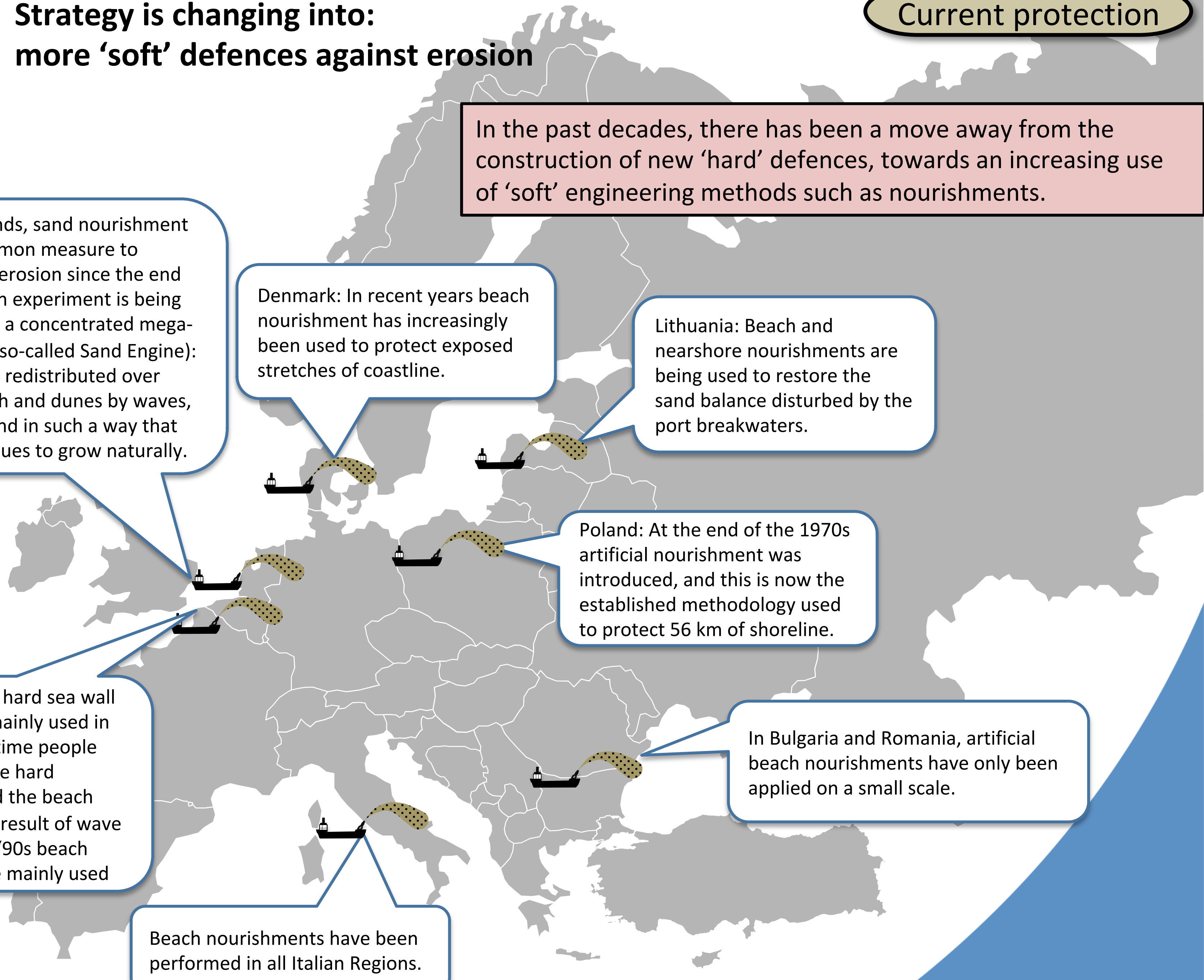
Strategy used to be:
'hard' defences against erosion



Strategy is changing into: more ‘soft’ defences against erosion

Current protection

In the past decades, there has been a move away from the construction of new ‘hard’ defences, towards an increasing use of ‘soft’ engineering methods such as nourishments.



In the Netherlands, sand nourishment has been a common measure to combat coastal erosion since the end of the 1970's. An experiment is being carried out with a concentrated mega-nourishment (a so-called Sand Engine): this sand will be redistributed over shoreface, beach and dunes by waves, currents and wind in such a way that the coast continues to grow naturally.

Denmark: In recent years beach nourishment has increasingly been used to protect exposed stretches of coastline.

Lithuania: Beach and nearshore nourishments are being used to restore the sand balance disturbed by the port breakwaters.

Poland: At the end of the 1970s artificial nourishment was introduced, and this is now the established methodology used to protect 56 km of shoreline.

Until the ‘70-’80s hard sea wall measures were mainly used in Belgium. At that time people realized that these hard structures eroded the beach even further as a result of wave action. Since the ‘90s beach nourishments are mainly used

In Bulgaria and Romania, artificial beach nourishments have only been applied on a small scale.

Beach nourishments have been performed in all Italian Regions.

Strategy is changing into: more 'soft' defences against erosion

Current protection

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Still, beach nourishment is often used in conjunction with 'hard' measures.

UK: In England, beach nourishment is mostly used in conjunction with the construction of rock groins and offshore breakwaters. Beach nourishment schemes are rare in Scotland and Wales.

Soft engineering in the form of beach nourishment is uncommon in Ireland.

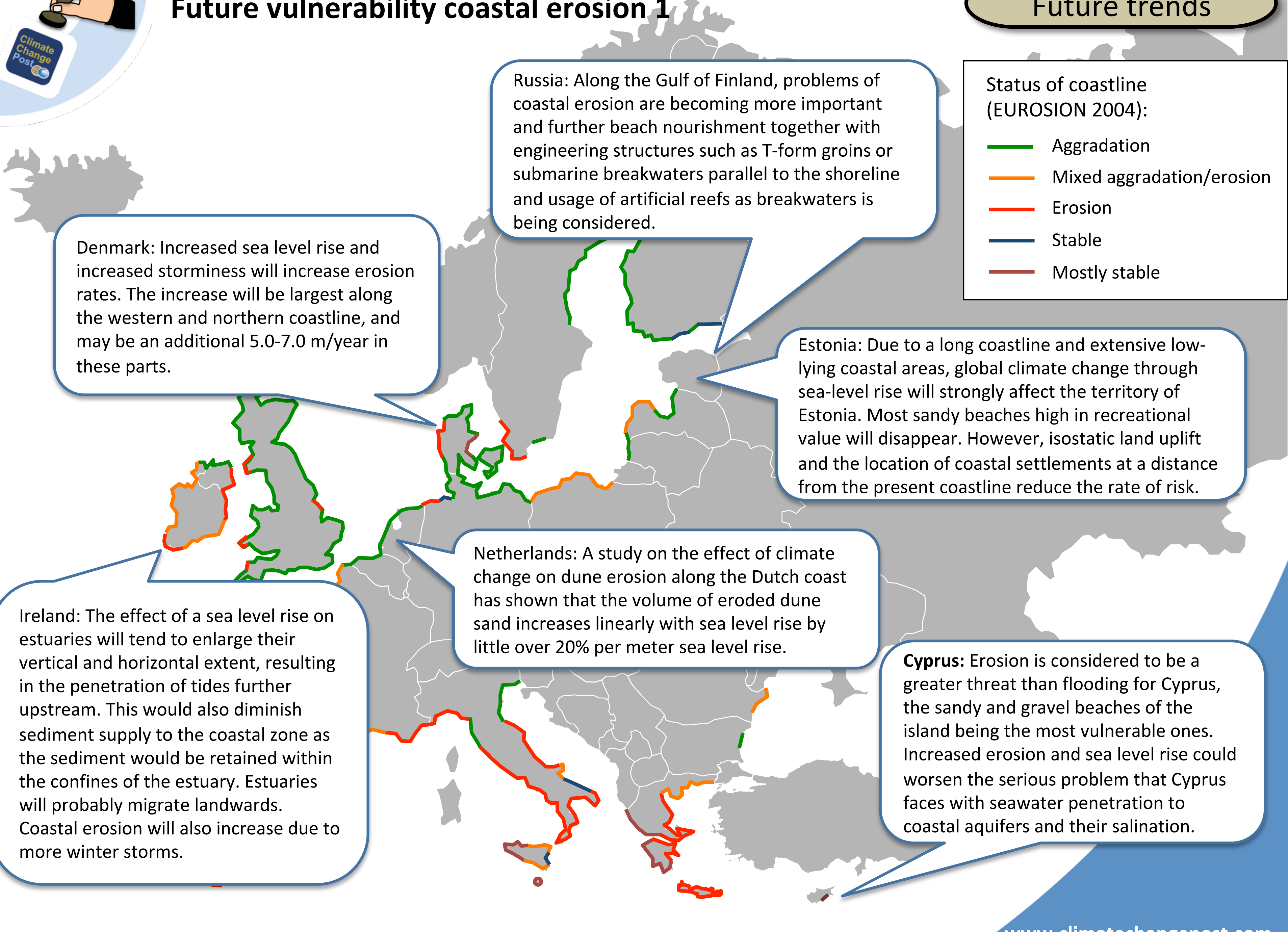
Since the 1980s softer coastal and beach protection methods such as beach nourishments have become more popular in France and now tend to supersede other forms of beach protection. Beach nourishment in France has traditionally been coupled with 'hard' structures such as armouring and sea walls, groins, and breakwaters, used as supporting measures to minimize sand losses and maintenance.

In Greece, the most commonly used soft protection methods are beach nourishment, sediment recycling (transport of sediment from the down drift end of a beach back to its up drift end), and stabilization of coastal dunes with vegetation.

Current coastal protection policy in Portugal is no longer based on hard protection structures. New structures are occasionally built to provide support to beach nourishment projects. Soft protection (beach and dune nourishments, sand fencing, access restriction, elevated footpaths, social awareness and education, housing removal) became a frequent management approach in Portugal in the 1990s.

Future vulnerability coastal erosion 1

Future trends



Russia: Along the Gulf of Finland, problems of coastal erosion are becoming more important and further beach nourishment together with engineering structures such as T-form groins or submarine breakwaters parallel to the shoreline and usage of artificial reefs as breakwaters is being considered.

Denmark: Increased sea level rise and increased storminess will increase erosion rates. The increase will be largest along the western and northern coastline, and may be an additional 5.0-7.0 m/year in these parts.

Estonia: Due to a long coastline and extensive low-lying coastal areas, global climate change through sea-level rise will strongly affect the territory of Estonia. Most sandy beaches high in recreational value will disappear. However, isostatic land uplift and the location of coastal settlements at a distance from the present coastline reduce the rate of risk.

Ireland: The effect of a sea level rise on estuaries will tend to enlarge their vertical and horizontal extent, resulting in the penetration of tides further upstream. This would also diminish sediment supply to the coastal zone as the sediment would be retained within the confines of the estuary. Estuaries will probably migrate landwards. Coastal erosion will also increase due to more winter storms.

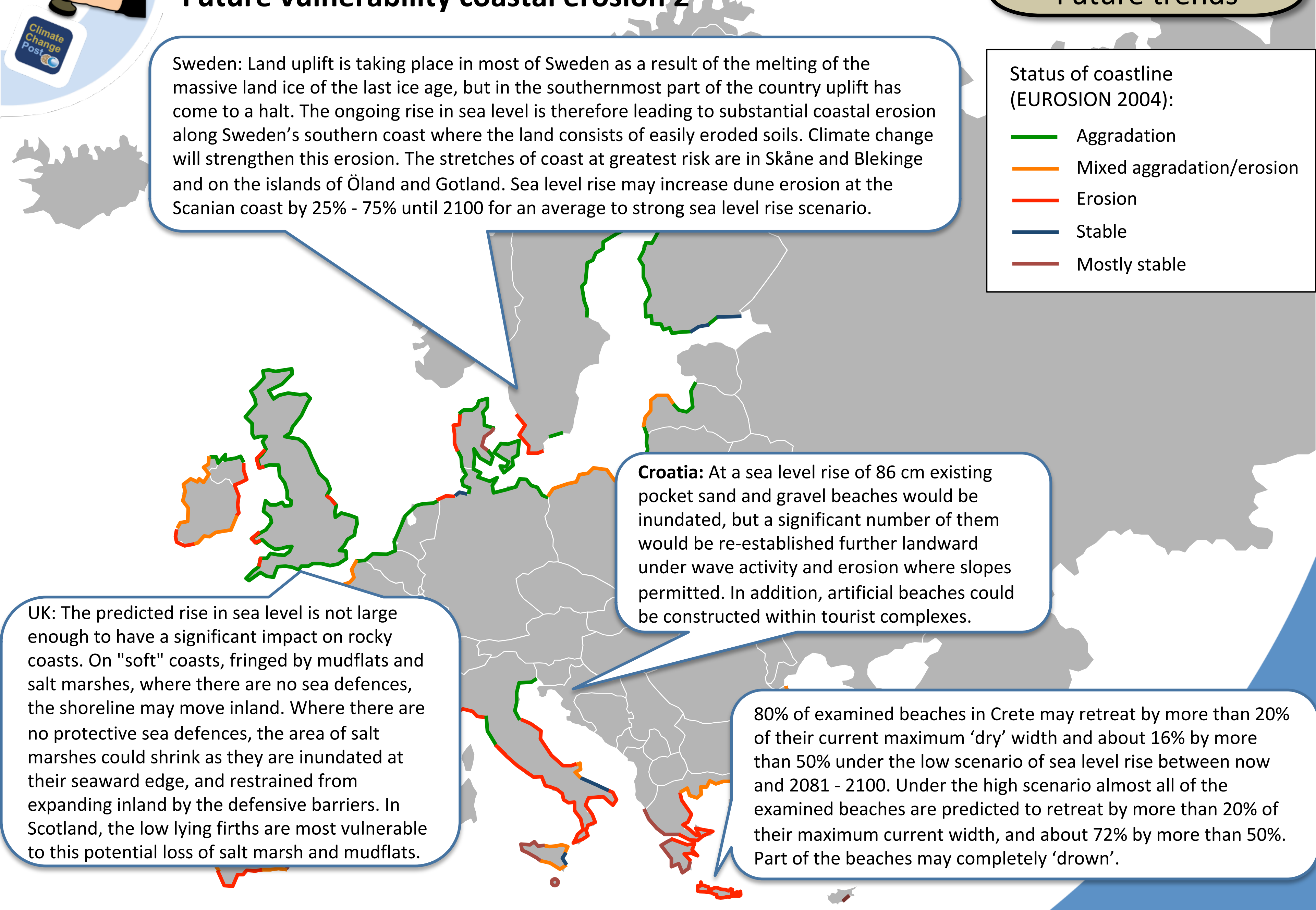
Netherlands: A study on the effect of climate change on dune erosion along the Dutch coast has shown that the volume of eroded dune sand increases linearly with sea level rise by little over 20% per meter sea level rise.

Cyprus: Erosion is considered to be a greater threat than flooding for Cyprus, the sandy and gravel beaches of the island being the most vulnerable ones. Increased erosion and sea level rise could worsen the serious problem that Cyprus faces with seawater penetration to coastal aquifers and their salination.

Future vulnerability coastal erosion 2

Future trends

Sweden: Land uplift is taking place in most of Sweden as a result of the melting of the massive land ice of the last ice age, but in the southernmost part of the country uplift has come to a halt. The ongoing rise in sea level is therefore leading to substantial coastal erosion along Sweden's southern coast where the land consists of easily eroded soils. Climate change will strengthen this erosion. The stretches of coast at greatest risk are in Skåne and Blekinge and on the islands of Öland and Gotland. Sea level rise may increase dune erosion at the Scanian coast by 25% - 75% until 2100 for an average to strong sea level rise scenario.



Croatia: At a sea level rise of 86 cm existing pocket sand and gravel beaches would be inundated, but a significant number of them would be re-established further landward under wave activity and erosion where slopes permitted. In addition, artificial beaches could be constructed within tourist complexes.

UK: The predicted rise in sea level is not large enough to have a significant impact on rocky coasts. On "soft" coasts, fringed by mudflats and salt marshes, where there are no sea defences, the shoreline may move inland. Where there are no protective sea defences, the area of salt marshes could shrink as they are inundated at their seaward edge, and restrained from expanding inland by the defensive barriers. In Scotland, the low lying firths are most vulnerable to this potential loss of salt marsh and mudflats.

80% of examined beaches in Crete may retreat by more than 20% of their current maximum 'dry' width and about 16% by more than 50% under the low scenario of sea level rise between now and 2081 - 2100. Under the high scenario almost all of the examined beaches are predicted to retreat by more than 20% of their maximum current width, and about 72% by more than 50%. Part of the beaches may completely 'drown'.

The future of the Wadden Sea

The Wadden Sea is a coastal region that spans a distance of nearly 500 km along the North Sea coast of the Netherlands, Germany and Denmark. It consists of a chain of barrier islands that shelter an area of extensive intertidal flats and salt marshes, dissected by tidal channels and creeks. No rivers debouch into the basins of this coastal zone. All sediment that settles into the channels and onto the intertidal flats is imported from the North Sea.

Photo: Rob Oo (www.flickr.com)

The future of the Wadden Sea

For the Wadden Sea's future it is the relative sea-level rise that is important: the combination of absolute sea-level rise and the subsidence of the intertidal flats. The subsidence results from the extraction of gas and salt in the area, and from natural processes (compaction of sediments, postglacial adjustment of the earth's crust).

The intertidal flats may slowly diminish or even disappear entirely when accretion of the intertidal flats cannot keep up with sea level rise. In the latter case, the system would degenerate into a tidal lagoon.

- Optimistic scenario: the tidal flats can keep up with relative sea-level rise up to 10.5 mm/year.
- Pessimistic scenario: if ice melt of Antarctica proceeds much faster than has been assumed so far, sea-level rise may be 14 mm per year in 2050, and possibly increasing up to 60 mm per year in 2100. Under these extreme scenarios, the Wadden Sea will be practically drowned before 2100.

Photo: Rob Oo (www.flickr.com)

What about other wetlands?

Assessment of global-scale changes in coastal wetland areas by 2100

In the absence of further accommodation space in addition to current levels, the loss of global coastal wetland area until 2100 will range between 0 and 30%.

The resilience of global wetlands is primarily driven by the **availability of accommodation space**. This is strongly influenced by the building of infrastructure in the coastal zone. Such infrastructure is expected to change over the twenty-first century. Large-scale loss of coastal wetlands can be avoided if sufficient accommodation space can be created.

Global wetland gains of up to 60% of the current area are possible, if more than 37% (their upper estimate for current accommodation space) of coastal wetlands have sufficient accommodation space, and sediment supply remains at present levels.

According to widespread perceptions, future sea level rise would result in large losses of salt marshes: regional and global assessments predict that sea level rise alone will lead to a 20-50% loss of marshland by the end of the current century. This may be **highly overestimated**.

What about other wetlands?

Coastal wetlands may respond more easily to sea level rise than previously thought

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Dynamic feedbacks:
Coastal wetlands more easily build up vertically by sediment accretion under increasing inundation heights and frequencies. Because of this, coastal wetlands may even benefit from accelerating sea-level rise.
The sea level rise salt marshes can handle largely depends on the suspended sediment concentration in the water that floods the marsh system, and on the local tidal range. Where suspended sediment concentrations are larger than 30 mg/l and tidal range exceeds 1 m, models predict that marshes can adapt to fast relative sea level rise rates of several centimetres per year.

Inland migration:
Coastal flood protection structures, coastal roads and railway lines, settlements, and impervious land surfaces do not have to be barriers (‘coastal squeeze’) to inland wetland migration. There is more accommodation space for new wetlands to develop inland, and these new wetlands may compensate for the loss of existing wetlands.

What about other wetlands?

But sea level rise is just one of the stressors

The global extent of and change in tidal flats (sand, rock or mud flats) has been mapped over the course of 33 years (1984-2016). About 16% of these tidal flats were lost between 1984 and 2016.
Causes: Extensive degradation from coastal development, reduced sediment delivery from major rivers, sinking of riverine deltas, increased coastal erosion and sea-level rise.
(Murray et al., 2019)

How can we make coastal erosion in Europe manageable?

Adaptation

Key recommendations (Salman et al., 2004):

- Increase coastal resilience by
    1. restoring the sediment balance
    2. allocating space necessary to accommodate natural erosion and coastal sediment processes
    3. creating strategic sediment reservoirs (supplies of sediment of ‘appropriate’ characteristics that are available for replenishment of the coastal zone, either temporarily (to compensate for losses due to extreme storms) or in the long term (at least 100 years)).
- Limit public responsibility for coastal erosion risk and transfer an appropriate part of the risk to direct beneficiaries and investors. Parties responsible for coastal erosion or the owners of assets at risk should pay the bill.
- Move away from piecemeal solutions to a planned approach based upon accountability principles, by optimising investment costs against values at risk, increasing social acceptability of actions and keeping options open for the future.
- Strengthen the knowledge base: avoid that measures to solve coastal erosion locally exacerbate coastal erosion problems at other locations.

Coastal adaptation strategies according to the IPCC

- Protection: advance or hold existing defence lines by means of different options such as: land claim, beach and dune nourishment, the construction of artificial dunes, hard structures such as seawalls, sea dikes and storm surge barriers.
- Accommodation: increase flexibility, flood proof land use, implement flood warning systems or replace armoured with living shorelines.
- Retreat: allow wetlands to migrate inland, set shorelines backs, and introduce managed realignment (retreat) by, for example, breaching coastal defences allowing the creation of an intertidal habitat.

Local adaptation strategies in response to coastal erosion

Adaptation

Ireland: Shoreline armouring is the dominant response to coastal erosion. The National Trust (the single biggest coastal landowner in Northern Ireland) has recently adopted a policy of non-interference in coastal processes. Sea defences will not be built or maintained and some of its beach infrastructure has been constructed in such a way as to render it demountable and movable should it be threatened by future coastal erosion.

Denmark: The opportunities for continuous climate change adaptation are generally good. The estimated additional erosion can be counteracted easily by coastal protection measures such as increased sand nourishment volumes or a heightening of groins and breakwaters. Compared with 2008 the additional artificial supply for compensating for anticipated climate change effects is estimated to be 17% in 2050 and 49% in 2100.

Estonia: In the case of a 1 m sea level rise, coastal cities of Estonia would need extended seawalls, dikes, and groynes to ensure effective protection and avoid socioeconomic damage. Beach nourishments may be too expensive except for areas with highly developed and economically efficient recreational facilities exist.

Germany: Coastal protection measures are both soft (beach nourishments) and hard. For the Baltic Sea coast there might be an increasing future demand of sand for beach nourishment due to the predicted sea level rise.

Netherlands: Currently, some 12 million m^3 of sand is replenished annually and an increase to 20 million m^3 is needed for the entire coastal base to grow apace with the current rise in sea levels. With a steady rise in sea level, the volume of sand needed to maintain the coastal base also increases apace. According to initial estimates this can vary, rising to an annual average of 30 million m^3 in 2050, rising to as high as 65 million m^3 annually in 2100.