Interreg Baltic Sea Region Programme funded project
Land-Sea-Act (R098)
"Land-sea interactions advancing Blue Growth in Baltic Sea coastal areas"

Case study Fehmarn, Germany

Coastal conflicts, climate impacts and adaptation

Output of Activity 2.4

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LAND SEA ACT
Interreg Baltic Sea Region
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Land Sea Act project partners worked in six geographical locations in six countries around the Baltic sea – Sweden, Denmark, Germany, Poland, Latvia and Estonia.
This is one of six case study reports that will share insights, achievements and solutions for the Maritime Spatial Planning and Blue Growth challenges in coastal areas with different land and seascapes, legislative and governance systems, and various stakeholders.

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The project Land-Sea-Act (#R098 Land-Sea-Act Land-sea interactions advancing Blue Growth in Baltic Sea coastal areas) aims to bring together stakeholders involved in coastal management and planning, to find solutions to Maritime Spatial Planning and Blue Growth challenges around the Baltic Sea and to elaborate Multi-level Governance Agenda on Blue Growth and Spatial Planning in Baltic Sea Region. The project will guide national, regional and local authorities, as well as stakeholders of various sectors to:

- improve transnational cooperation and facilitate knowledge exchange to foster Blue Growth
- raise awareness, knowledge and skills to enhance Blue Growth initiatives and integrated development in coastal areas
- balance development of new sea uses with coastal community interests by improving coastal governance

Project implementation duration:	January 2019 – December 2021
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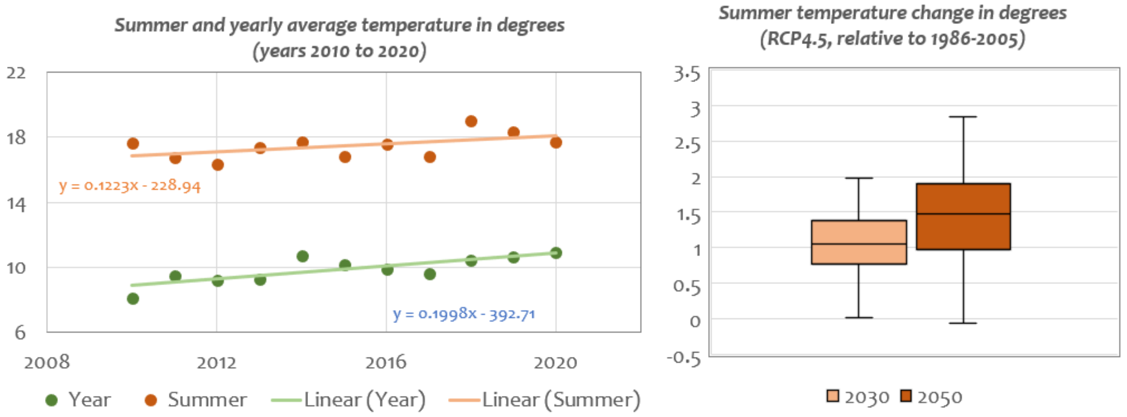
Contents

Introduction

Climate and tourism

The climate at the Fehmarn Island is classified as *oceanic* and characterized by mild summers, cool (but not very cold) winters and few days of extreme temperature. Between 2010 and 2020, average annual temperature increased by 0.19 degrees/year and summer temperature, defined as the average of the June-July-August months, by 0.12 degrees/year, see Figure 1 left (Source: BEF using ERA5 reanalysis - ECMWF). Although decadal trends do not necessarily represent the pace of long-term global warming, they serve as a warning sign of the direction and speed of temperature change in Fehmarn over a time-frame relevant for climate adaptation. In terms of precipitation, over the last two decades a slight downwards trend in the total precipitation was observed (see Figure 22 of the Annex). Looking into the future, climate projections under RCP4.5 (a scenario where global emission peak around 2040 - declining thereafter - and global temperature rise between 2 and 3 degrees by 2100[1]) indicate an median increase in the summer temperatures of about 1.1 degrees by 2030 and 1.5 by 2050 (referenced to the 1986-2005 average), see Figure 1 right panel. Evaluating the output of 43 models (see Figure 3 of the Annex), this report finds the most likely interval of summer temperature increase to range between 0.8-1.4 degrees by 2030 and between 1.0-1.9 degrees by 2050.

Figure 1 – Yearly and summer average temperatures (left). Projected changes in average summer temperatures(right)
(Source: BEF based on data from KNMI Climate Change Atlas)

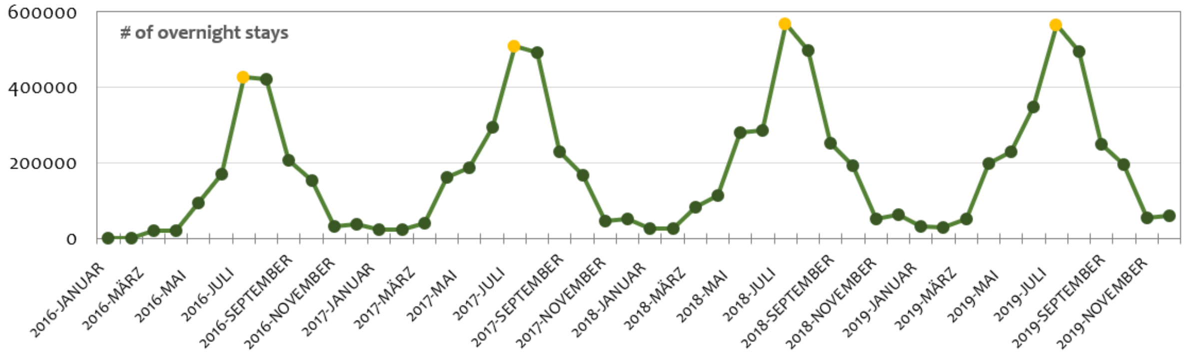


Mild summer temperatures make Fehmarn is a popular holiday destination at the German Baltic coast and recent trends in overnight stays reflect an increase in the popularity of the island (see Figure 2). Between the years of 2017 and 2019 the total number of overnight stays grew 12% from 2.2 to about 2.5 million (Source: BEF using data of the Fehmarn's tourism office). In 2019 the summer months of June, July (traditionally the peak month regarding of overnight stays) and August made up 56% of the total overnight stays (circa 1.4 million), underlying the high seasonality of the tourism sector in the island. The average length of overnight stays during the summer months have nevertheless decreased between the years of 2016 and 2019. In 2016 the average length of a stay during the summer months was about 6.3 nights while in 2019 that number was reduced to 5.8. Increasing number of tourists competing for a limited number of beds may be leading visitors to spending less time in Fehmarn. The Covid-19 pandemic has likely pushed the number of visitors in 2020 further upwards, as travel constrains abroad would tend to favour the German internal tourism market. Nevertheless, the short-term trend of increasing number of overnight stays in Fehmarn does pre-date the pandemic.

1 Referenced to pre-industrial temperatures

Figure 2 – Monthly variation in the number of overnight stays in Fehmarn between 2016 and 2020. Month of July highlighted in yellow

(Source BEF using data of the Fehmarn's tourism office)

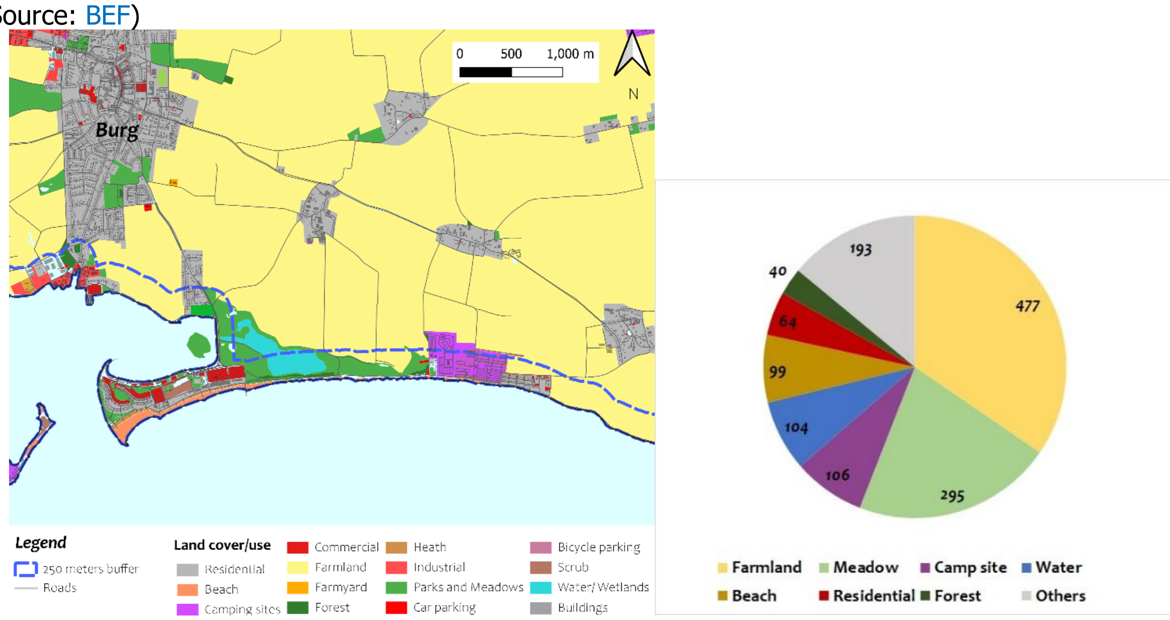


Spatial distribution of blue economy activities

With the increase in the number of visitors a growing demand for blue economy activities is also expected, which in turn poses additional challenges for spatial planning at the coastal zone. For example, some blue economy activities can overlap spatially with each other (e.g., sailing and windsurfing), or their spatial distribution affected by ongoing and future climate change (e.g., swimming, and blue algae outbreaks). To provide a first analysis of the spatial distribution of blue economy activities, this report makes a stock-taking of land cover/use and infrastructure along the coastal zone of Fehmarn (defined in this report as land extent 250m from the shoreline), see example in Figure 3 left panel. Most of the coastal land in Fehmarn is dedicated to agriculture activity, see Figure 3 right panel. In 2020 farmland composed approximately 34.5% of the coastal land, or circa 477ha (Source: BEF using data from Geofabrik and own observations). Green spaces, such as meadows, make up 295ha (or 21.4% of the coastal land) while forests account for less than 3% of land cover at the coastal zone. Reflecting the high demand for camping, about 106ha of coastal land is allocated to this activity. For perspective, the coastal space allocated for camping is comparable to the total beach area at Fehmarn, circa 99ha (or 7.2% of the coastal land). Finally, residential areas at the coastal zone make up about 4.7% of the land use. The existence of several nature protection areas, particularly for bird life, further shape the use of land in Fehmarn. Circa 20% of the coastal perimeter in Fehmarn is dedicated to nature protection. This is particularly noticeable in the north and northwest regions of the island.

Figure 3 - Example of land cover/use acquisition near Burg and the delimitation of the coastal zone (left). Distribution of coastal land cover/use over Fehmarn's coastline (right)

(Source: BEF)



Multiple attractivity-influencing data proxies are collected to inform on the degree of attractivity of a blue-economy activity at a given coastal location. Attractivity is based on the proximity of a given coastal segment to an indicator of infrastructure presence or biophysical feature. For example, the closer a bus stop, a car park or a toilet is to a wide beach, then the higher the potential of that same beach segment to attract beach tourism, see first row of Table 1.

Table 1

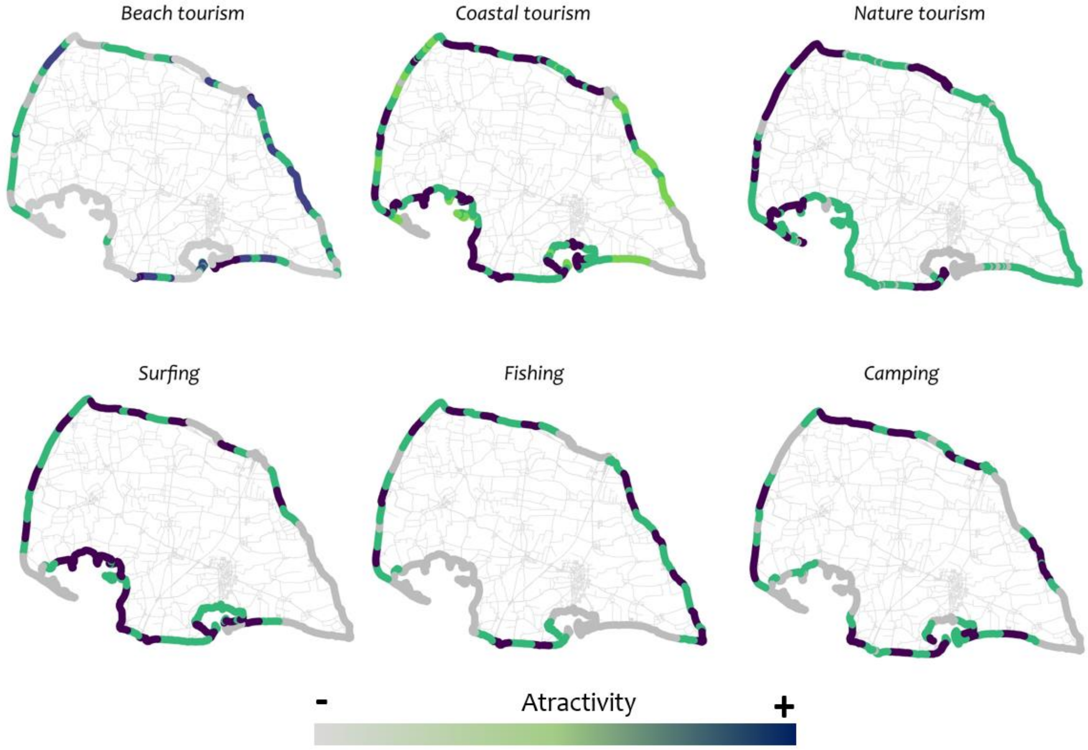
Data proxies and rational to estimate the attractivity of a coastal location by blue economy activity. All indicators are calculated in meters (m) unless otherwise stated

Activity	Indicator	Rationale
Beach tourism (swimming, walking on the beach, sunbathing)	Beach width - wide Proximity to carparking Proximity to toilet Proximity to bus stop	The wider the beach the more attractive it is for a larger number of users. The existence of a carpark and toilet facilities increase the convenience of the location and hence its attractivity.
Coastal tourism (Biking, walking, eating, hotel)	Proximity to dike Proximity to footpaths Proximity to amenities or infrastructure such as benches, restaurants, caffes, etc…	At Fehmarn the top of the dikes is bike-ridable and a popular activity. The existence of footpaths eases the accessibility of the coast for tourists and so does the presence of amenities such as restaurants.
Nature tourism	Proximity to natural reserves Proximity to forest Beach width - narrow	The existence of nature reserves or areas with close to natural vegetation increase the potential of such areas being used for nature tourism such as bird watching. Narrower beaches provide more close-to -natural features that are more attractive to tourists sensitive to nature
Surfing	Proximity to surf spots Proximity to car parking	The existence of adequate parking conditions is determinant in the attractivity of a give surf spot
Fishing	Proximity to fishing spots	Proximity of the coastline to the fish stop enhances its attractivity
Camping	Proximity to campsites	Presence of the camp parks enhances the attractivity of the coastline to the activity of camping

The attractivity assessment is carried for the entirety of the island by sectioning the coastline of Fehmarn in circa 900 equal-distance coastal segments (each approx. 100 meters length). For each segment the indicators shown in Table 1 are calculated in meters. To calculate how attractive a coastal location is to a blue economy activate the logic in column "Rationale" in Table 1 is applied (see Figure 24 in Annex for and illustration of the process). The attractivity of some blue economy activities are informed by a single indicator (see for example *Fishing*) while the attractivity of others are informed by a combination of indicators, for example *Beach tourism*. For the latter case, a composite indicator is created to reflect the individual contribution of each sub-indicator. Each sub-indicator is converted from its original unit (in metres) to a non-dimensional score ranging between 0 and 1. For example: "beach width" is converted to range between 0 and 1, with 0 the coastal segment with the narrowest width and 1 the segment with the highest width. This allows for sub-indicators to be summed and inform on the overall attractivity of a coastal segment to *Beach tourism*.

The maps in Figure 4 report on the attractivity of coastal segments to the presence of a blue economy activity following the rationale presented in Table 1. It can be observed that the blue economy activities focus of this report are widespread throughout the coastline of Fehmarn but with different degrees of attractivity. Beach tourism is higher at the southern portion of the island due to the presence of wide beaches and presence of good accessibility and amenities such as carparking and toilets. In the north region this activity is less attractive due to, respectively, harder accessibility, fewer parking opportunities and lack of amenities such as toilets. Coastal tourism is attractive overall driven by the good presence of amenities such as benches, restaurants, caffes or vending machines and the extensive dike network covering a total of 35.7km (covering circa 41% of the coastline) and that attracts many tourists for walking and biking. Nature tourism is mostly attractive around the nature reserves but also along narrower beaches. Surfing activity is predominantly found in the South and North and Northeast sides of the island. Fishing activities concentrate on the North and East sides of the island. In the South this activity is concentrated in the *Fehmarnsund* region. Camping activity is scattered across the island but most predominant in the North and South portions of the island.

Figure 4 - Estimated attractivity of a coastal segment to a blue economy activity
(Source: BEF)



Iterating over all the different indicators a combined index of Coastal Use Intensity can be proposed. Such index ultimately informs of the overall attractivity of a coastline segment and hence inform on the potential for overlap of the coastal activities identified in Table 1.

Spatial conflicts

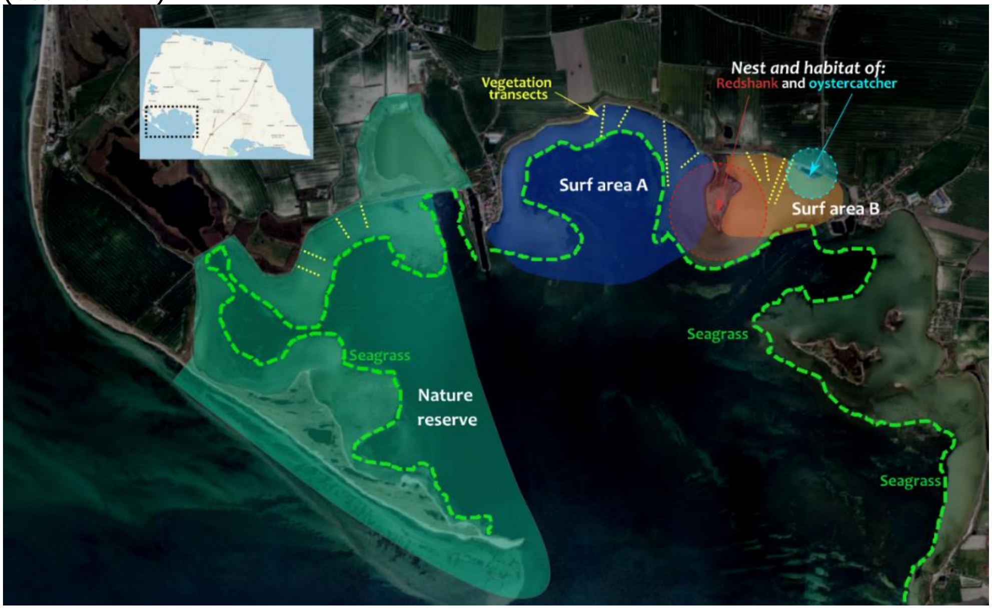
In the context of Marine Spatial Planning (MSP) spatial conflicts arise from a) the direct competition over a limited space or, b) one coastal activity negatively impacting one or several other activities (Source: European MSP Platform). In practice, the word "conflict" should better be understood as degrees to which one activity is incompatible with another. Although there are cases where the conflict dictates that the activities are incompatible (meaning they cannot co-exist in the same physical space), such as the case of wind parks *vs* shipping, or water sports *vs* port operations. In many cases it is possible to conciliate different activities in a common space (Source: BaltSeaPlan report 16, 2012).

Surf coastal vegetation and nature protection

In the context of the Fehmarn Island, the activity most likely to generate variable degrees of incompatibility is water sports. At *Orther Bucht* (located in the southern coast of Fehmarn) surf areas were found to overlap spatially with coastal vegetation at shallow waters, and areas that are worthy of protection from an ornithological point of view as it was found that nesting and resting places of the occurring waterbirds overlap with surf spots, see Figure 5 an example how the nesting and habitat of the Redshank and Oystercatcher bird species overlaps with surf areas. Please see Figure 25 of the Annex for a more complete distribution of bird species at *Orther Bucht*.

Although the distribution of seagrass, breading and resting birds and surf areas overlap spatially the existence of a "conflict" needs to be evaluated regarding the degree to which water sports negatively impact the shallow vegetation at *Other Bucht*. For this purpose, researchers from the Gesellschaft für Freilandökologie und Naturschutzplanung sampled and compared the coverage density and type of vegetation found on shallow waters of surf areas A and B, with the vegetation in shallow waters located within the nature reserve, see Figure 5. The latter served as reference to the evaluation of whether surf activity has an impact in the vegetation. The sampling of vegetation was done across segments noted yellow in Figure 5 and focused on the evaluation of the coverage, depth, and type of macrophytes (aquatic plants growing in or near water). Macrophytes influence habitat structure and nutrient dynamics and their absence may indicate water quality problems such as excessive turbidity, herbicides or salinization which interfere with plant growth and development.

Figure 5 – Spatial overlap of surf areas, shallow water vegetation and bird habitat at Orther Bucht (Source: BEF)



Results of macrophyte coverage (the % of sea ground covered by macrophytes) along the transect within the two surf areas and the nature reserve (see Figure 26 of the Annex) reveal that coverage of macrophytes increases with water depth until a maximum of 0.75 meters and decreases thereafter. This was consistent across the three evaluated locations and therefore independent if surf activity takes place or not. Comparing the coverage of macrophytes within each depth class, no significant differences were found between the coverage in surf areas and that observed in the nature reserve. It was concluded that the current pressure of surf activity at *Orther Bucht* does not pose an existential threat to the shallow water vegetation. However, it was recommended to limit water sports activity to current levels as precautionary measure for biome protection. In addition, the existence of a nature protection area in the east of the bay further makes it important to notify water sports enthusiasts when they are approaching the protection zone.

For the first time it was investigated the direct effects of water sports activities on underwater vegetation and birds. The studies formed the basis for capacity limitation in consultation with the local water sports schools and for zoning in water sports areas and voluntarily protected zones. In order to guide water sports enthusiasts to the areas that have been identified as unproblematic from a nature conservation point of view, the " *yellow plank*" guiding system - see Figure 6 right panel - was established and additional information boards (see Figure 6 left panel) set up for the visitors. In addition, buoys were placed along the boundaries of the nature reserves to prevent water sportsmen from entering the nature reserves involuntarily. At the end of the 2021 season, a survey of water sports schools and tourism providers was carried out to determine how the measures taken were perceived and whether there had already been relief within the areas.

Figure 6 - Surf guidance system "Yellow Plank" (right) and information boards for visitors (left).
(Source: City of Fehmarn)

Two thirds of the respondents expressed the opinion that the measures taken so far have already led to a noticeable relief in the areas at *Orther Bucht* and *Grüner Brink*. 53% of respondents would like to see further restrictions on access, e. g. on parking. The steering of water sports enthusiasts by the "yellow plank" was considered a success by all the respondents. The desire to extend this system to more surf spots on the island was expressed by 81% of the respondents. The creation of a parking or surfing app would also be welcomed by 98% of the respondents

Nature, surfers, and tourists

Surfers, nature, and tourists populate the coastal zone stretching eastwards of *Grüner Brink* nature reserve, see Figure 7. The nature protection zone borders one of the most visited beaches in Fehmarn, particularly popular among families. Further east, the *Grüner Brink* surf spot is lauded as one of the top places for the practice of kite and windsurf in Germany. Predominantly east winds combined with flat shallow waters provide the close to ideal conditions for the practice. At the coastal stretch east from the bathing zone, surfers get in and out of the water and set up their equipment at the beach that can be as narrow as 25m. In a popular online platform dedicated to kite and windsurf, the location is compared to a "*beehive"* (Source: Kitedrop.de), such is the amount of activity. The popularity of the location is enhanced by the presence of good accessibility infrastructure like nearby parking place, bike and footpaths and a restaurant. It is not uncommon to observe minor spatial overlaps between the different coastal activities and with the existing fauna. In communication with a local stakeholder – responsible for promoting beach cleaning actions in Fehmarn's beaches since 2013 – it is mentioned that surfers do occasionally sail within and north of the swimming/bathing zone. The stakeholder underlines nevertheless that although the location is densely visited the behaviour of the different visitors has improved along the years, "*people take now more care and are more thoughtful*" when relating to each other. The large concentration of surfers and respective equipment can disturb some of the other users of the beach because kites and ropes can get in their way. When that happens, people take *"extra care when walking through the beach or then use some of the paths nearby*", the stakeholder notes.

Figure 7 - Depiction of the spatial overlap of several coastal and blue economy activities at Grüner Brink (Source: BEF in communication with Strandpate)

Kite surfers remain in the designated zone when other beachgoers or large numbers of windsurfers were present. The area mostly used by kite surfers is within and north of the swimming/bathing zone. North from the bathing area it can occur that kite surfers also use areas close to or within the nature reserve, see Figure 7. In the nature reserve several bird species are commonplace. For example, oystercatchers, lapwings and redshanks were geolocated along the nature reserve as shown in the map (Source: Managementplan für das Fauna-Flora-Habitat-Gebiet DE-1532-391). Birds often react to the presence of humans as they would react to the presence of predators and in some situations a disturbance caused by humans has a greater effect than that caused by natural factors (Source: Krüger 2016).The presence of kite surfers can lead to birds getting scared or agitated although how sensitive the birds are to the presence of kitesurfing depends on many local factors such as intensity of surfing, proximity, noise, time of the year, type of bird species etc...

Evaluations on the behaviour of birds to the presence of kite surfers have pointed that number of birds in a location tend to decrease when surfers are present in the vicinity. For the case of Oystercatchers and Redshanks (species present at *Grüner Brink* nature reserve) studies at the Dee Estuary (Liverpool, England) concluded that the presence of kite surfers to be associated, respectively, with a 43% and 14% decrease in bird numbers compared to a situation in which kite surfers where absent (Source: Krüger

2016). For the specific case of Fehmarn, a study from July 2012 conducted bird observation during 11 days at two sites: one near the lagoon within the nature reserve and one on the beach 300 m to 550 m away from the designated kitesurfing zone (Source: Kitesurfen und Vögel – Eine Gutachten (Literaturestudie) citing *Hüttemann M., 2013*). The study reports that different bird species exhibited a variety of reactions to kite surfers. *Gulls* and *Terns* showed the shortest flight initiation distance - distance at which a prey begins to flee from the approaching predator/human. *Shelducks* were observed expanding their areas of use towards kite surfers or flying towards them before changing direction just before reaching them. Some species presented clearly different spatial distribution within this area when kite surfers were present. *Oystercatchers* and *Dunlins*, for example, roosted and foraged in much smaller numbers or not at all. Nevertheless, the author points that this could also have been due to other environmental factors than cannot be totally controlled for. In addition, *Hüttemann M., 2013* emphasizes that kite surfers generally do not pose a threat. Still, the highest densities of birds did coincide with the times of lowest anthropogenic activity along the mudflats and high tide lines close to the inlet of the lagoon. Given the high frequency of recreational activities and their spatial expansion, spatial competition occurs between birds and people. The study points that general recreational use (swimming, hiking, biking, walking dogs, tourist service) caused most of the disturbance events. Indeed, passers-by and tourists on bikes are also commonly found traveling along-side the *Grüner Brink* nature reserve, attracted by the natural scenery, or enjoying part of the 85km of the island's dike-tour. The tourists "*mostly stay on the designated paths, but their presence can be noted by birds once they get close into the protected area*", signed off the interviewed stakeholder.

Avoiding overcrowded surfspots

Surfers Island App

Given the increase in number of tourists, limiting the increase of water sport activities at *Orther Bucht* (see section Surf coastal vegetation) and avoiding the overcrowding of *Grüner Brink* implies to manage the access of surfers to surf spots. The city of Fehmarn, together with relevant stakeholders, has discussed the creation of the Surfers Island App (SIA) to help manage the access of surfers to the surf spots. The idea of the SIA acting on parking places was well received by relevant stakeholder, see section Surf coastal vegetation and nature protection.

Figure 8 - Compilation of available public parking capacity nearby surf spots
(Source: BEF using data from Fehmarn's Parkraumkonzept und Parkleitsystem)

The core principle is to manage the flow of surfers by incentivising the use of parking spaces in the vicinity of surf spots according to the spot's sustainable capacity. For these purposes this report compiled a database of available public parking places in the vicinity of surf spots by geo-referencing the existing carpark areas in Fehmarn and linking these to the capacities of public parking lots from Fehmarn's *Parkraumkonzept und Parkleitsystem*. The result is shown in Figure 8. The size of the blue circles represents classes of parking capacity, the higher the area of the circle the higher the capacity. Magenta circles indicate parking places that are not public but whose capacity needs to be considered when developing the SIA as surfers using non-public parking facilities also influence the sustainable capacity of each surf spot.

Practical data needs and challenges

The most challenging element of the SIA is to meaningfully define the sustainable capacity of each surf spot. Such capacity is a function of the current number of visitors at one given time, the free parking places available in the vicinity and ecological considerations such as for example seasonal breeding dynamics of birds or the carrying capacity of the aquatic ecosystem. The SIA should discourage the surfers to visit spots that are already at the maximum capacity by making those that are free more prominent and easily accessible (see Table 2). For example, by choosing a non-crowded surf spot the user of the SAI can pay in advance for the parking fee, the tourism taxes or accessing some discount for a city-sponsored activity in the vicinity of the surf spot. In the same measure, the SIA should discourage surfers to visit spots that are close to or at their sustainable capacity. The app could also be utilized to provide surfers and wider public with information like general rules for the use of the beach and surf spots or other aspects of the coastal fauna and flora of the surf spot.

Two additional challenges need to be considered when proceeding with the real implementation of the SIA. The first is that the SIA is targeted specifically at surfers, but it would make more sense to have a more general "parking App" that would categorize visitors of a parking place as surfers and non-surfers. The reason being is that the public parking places are not for exclusive use of surfers and hence the SIA should not take the total capacity of a parking spot but instead the current capacity of the parking place minus the places taken by non-surfers. This capacity should then be compared with the sustainable capacity of the surf spot. The second reason is that the App is only planned to operate in public parking places of those subject to a parking fee. This means that surfers could park in available parking places and hence not be accounted for the calculation of the surf spot sustainable capacity. Finally, it is important to note that although the SIA is one element of the strategy to manage the surfer flows, it is not the only. The future App needs to work in combination with other actions such as the physical demarcation of the hotspots themselves or guiding structure to channel surfers entering the water and avoid dispersion, such as described in section Surf coastal vegetation and nature protection.

Visuals and functionalities

It was not the objective of this report to produce a working prototype of the SIA. Instead, the work focused on providing illustrations on the look and feel of the app as well as visual examples of the functionalities discussed during the stakeholder interaction. Accordingly, Table 2 makes a description of the main SIA functionalities and menus, supported by visuals illustrating its potential look. It should be reinforced that the visuals presented *do not* refer to a working prototype of the App itself but only static illustrations.

Table 2

Illustration of the SIA and its potential functionalities

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<tr><th>View</th><th>Description</th></tr>
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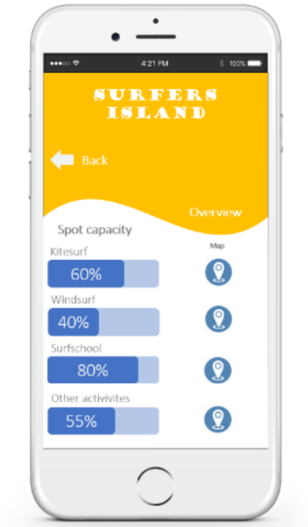

</td><td>In the overview screen (left) the user is presented with a breakdown of the current capacity of sur spots categorized in kite, wind, schools, or other activities. From this screen the uses can tap the icons on the right and select the type of spot she/he is interested. The user will then be prompted to a map view in which the geo-location of the different surf spots in Fehmarn are presented.
In the map view (right) the user obtains a more granular representation of the capacity at different spots (in this case Kitesurf ones) via a color-coded label ranging from red to green depending on the capacity. Spots marked in red have reached their full capacity, those in yellow are currently at between 60 and 80% capacity and those shown in green are below 60% of their capacity. The App cannot forbid a surfer from going to a spot marked as red but can discourage the trip by not allowing the user to do a reservation for a parking place nor showing any other contextual information about the spot.</td></tr>
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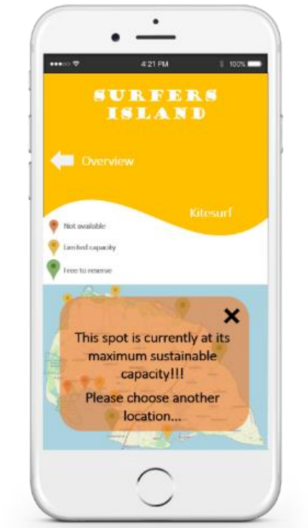

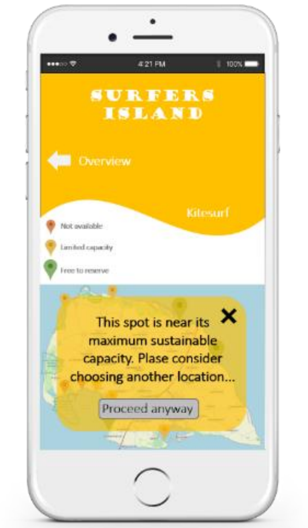

</td><td>In case the user selects a spot that is at full capacity (let) there is a warning screen notifying her/him that the current spot is unavailable, and that no reservation is possible through the App. The user is also prompted to choose another spot location.
In case the user chooses a spot with limited capacity (right) a warning screen will suggest the user to choose another location but unlike in previous case the user will still be able to proceed for the reservation screen and continue using the App.</td></tr>
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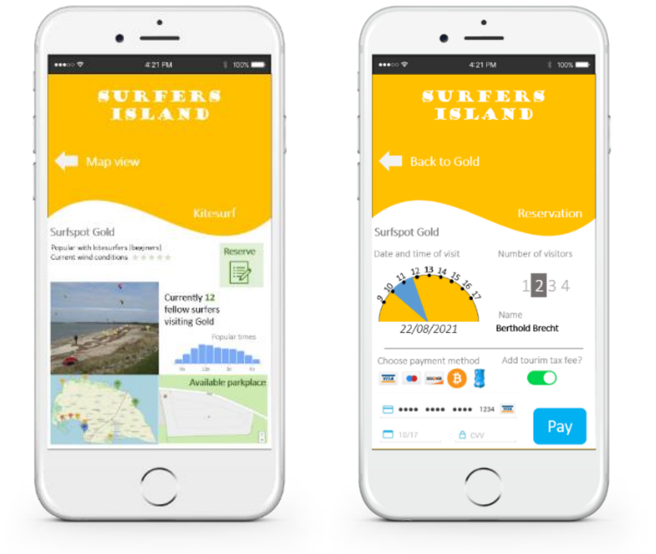


In both that cases that the use selects a spot with free or with limited capacity she/he will move to the spot detailed screen (left) in which additional information about the selected spot is provided. The details screen contains: (from top to bottom), the name of the spot, the activities the spot is popular for, information on the wind quality, a contextual figure of the spot, the current number of kite surfers at that spot, an overview of the busiest times at the spot and the information of the availability on the nearest parking place. The user can then proceed to make the reservation by means of the green reserve bottom.
In the reservation screen (right) the user will need to introduce the details of the planned trip such as days or days of visit, hours for the activity, number of visitors and name for the purposes of invoicing. The user will be able to pay in advance for the parking place via the SIA and as option be prompted to also pay the tourism tax fee in advance. Several option for payment should then be available.

Invisible but potential conflicts

Coastal conflicts may not always be immediately visible nor taking place at the present. In this short section we discern about interactions between costal activities that have the potential to be classified as conflicts in case we expand the time horizon and the scope of the analysis.

Camping and agriculture

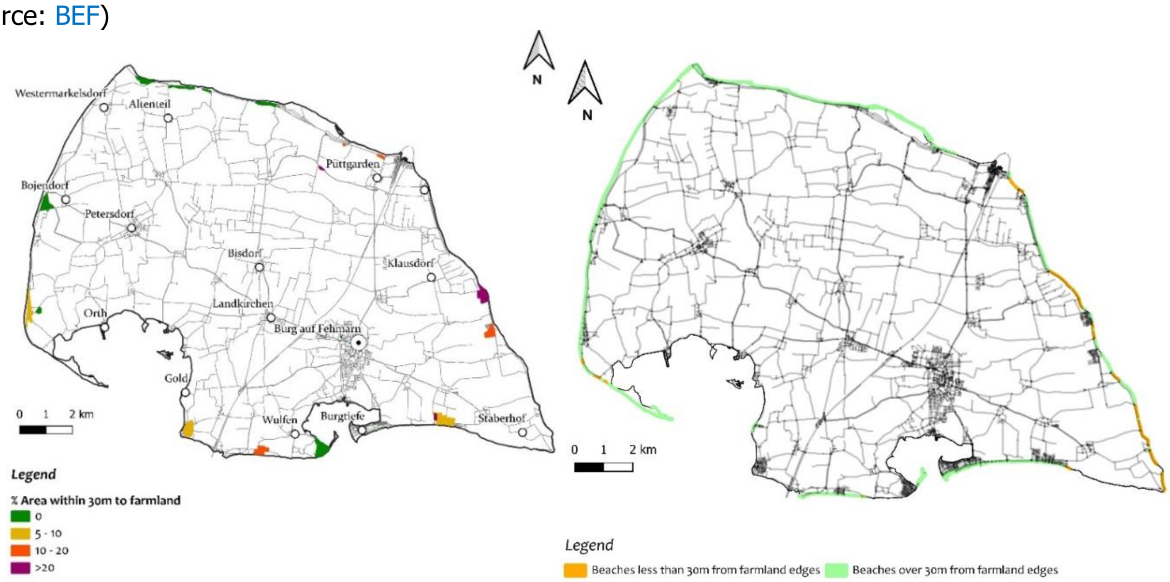
Field experiments for Germany (and Netherlands) show that spray deposition from agriculture operations can take place in areas up to 30 meters distance from the application zone (Source: Zande et al, 2015). Given the strong presence of agriculture in the coastal zone and in the island of Fehmarn it is plausible to assume that some type of spray accumulation might take place in locations close to farmland edges. This might occur at specific times of the year but because of the bio-accumulation characteristics of some agricultural products, the compounds may remain in the location for larger periods of time. Additionally, tourists in the island of Fehmarn appear be aware of the negative impacts of agriculture. A BEF survey conducted at Fehmarn shows that 50% of inquired tourists (n=127) points reductions of pesticides as a concrete measure to make tourism in the island more attractive.

Investigating campsites at the northeast coastline, it was evident their closeness to farmland edges, see example in Figure 9. It was also noted that campsites in this region are usually separated from farmland by rows of trees, which provides a physical barrier that reduces the amount of spray drift from agriculture. Using the empirical results in Zande et al, (2015) it was determined how much area of campsites and beaches fall within 30 meters or less of farmland edges, see illustration in Figure 9 right panel. The rationale of this analysis is that the higher the area of a campsite/beach in the proximity of farmland edges the higher the risk of spray accumulation to take place.

Figure 9 - Closeness of farmland to campsites and conversion of land cover/use
(Source: BEF)

It was estimated that a total of 14.7ha of camping sites (or 14% of the total area for camping at the coast of Fehmarn) to be at risk of experimenting stray deposition from neighbouring farmland (under the rationale explained beforehand). In terms of geographic distribution, the campsites with higher risk of spry deposition are in the East portions of the island, see Figure 10 left panel, namely in the region of *Klausdorf* where over 20% of the campsite area was found to be less than 30m from farmland edges. In the north region of the island, due to the lower prevalence of agricultural area, no campsite was identified as being at risk of experimenting spray deposition. In the southern coastline, risk of spray deposition was determined to be in general smaller, typically with 0 - 10% of campsite area close to farmland edges. The BEF team tried to get in touch with camp site holders to evaluate if this potential conflict has been noted in the past but to date no statement was returned. For the case of beaches, the risk of spray deposition was estimated to be far lower with only 7ha of beaches were found to be less than 30 meters from farmland edges. These beach segments are located primarily at the East coast around *Staberdorf*, *Klausdorf* and *Marienleuchte*, see Figure 10 right panel.

Figure 10 - Campsites according to the percentage of campsite area within 30meters from farmland edges (left) and beach segments according to their proximity to farmland edges (right)
(Source: BEF)



Furthermore, it is plausible that agriculture land can be converted to campsite usage provided there is physical expansion potential and adequate market conditions. Such would qualify – in academic terms – as a conflict of direct competition over a limited space (Source: European MSP Platform). An example of this phenomenon has been identified, see Figure 9 left panel, but is has not been evaluated systematically across all campsites as this would demand to compile large numbers of satellite imagery or conduct on-site surveys with the owners of the sites. Future work could also conduct an analysis of the number of permits for camping spaces in Fehmarn to identify the rate of campsite expansion. It is worth to point out that the ownership of campsite and adjacent agricultural land can fall under the same entity and hence the conflict would be minimized.

Climate-related impacts

Ongoing changes in climate will impact both human activities and the economic sectors they depend on throughout the 21st century. On a short to medium perspective (e.g., 2030 or 2050), the quantification of climate-related impacts provides important entry points to discuss and evaluate the feasibility of adaptation options. In consultation with the city of Fehmarn the impacts of climate change on water supply, coastal flooding and urban heat were identified as relevant for the island. A key driving factor of the magnitude of future impacts are the expected changes in air temperatures for the region. During the summer, these are expected to increase on average by 1 and 1.5 degrees by 2030 and 2050 respectively, following a scenario in which climate action is weak. A second driver of future impacts is the *local rate* of sea-level change that depends, among other factors, on global temperatures, regional oceanic currents, and local rates of land uplift/subsidence.

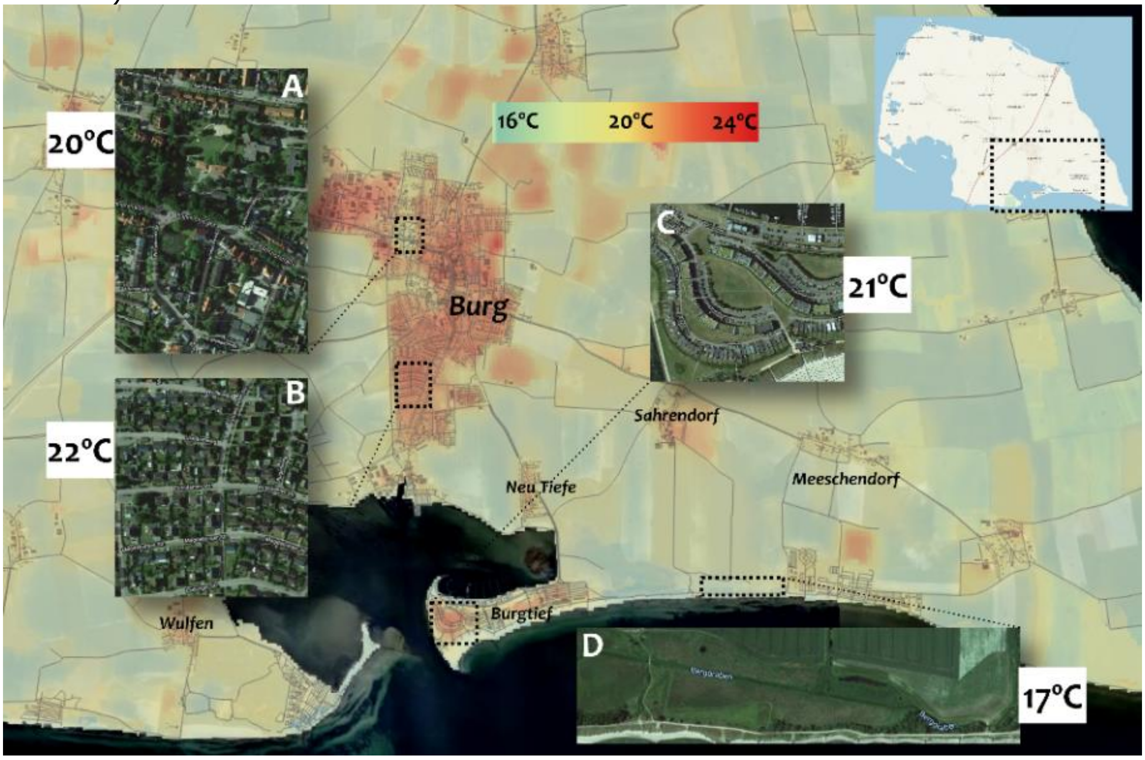
Urban heat

Locations with higher shares of sealed surface (such as buildings and roads) absorb and re-emit the heat from the sun in higher amounts than areas with higher shares of vegetation (Source: Li et al, 2020). This leads to the Urban Heat Island effect by which air temperatures in urban areas are on average higher than those in rural surroundings. Remote sensing data of surface emissivity allows to expose the complex spatial patterns of surface temperatures in cities and can be used as urban planning supporting tools. For the island of Fehmarn, day-time surface temperatures were acquired for the summer of 2020, comprising the months of June, July and August (Source: BEF using Landsat8 data from USGS). The surface temperatures are then approximated to air temperature following the baren-land relationship proposed in Mildrexel et al, (2011).

In Figure 11 the spatial distribution of the summer 2020 mean-day-time air temperature is shown for the region of *Burg* and *Burgtief*. It can be intuitively observed that areas with a higher prevalence of buildings and roads (including parking) are associated with hotter temperatures than areas with higher shares of vegetation. To exemplify what different planning choices have on urban temperatures at Fehmarn, four locations representing different characteristics of local urban fabric are pointed out. These include a location of mixed urban fabric with significant shares of green spaces intertwined with low-rise building (A); dense urban fabric with wide roads and small sparse trees (B); high-rise buildings with green spaces but without trees (C); and an area with near-zero presence of infrastructure (D).

Summer temperatures in mixed urban fabric at *Burg* (A) to be 2 degrees lower than those associated with dense urban fabric (C), see Figure 11. Because the two locations are geographically close and not located at the coastline (where cooling due to sea-breeze occurs), the difference in temperature is most likely down to differences in the urban fabric. At *Burgtief* (C), summer temperatures ranged between those found in A and B location at *Burg*. Because the location is directly at the coastline, a direct comparison with the temperatures at *Burg* is not straightforward. Nevertheless, it was expected that due to the absence of trees and presence of wider roads and parking spaces, the temperature in *Burgtief* to be somehow higher than those of mixed urban fabric in location A. Temperatures at *Burgtief* can be directly compared with those observed in location D which is situated at coastline. Temperatures at location D – a location without presence of infrastructure – were found to be the lowest in the sample and 4 degrees cooler than temperatures at *Burgtief*.

Figure 11 – Average 2020 summer day-time temperatures at Fehmarn with focus on different configurations of urban fabric at Burg and Burgtief
(Source: BEF)



Adaptation

Adapting the existing and new urban fabric in Fehmarn to mitigate heat-stress in the context of climate change will have to consider the dependency of urban air temperatures with difference degrees of urbanization and green spaces. From *Shenzhen* to *Cairo* and *Berlin*, increasing the shares of vegetation in urban areas has been pointed as one of the most cost-effective measures to lower the heat burden of the population. Research measuring temperatures under and outside tree canopies during the hottest summer days of 2018 in *Northern Bavaria*, revealed differences in temperature ranging from 2.8 to 11.0 degrees depending on the tree species and urban topography (Source: Rahman et al, 2020**).** A comprehensive review evaluating the cooling effects of vegetation in urban areas has identified that the existence of green spaces such as parks and the greening of buildings rooftops and walls add important cooling potentials. The main results of the study are summarized in Table 3 (Source: Wong et al, 2021) and highlight the small scale dependencies of each measure. Nevertheless, all the measure points for a significant cooling potential of greening urban spaces. In some cases, the cooling effect can be as high as 4 degrees. This is significant as small variations in air temperature have disproportionately large effects in lowering the mortality risk across German cities (Source: Hubber et al, 2020). The efficiency of the adaptation measures in Table 3 depend on several city and location-specific factors that would need to be investigated in detail, for example, the orientation of the building facades suitable for the implementation of green walls or the approximate shape of future parks and green spaces planed in the city.

Given the resource and time constrains it was not feasible to conduct a small-scale assessment of the cooling potential of heat adaptation in Fehmarn that accounts for all the described factors. Instead, this report focusses on evaluating the cooling potential of generally increasing the percentage of vegetated area at selected locations of Fehmarn. The adaptation measure is therefore more generic than those presented in Table 3 but has the advantage of being generally applicable. The generic measure of increasing the fraction of vegetated areas provides information on the location and extent of the interventions but does not detail if the intervention should be a park, a green roof, or a green wall. Such assessment must be undertaken in subsequent studies.

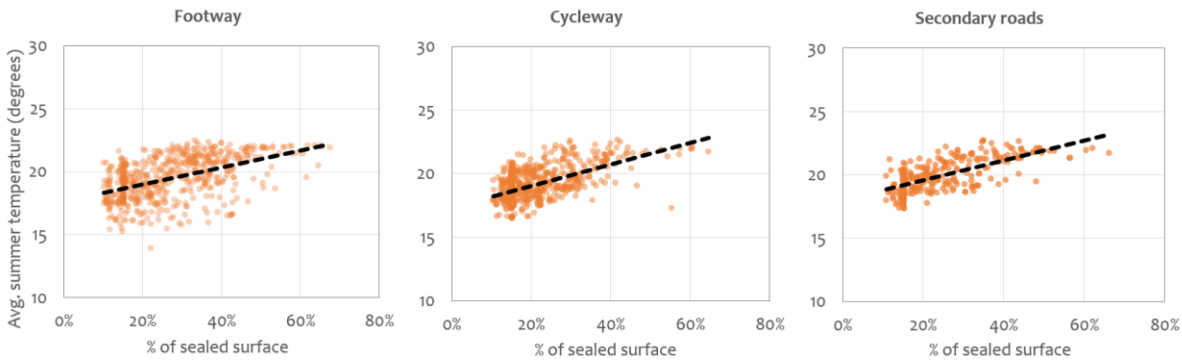
Table 3

Measures of urban greenery, cooling potential and dependency on extra factors, adapted from Wong et al, 2021

Measure	Temperature reduction range	Depending on:
Green parks  (Park Gleisdreieck, Berlin)	2 to 4 degrees	Distance to the park Typically, cooling effect takes place <50m from the park. Park size Larger parks tend to have a more pronounced cooling effect. In temperate cities optimal size between 0.5 ha and 0.69 ha. Park shape Cooling effect more pronounces in regular shaped circular or polygonal parks.
Green roofs  (Green roof in Stuttgart)	1.5 to 4.1 degrees	Climate temperature reduction is most effective in sunny weather, becoming less potent during cloudy or rainy periods. System Intensive rooftop systems (soil depths >250 mm and able to hold large shrubs) exhibit greater heat absorption and reduced temperature fluctuations.
Green walls  (Green walls at the Embankment station, London)	2 to 4 degrees	System Green walls in which the plant substrate is distributed along the wall (carrier system) are more effective than those where the substrate is limited to the bottom of the wall (support system). Placement East-facing and west-facing walls typically experience maximum cooling potential at different times of the day.

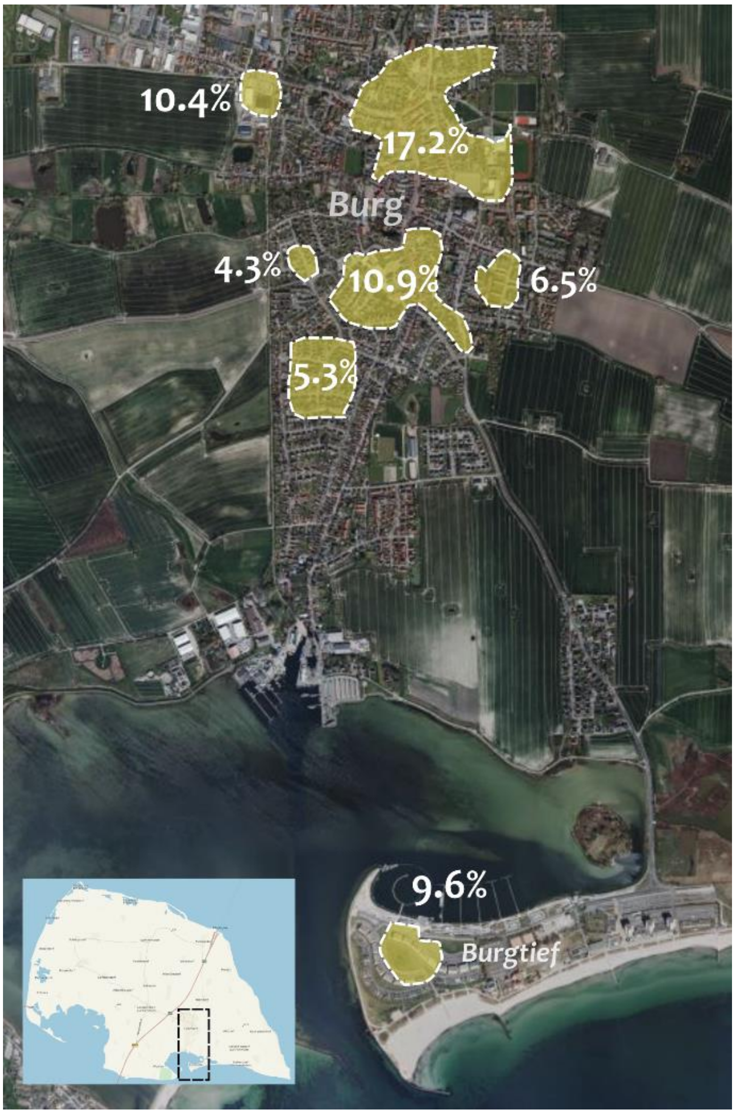
Day-time surface temperatures in Figure 11 and percentage of sealed surface are sampled along all roads, cycleways, and major footways of Fehmarn using GIS. The sampling is done as follows: 1) roads, cycleways and footways at Fehmarn are sectioned in 200meters interval; 2) at the end of each interval a 100-meter radius is drawn; 3) average temperature and percentage of sealed surface falling within the pre-defined radius are calculated. The two quantities obtained - average temperature and percentage of sealed surface – are then correlated to investigate their statistical dependency. The results are shown in Figure 12 for the case of footways, cycleways, and secondary roads. In all cases the average summer temperature shows a linear and positive dependency with the percentage of sealed surface at a given location, but the strength of the dependency varies among cases. Along Fehmarn's footways, a 10% increase of sealed surface comes, on average, associated with an increase of 0.67 degrees. The same increase of sealed surface leads on average to an increase of 0.84 and 0.78 degrees along cycleways and secondary roads respectively. Naturally, the relation is the opposite in case the amount of sealed surface decreases. Accordingly, a 10% decrease of sealed surface would provide the same amount of cooling as reported beforehand.

Figure 12 - Relationship between summer temperature and percentage of sealed surface along Fehmarn roads
(Source: BEF)



With these relations at hand, it becomes possible to determine the amount of additional green area necessary to lower urban temperatures in Fehmarn. In this report an example is provided showing how adaptation needs might be estimated but surely multiple approaches would be possible. First temperature hotspots are identified at *Burg* and *Burgtief* regions. This informs the locations in which adaptation would have potentially a larger positive effect. Hotspots are defined as a combination of high day-time summer temperatures as in Figure 11, but also as places frequently visited by tourists and the general population. This excludes like industrial areas that although often presenting above average temperatures, are not a place usually frequented by large amounts of population. For the purposes of this report a temperature value of 21 degrees as indication of high summer temperature is chosen but ultimately this value would need to be discussed on a broader forum. Applying these two principles the areas shown in Figyure13 are identified for the implementation of heat-adaptation. Having identified the priority areas for intervention the adaptation options can be many but, in this report, we focus on the generic measure of increasing the percentage of green area at the locations to lower summer temperatures to a particular target. For the purposes of this report the temperature target is set at 20 degrees to demonstrate the analysis. In short, this report calculates the extra amount of green are to lower summer temperatures of the locations in Figure 13- which are above 21 degrees - to an average of 20 degrees. It is important to point that the specific adaptation measures such as those in Table 3 to increase the amount of green area at a given location is ultimately an urban planner's decision has they need to be equated in the context of architectural and cost constraints. What is provided in this report is the additional percentage of green area to be achieved in the location so that the local summer temperatures reach the identified target. From the results, it can be observed that the reductions in temperature in most of the identified areas can be achieved with a relative low increase of green area, typically between 5 and 10%, see Figure 13. The region with the highest need of additional greenery - following the logic of this exercise - is the "city centre" of Burg with about 17%. Additional green public spaces come with the additional need of maintenance. In a warming climate this can mean additional water needs. Such an adaptation strategy would need to further consider additional water use for maintaining the green spaces, something that is not evaluated in this report.

Figure 13 - Identification of regions with summer day-time temperature in 2020 equal to or above 21 degrees and estimation of additional amount to green area needed to lower temperatures to 20 degrees (Source: BEF)

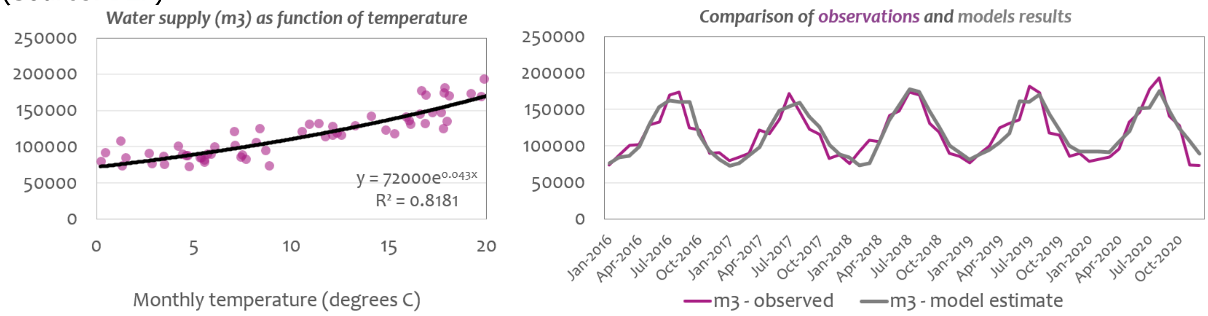


Water demand

Fehmarn obtains its water supply exclusively from ground source provided via the mainland. Water consumed in Fehmarn is pumped from *Klötzin*, circa 25km from *Burg* (see full replies from the water expert in the Questionnaires section of the Annex). The island receives daily about 6600 m^3 of water which is stored in the network or in the reservoirs of *Strukkamp* and *Sahrensdorf* with a joint capacity 6000 m^3 (Source: Wasserbeschaffungsverband). Between the years of 2016 and 2020 an average of 1.4 million m^3 of water annually were delivered to the island (Source: **BEF**, with data from Wasserbeschaffungsverband). During the same timeframe, yearly supply increased moderately by 0.65%, from 1.29 million m^3 in 2016 to 1.41 in 2020. Supply in the summer months increased from about 480 to 520 thousand m^3, a rise of 8.4% and substantially higher than the annual increase.

With the prospect of growing tourism activity and warmer summers, the supply of water to Fehmarn is expected to come under additional stress. To evaluate under which climatic circumstances the supply of water to Fehmarn might become under stress, a statistical model correlating monthly data on temperatures (source: BEF using data from ERA5 reanalysis) with that of monthly water supply was established. Water supply and temperature were found to be positively and non-linearly correlated, see Figure 14 left. An exponential function was fitted to the data and tested for its ability in reproducing the past variability of supply. Past water supply was reproduced by means of the established model and past temperature data and compared to observations, see Figure 14 right. It was found that the simple model (which used only temperature and independent variable) captures adequately 82% of the variability of water supply to Fehmarn when all months are considered. Regarding the total water supply taking place in the summer months (the period of the year when the supply system is more likely to come under stress) the model underestimates the supply by a range of 1.4 to 9.2%. Because of this model feature, the estimates of supply during the summer period are recalibrated by +10%.

Figure 14 - Water supply model and comparison of model outputs with observations
(Source: BEF)



Making use of the established water supply model it is now feasible to approximate the future supply needs (2030 and 2050) for Fehmarn under a changing climate. Average monthly temperatures for Fehmarn under RCP4.5 are obtained (see Climate and tourism and Figure 23 of the Annex) and used as input to the supply model. Historically, the higher supply volumes to Fehmarn have been registered during the months of June, July, and August and accordingly these are the months in which the supply system is likely to come under higher stress. Assuming the number of visitors to Fehmarn remains constant at 2019 levels, the future water supply to Fehmarn can be estimated using only future projections as input to our model. Making use of the model of Figure 14, but replacing the observed temperature values with summer temperatures expected under RCP4.5, the future summer water supply needs for Fehmarn can be estimated by 2030 and 2050. The results come expressed in Table 4 and show an increase in summer water supply of 9.5% and 11.5% in Fehmarn - in reference to past mean values of summer supply - respectively by 2030 and 2050. This increase is driven by the regional warming expected. In absolute terms the central model estimate of summer supply at Fehmarn is 179K m^3 by 2030 and 183K m^3 by 2050 (95% range of model uncertainty is given in Table 4).

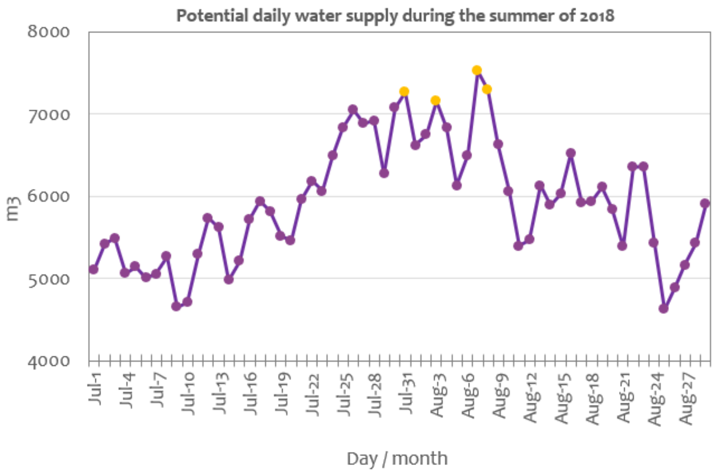
Table 4

Results of the projected change in water supply to Fehmarn under RCP4.5 and absence of adaptation (Source: BEF)

	Projected summer supply (2025-2035 and 2045-2050 summer mean)	
Reference summer supply (2016-2020 mean)	2030	2050
162K m^3	179K m^3 (171 – 189)	183K m^3 (170 – 194)
% Change	9.5%	11.5%

For management purposes it is far more relevant to evaluate the water supply needs at the daily or even optimally at hourly level given that the management of the in- and outflow of water in the reservoirs and the supply network is done on an hourly basis. The utility of climate models needs nevertheless to be put into perspective. While there are useful for providing expected seasonal changes over the medium to long run, they are less useful on pinpointing changes expected over particular calendar days. To overcome the mismatch between the temporal resolution of management decisions (and for that matter adaptation) and that of useful climate model outputs, this report makes use of the following approach. It starts by identifying a summer period in recent past in which the water supply system has come under stress. Second, it evaluates the daily temperatures of that period. Third, it uses daily temperatures to disaggregate the projected average summer consumption calculated in the previous section to the daily scale. The best way to interpret this approach is has a "what if scenario", namely, *what* would the supply implications be *if* a past stress event would take place under future warming. Evaluating the news during the year of 2018, the hottest summer over the last 10 year (see Figure 1) it comes reported in the media that the water supply in Fehmarn has come under stress during the month of July (Source: Fehmarn24[2] citing the Wasserbeschaffungsverband Fehmarn). Extreme heat, calm winds and high number of tourists have led to a daily water consumption of "a bit more than 7000 m^3" over the "24 hours of Thursday" (that is the 26th). In the same piece the population is warned about the possibility of water becoming scarce and suggested to adopt a water-saving conscious. Should water demand continue to rise above the supply capacity, so goes the piece, other measures are being planned. In the article, the *Wasserbeschaffungsverband* does not exclude curtailing the the water supply during 21pm and 6am. This indicates that during the end of July 2018 period the water supply to Fehmarn did come under stress. Having established a temporal reference for the stress event the next step is to evaluate the corresponding evolution of daily temperatures.

Figure 15 - Potential water supply to Fehmarn in the absence of curtailment measures in the summer of 2018 observations
(Source: BEF)



Using ERA5 reanalysis data on a daily time-scale the evolution of average daily temperatures over the island of Fehmarn for the time period between 1st July and 30th August 2018 is evaluated (see Figure 27 of the Annex). Average daily temperature on the 26th of July reached 24.2 degrees and 24.9 degrees on the 31st of July. Thereafter temperatures level off until reaching 19.1 degrees on the last day of August 2018. As final step, daily temperatures are used to downscale the July monthly value of water supply to Fehmarn to the daily scale assuming direct proportionality (days within a month are ranged by temperature and the total water supply in that same month distributed proportionally). The results are shown in Figure 15 and can be contrasted to the numbers reported during the stress event reported. On the 26th July 2018 the downscaling results indicate an estimated 7050 m3 of water supplied, which is in line with the reported during the stress event of "*a bit more than 7000 m^3*" (Source: Fehmarn24[3] citing the *Wasserbeschaffungsverband* Fehmarn). It is therefore feasible to obtain an adequate approximation to daily water supply to Fehmarn by simply disaggregating monthly supply data proportionally to daily temperatures. Using the value of 7100m^3 as indicative threshold of *supply stress* it is estimated that daily supply - in the absence of any curtailment strategy during July/August 2018 - would be over this threshold for a total of 4 days, noted as yellow dots shown in Figure 15. It is important to underline that if supply limitations were indeed imposed in Fehmarn from the 26th of July onwards, this fact would distort the temperature-supply relationship and hence the downscaled results. Therefore, it is more correct to frame the result as *days of potential supply stress*.

2 Accessed on 20 July 2021, 15:45
3 Accessed on 20 July 2021, 15:45

Adaptation

Judging by change in days of potential supply stress, there is a non-negligible medium-term risk to the to the island of Fehmarn. The potential impact is manageable and can be put into perspective by determining how much water would need to be saved for the daily supply to remain below 7100m^3. This is done by subtracting this threshold value to the estimated potential water supply during the projected days of potential supply stress. The saving needs are calculated at 3968m^3 during a 2018 summer taking place in 2030 and 5885m^3 for the same analogy but in 2050. In terms of daily average savings during the days of potential supply stress, the totals beforehand equate to 361 and 453 m^3. It is important to underline that these estimates *do not account* for a further increase of tourists visiting Fehmarn in the future nor changes in their water consumption behaviour. Factoring these variables would lead to the introduction of more assumptions and would require a more in-depth study on the growth perspectives of the tourism industry in Fehmarn. But there are relevant insights that can already be made. For example, during the summer of 2018 average daily supply was estimated at about 5976m^3. If the summer of 2018 would have taken place in 2050, Fehmarn would require the equivalent to an extra days' worth of water to maintain daily supply below the 7100m^3 threshold. More importantly than the total amount of water is its availability in time and therefore the estimated savings could inform the upgrade of new reservoir capacity to serve as back-up to cover future impacts.

The extra supply projected can be fulfilled by increasing the supply capacity to Fehmarn in the form of enhanced or new pipelines from the mainland. The current physical limit of water supply to Fehmarn stands at 299m^3/hour, which translates into a theoretical daily water supply of 7176m3 (Source: Fehmarn's Wasserbeschaffungsverband), only marginally higher than the daily proposed threshold for supply stress. The theoretic value does not account for the existence of other constraints in the supply network, for example, it assumes that there is always water available to be pumped from *Klötzin* into Fehmarn, which might not always be the case. In a questionnaire sent to Fehmarn's *Wasserbeschaffungsverband* the idea of investing in future improvement to the supply infrastructure of Fehmarn is voiced. When questioned: "If adaptation to climate change was required by law next year, what immediate actions do you think should be taken in your sector?" the reply was "the construction of a desalination plant". The results of this report (see Table 4) can inform what extra water volumes such hypothetical desalination plant would have to produce to counteract the additional supply stress caused by regional warming. The questionnaire reveals the absence of a climate adaptation plan for regional water supply and that adaptation will be on the agenda of the *Wasserbeschaffungsverband* over the next 5 years, including the need to deploy concrete measures. The main hindrances for adaptation pointed out were the necessary financial means and the need for clear guidelines at the regional/local guidelines for adaptation implementation.

Alternatively, or in addition to new/improved supply infrastructure, adaptation can be looked at from the perspective of reducing water demand. In Table 5 the average daily use of water per capita in Germany during the year of 2019 is shown (Source: Statistica). Note that these are German averages and hence limited in providing the complete picture for Fehmarn, but they serve to demonstrate the potential of demand side measures. At the household level the activity that consumes more water is bath/showering/hygiene, followed by toilet flushing, laundry, dishwashing, and finally car-washing/garden. Taking the values in Table 5 as indicative and somehow representative of the population in Fehmarn, then it is possible to devise adaptation measures to be implemented (on the demand side) to achieve the projected savings necessary for avoiding a situation of supply stress.

12 MSP in Poland in an on-going process. The only completed (and accepted in 2021) maritime spatial plan is the plan for the whole Polish marine areas (at a 1:200 000 scale). This plan is complemented by smaller plans prepared in higher resolution for the areas of high intensity of spatial conflicts such as lagoons, coastal areas or waters of ports. Out of all these plans, the processes relevant for the Polish Land-Sea-Act case study include the plans for the Gulf of Gdańsk and for the Vistula Lagoon. Unless stated otherwise, all the information refers to all three planning experiences.
13 And, indeed, these interactions between the land and the sea are clear when stakeholders were to identify their cultural values (see chapter 4 for more information).

Table 5

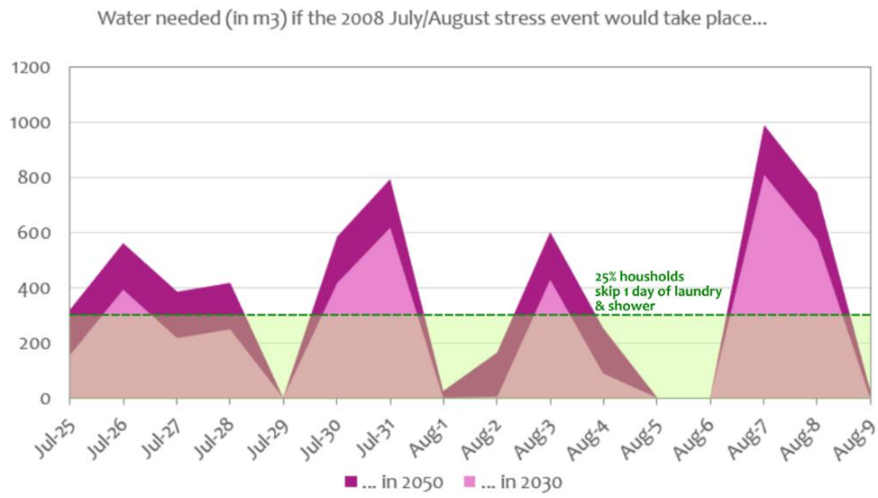
Daily water consumption per household activity in Germany 2019 (Source: Statistica)

Activity	Water consumption (litres/day)
Bath/showering/hygiene	45
Toilet flush	34
Laundry	15
Dishwashing	8
Car washing/Garden	8

Consider the stress event shown in Figure 15, in which water needs in Fehmarn are likely to have surpassed the 7100m^3 threshold mark for 4 days. Assuming such event would take place in 2030 or 2050 under the warming under RCP4.5, then (all things equal) water needs are simulated to surpass the threshold for a total of 11-13 days in case the event takes place in 2030 or 2050 respectively. The amount of additional water needed during those days - projected water needs minus 7100m^3 supply - is shown in Figure 16. From a demand-side perspective, the management challenge would be to achieve short-term daily water savings equivalent or higher than the projected values in Figure 16.

During July of 2018 Fehmarn received circa 876070 visitors (Source: BEF using data of Fehmarn's tourism office). The average length of visitors in July is about one week. Dividing the July visitors by 3, given there is always some overlap of visitors during the 4 weeks of July, informs that about 29200 thousand visitors are likely to be at the island at any given week of July. If to these one adds the 12875 permanent residents of Fehmarn (Source: Wikipedia), then the population of Fehmarn should be about 42000 persons at any given week of July. As the numbers in in Table 5 refer to household, we convert the population of Fehmarn during July to households using the factor of 1 household = 2 persons (Source: Eurostat).

Figure 16 - Water-saving potentials of hypothetical adaptation measures and additional water needed in case the 2018 supply-stress event takes place in 2030 and 2050
(Source: BEF)

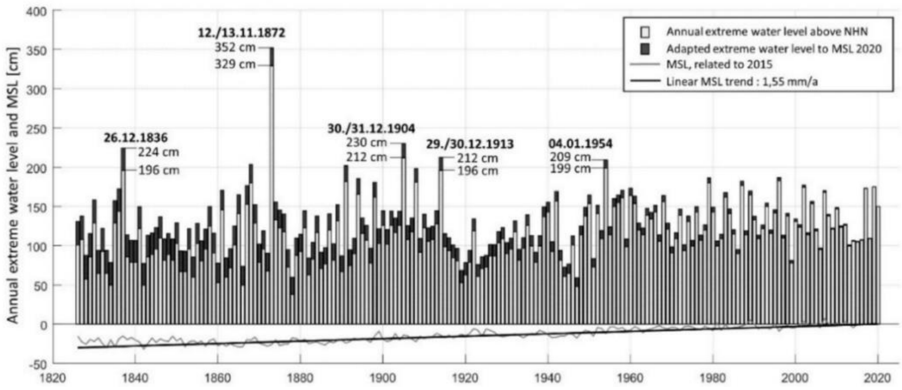


Making use of the total number of households and the water consumption values Table 5 as indicative, several water-saving strategies can be elaborated and approximated. For example, one can suggest an awareness campaign to promote having one less shower/bath (assuming 35 litres of water usage), skip one day of laundry or avoid washing the car (assuming 4 litres of water usage). If such campaign is effective across 25% of the households, then savings in the order to up to 300m^3 are conceivable. If achieved, such savings could cover a considerable amount of the extra water needs shown in Figure 16. Such savings would alleviate the pressure on existing or for future infrastructural investments. It is relevant to point again that this report made use of national numbers of water consumption which do not fully capture the patterns of water consumption in Fehmarn. For example, it is likely that in Fehmarn single house ownership is higher than that of Germany, implying that water use for purposes of watering the garden/washing the car can be higher than national averages. This would further boost the potentials of water savings from the demand side shown in Figure 16.

Coastal flooding

The island of Fehmarn has experienced several degrees of physical impact from storm flooding in the recent and distant past, see Figure 17. Most recently, in January 2017, a surge between 1.5 and 1.7m moved across the Baltic and hit the West coast of Fehmarn. The region of *Wallnau* was particularly affected with physical damages to the regional dike with estimated repair costs of 3.2 million € - in 2021 values (Source: LN ONLINE). On 1st November 2006, a surge of 1.78m lead to flooding of the lower regions of *Westerbergen*, *Lemkenhafen* and *Fehmarnsund*. In November of 1872, an unusual combination of winds in the south Baltic Sea created a storm surge reaching up to 3.5m above mean sea level - more than a meter higher than observations over the past 200 years (Source: Hallin et al, 2021). Historical accounts of the 1872 of flood event in Fehmarn report that 366 houses were damaged and that "about a quarter to a third of the island of Fehmarn was flooded" (Source: Kiecksee et al, Schriften des Deutschen Schiffahrtsmuseums, Bremerhafen).

Figure 17 - Annual extreme water level at Lübeck-Travemünde station for the period 1820-2020 (Source: Hallin et al, 2021)

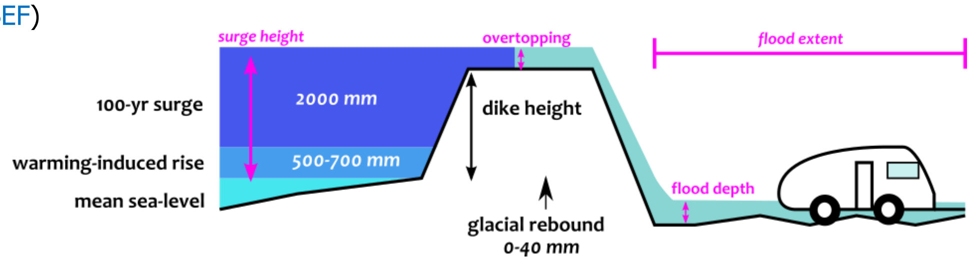


Driven by oceanic thermal expansion and melting of land-based ice, the Baltic Sea will experiment upward change in sea-level over the 21st century. In fact, contemporary rates of sea-level change have already been detected from satellite measurements. Between 1995 and 2019, sea level has risen at an annual rate of 2–3 mm along the German and Danish coasts (Source: ESA and Balticseal project). But while it is certain that sea will rise along the Baltic coast, the associated impacts on a variety of factors such as height and frequency of storm surges, state of coastal defences or future land planning decisions. Research shows that flood damages by the end of this century are much more sensitive to the applied protection strategy than to variations in climate and socioeconomic scenarios, as well as topography and climate model (Source: Hinkel et al, 2014). Given that the processes governing sea-level rise are long term, coastal regions have some amount of time to implement adaptation.

Future surge heights and flood modelling

To estimate the future height of a hypothetical surge hitting Fehmarn by 2100 three factors must be considered: a) the regional rate of sea-level rise; b) the regional change in coastal elevation due to isostatic rebound; and c) the local expected height of historical surge maxima (usually the 100yr flood level is used for coastal planning purposes), see Figure 18. For the case of Fehmarn, by 2100 sea-level rise under RCP4.5 is projects at about 0.5m (see Figure 28 of the Annex), with a 95% ensemble ceiling of 0.7m. In the Baltic region, land uplift due to isostatic rebound has been estimated between 0 and 0.5mm/year for the German Baltic coast (Source: Vestøl et al, 2019), which translates to a 0 - 40mm range by 2100 (assuming linearity and 2020 as starting year). Regarding the surge height at Fehmarn, communications with a local expert pointed 2-meter level as the reference level for a 100yr surge event at Fehmarn (see full replies of the coastal expert in the section Questionnaires of the Annex). A reanalysis of high-resolution readings of extreme sea level for the Baltic region confirms this level but also highlights the uncertainty around the distribution. The 100yr surge level at the upper bound of the 95% confidence level for *Travemünde* has been calculated at circa 2.7-meters, while the central estimate is of 2.0 meters (Source: MacPherson et al, 2019), in line with the information obtained for Fehmarn. This serves to highlight that higher surge levels cannot be entirely disregarded. Integrating all surge-contributing factors, a future reference 100yr surge at Fehmarn is likely to range between 2.46 and 2.70 meters[4] above sea-level.

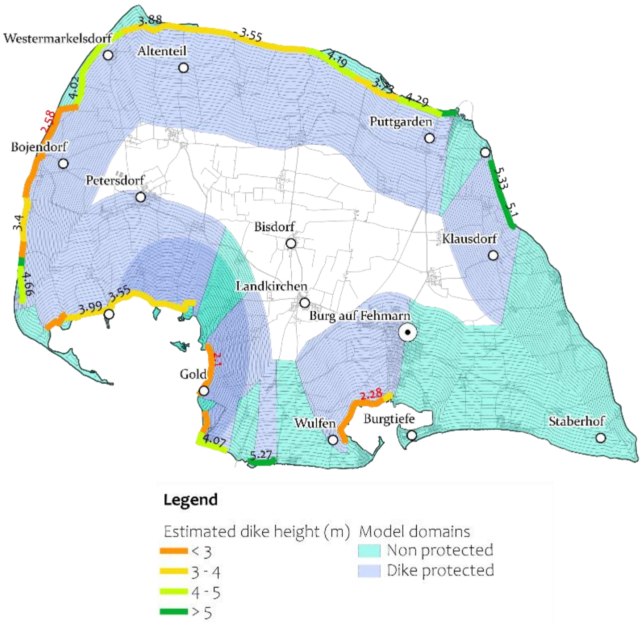
Figure 18 - Illustration of the main contributing factors for coastal flooding in Fehmarn
(Source: BEF)



To simulate the future risk of coastal flooding a simple coastal inundation model for Fehmarn was programmed, see Figure 19. The model follows the connected component approach of Kulp & Strauss 2019 and uses SRTM30 surface elevation data (Source: SRTM30) as input. The model was programmed using Google's Earth Engine JavaScript editor to take advantage of the computational requirements typical needed for flood modelling. Because current digital elevation models do not have sufficient spatial resolution to capture coastal defences, we consulted with a coastal protection expert on the maximum and minimum heights. These were reported, respectively, at 6-meters for at *Puttgarten* and 3 meters for the so-called regional dikes. A GPS survey along some stretches of dikes was conducted and for *Puttgarten* a dike height of 5.7 meters was recorded, which is in good agreement with the information provided. For the dike segments surveyed, this report directly uses the height values obtained via GPS. To approximate the dike height of the remaining dikes (those not surveyed by the BEF team) this report makes the following assumptions. It starts by using the difference between the GPS heigh recorded at *Puttgarten* dikes and the elevation from SRTM30 as reference. Then, it assumes that the relative difference is maintained throughout the dike network. This report acknowledges the crudeness of the assumption but would like at the same time to highlight the results obtained in Figure 19. As can be observed, the highest dike heights are generally estimated at the North portion of the island. Interestingly, on the West coastal portion of Fehmarn, where regional dikes are dominant, estimated heights from the simple approach outlined ranged between a minimum of 2.58 and a maximum of 4.66 meters. This reveals that our results of the minimum dike height in regional dikes is not so dissimilar to the value obtained from the expert. Nevertheless, for the purposes of this report the estimated height values below 3-meters (highlighted red in Figure 19) are "raised" to 3 meters as to align with the information provided by the expert. The dike heigh estimate remains, as stated before, a crude approximation but it is nevertheless an advance in the modelling of flood risk for the island. Dikes are implemented in the flood model as impenetrable barriers without the possibility of suffering partial nor total breach. Dikes are nevertheless susceptible to suffer overtopping. Dike overtopping takes place when the projected surge height is superior to the dike height. In this case the height of the dike is subtracted to the surge height to obtain the flood depth (see Figure 18).

4 Upper bound: 700mm sea level rise + 2000mm storm surge – 0mm glacial rebound;
Lower bound: 500mm sea level rise + 2000mm storm surge – 40mm glacial rebound

Figure 19 - Estimated dike height and different domains of the flood mode
(Source: BEF)



It is necessary to differentiate in the model two flooding domains, one where the surge can flow freely in the landscape as there is no dike protection, and a second one where the surge flow is constrained by the existence of dikes. These two domains are shown in Figure 19. For the stretches of coast without dikes the surge height decrease at a constant linear slope with increasing distance from the coastline. This is done in order to account for the effect of water level attenuation with distance to coast similar to the approach followed in Vafeidis et al, 2018. In a location not protected by dikes flooding takes place as long as surge height > terrain elevation. Finally, it is a disadvantage of the model the fact that it can only simulate a constant flooding for the entire coastal length, or in other words, it cannot simulate *at the same time* a 2-meter-high surge at Burgtief and a 1.2-meter surge at Gold (see pervious map). In the forthcoming results, all coastal locations at Fehmarn are hit by the same surge level. This report makes the GEE code available for those planning re-purposing the model in future work, together with a basic set of instructions. See more details in section Flood model of the Annex.

Flood simulation

The simulated flood extent and depth of a 2.70-meter surge hitting the coastline of Fehmarn are shown in Figure 20 for selected regions in the north and south coastlines. Note that no changes in the frequency nor intensity of storm surges are consider in this report, only the upwards displacement of past storm surges caused by projects regional sea-level change. Results point that a 2.7-meter surge would generate a substantial flood extent around the coastal region of Nördlicher Binnensee and Salzensee located in protected areas, see Figure 20 top panel. The Fehmarnbelt camping place would likely be substantially affected - as it lacks direct dike protection - with on average flood depths of about 1m. Further east, the campsite Belt-Fehmarn is protected with existing dikes that shield the campsite from the hypothetical flood level assumed. In general, along the north and east portions of the island a 2.7meter is contained to coastal areas not directly protected by the current dike system.

On the south coastline along the region of Orther Bucht - see Figure 20 lower panel - flood simulations point for the nature protected area, the Lemkenhafen harbour and the region south from Lemkenhafen as particularly vulnerable. Given the distinct coastal configuration of this region - a bight, compared to open waters in the north - a 2.7-meter surge estimate could be too high but given the limitations of our model we can only evaluate the flood risk under a homogenous level. Nevertheless, the results highlight again the effect of coastal defences in limiting the flood propagation. Like the northern region also in the south there are camping places estimated to be affected. This is the case of Miramar and portions of camping place Wulfener Hals. For the latter, a storm surge in 1989 of about 2.2-meters (Source: Landesregierung Schleswig-Holstein) was responsible for considerable flooding at Wulfener Hals camping place, see video-capture inset in in Figure 20 lower panel (Source: Poko 2009). This indicates that at least for this coastal location the flood model is delivering realistic approximations of flood extent, but more work would be needed to account properly for all the factors influencing the flood dynamics at Fehmarn. These estimates serve as a first attempt to conciliate global projections of sea-level rise and features such as dike protection in estimating local flood risk and how this substantially adds value to previous global estimates.

Figure 20 - Estimated flood extent of a 2.7-meter surge hitting the entirety of Fehmarn's coast at selected locations
(Source: BEF)

Adaptation

Adaptation to sea-level rise includes a range of changes from individual actions to collective coastal management policy. Adaptation measures to sea-level rise can be classified along three broad categories; protect (e.g., new or upgraded coastal defence systems), accommodate (e.g., improve warning systems or raise height of infrastructure) and retreat (e.g., give up on developed land in risk-prone areas and set this further back from the coastline). Importantly, adaptation to sea-level rise should be viewed as a process that requires an integrated coastal management philosophy to be consistent with wider coastal activities and other stresses. Hence, in addition to technical skills, adaptation requires an appropriate institutional capacity (Source: Nicholls 2015). When the coastal expert providing us with technical information was questioned: "If adaptation to climate change was required by law next year, what immediate actions do you think should be taken in your sector?" the reply was "measures in the coastal land ahead of the dikes that better secure the dike function". Examples of such measures are land reclamation techniques that would increase the distance from the coastline to the dike so that more energy form the surge is dissipated. In the context of this report, it was not possible to explicitly model the effect of such short-term adaptation measures, but this is something worth pursuing in forthcoming research activities in the island. When questioned about the mains constraints to the implementation of adaptation, the expert underlined the lack of knowledge regarding the impacts of climate change in the coastal domain and the need for clear regional and local guidelines to the implementation of adaptation (similarly to the what is reported from the expert of adaptation of the water supply system, see section Water demand). This report goes a step further in providing a clearer picture of the flood extent expected from a 100-year flood level under the effect of additional sea-level rise and in the context of today's coastal protection standards in Fehmarn. The flood model provided should be seen as a foundation for further studies occupied with evaluating the effect of local adaptation measures.

SWOT analysis for Fehmarn

A SWOT analysis was undertaken for the island of Fehmarn focusing on the dimensions of sustainability and climate, spatial conflicts, and blue economy, see Figure 21. Regarding the Sustainability and climate dimensions, it was notes as inherent strength the broad acceptability of the population to sustainability measures such as water saving and reductions in one-way plastics. In addition, there is significant acceptability in the population to finance a free public transport in the island, which would provide an opportunity to make collective transport more attractive while targeting at the same time one of the major weaknesses which is the high prevalence of individual transport in the island. The Fehmarn tunnel connecting the island and German mainland to Denmark is expected to substantially change the transport dynamics in the island and increase the transit of road-based transport, posing an additional to the climate-neutrality objectives of the island.

The city of Fehmarn is currently aware of the risks posed by climate change across some key sectors (e.g., water and coast), while this is a good starting point the issue of adaptation to climate change has so far been kept on the side-lines. The lack of a dedicated mid- to long-term adaptation plan to climate change in the key economic sector of tourism reflects that and therefore a notable weakness. On the other hand, the declared climate-neural ambitions of the island are well in line with financial research and project implementation opportunities available at Germany and Europe level. When it comes to climate impacts, it is a strength of the island its past and recent experience with damaging flood events and the overall good protective dike infrastructure covering about 40% of the island perimeter. On the other hand, climate-related impacts assessed in this report point for negative effects in water supply, and adaptation opportunities to urban heat which would be useful to investigate more in depth from a implementation perspective - once gain linking to the lack of a comprehensive adaptation plan for the tourism sector.

Regarding spatial conflicts, it was found that the population has grown more conscious of the environmental impacts of blue-economy activities as well as more thoughtful when sharing the coastal space. In addition, scientific inquire and stakeholder dialog are seen as the basis for conflict solving by the island (see section Surf coastal vegetation). The use of technology to help managing some of the potential conflicts is also a strength in the island but these solutions need to consider some practical implementation challenges (see section Surfers Island App), which constitutes a weakness. There is considerable perception amount tourists that reducing the amount of phytosanitary applications in Fehmarn’s agriculture would make tourism in the island more attractive (see section Camping and agriculture) and hence it would be important to reflect on the opportunities at hand to de-intensify some of the agricultural production in the island. On the other hand, the potential increase if global or national demand for bio-fuels crops could threaten this opportunity by continuing making conventional agriculture more profitable. An additional threat is the prospect to a continuing surge in tourism demand driven by restrictions on international travel which would mean that more visitors would have to accommodate their activities within the finite coastline.

Figure 21 - SWOT analysis on the dimensions of Sustainability & climate, Spatial conflicts, and Blue economy

(Source: BEF)

	Strengths	Weaknesses	Opportunities	Threats
Sustainability & climate	• Broad acceptance for sustainability measures like water savings or less one-way plastic (~78% acceptance). • Good awarness of the municipality regarding the risks posed by future climate impacts. • Past experience with damaging flooding events and existing 35km of coastal protection infrastructure.	• Low participation in sustainability actions like using public transport (<10% participation). • Lack of a mid- and long-term climate adaptation plan for the tourism sector. • Water supply infrastructure projected to come under additional stress from climate change.	• Moderate acceptance in paying for a free public transport system in the island (~41% acceptance). • Climate-neutral ambitions in are aligned with financing opportunities from Germany and the EU. • Further growth of the tourism sector as travelling abroad remains lower than pre-pandemic levels.	• Tunnel to Denmark will disrupt the transport dynamics and likely increase road transport emissions. • Climate-related impacts (e.g., extreme rainfall) cited as resons not to visit Fehmarn in the future. • Aditional water demand in the summer months projected for the near future (2030) under a week climate protection scenario.
Spatial conflicts	• Conflict-solving capacity via scientific enquiry and stakeholder dialog (e.g., presure of surfers on seagrass). • Consideration of innovative technological solutions to manage tourism flows. • Population has grown more thoughtful of environmental impacts and competing blue economy activities.	• Habitat diversity is primarily viewed as aesthetical issue by stakeholders. • Dominance of intensive agriculture land use in the coastal zone. • Digital solutions to manage flows in surf spots face significant practical barriers.	• Tourists wish for a reduction on the use of phytosanitary products on agriculture (~50% of respondents). • Untapped potential to de-intensify agriculture production. • Future surf activity at some spots suggested to be kept at current levels.	• Additional global demand for energy crops can lead to the perpetuation of intensive agricultural practices. • Risk of further environmental impacts from large domestic tourist flows if international travel remains limited.
Blue economy	• Good levels of infrastructure and geographical positioning.	• Historical focus on coastal tourism and lack of new/emerging blue economy sectors.	• Potential for tourism outside the main season via lower prices and increase offer for indoor activities (~30% of respondents).	• Continuous rise in tourism demand avoids focusing on exploring other forms of blue economy.

Lastly, in terms of the blue-economy sector it is positive that the island is well positioned geographically and currently operating a good level of infrastructure. The construction of the Fehmarn tunnel can bring some further opportunities in terms of connectivity, but these are not yet fully clear. What seems to be a more tangible opportunity is that circa 30% of the responding tourists to the BEF survey would like to have more off-season tourism offer such as more indoor activities and more attractive pricing. On the other hand, the historical focus on the tourism sector can hinder the exploitation of other innovative forms of blue economy.

Annex

Auxiliary figures

Figure 1 - Linear trends of total precipitation between 2000 and 2020
(Source: BEF using ERA5 reanalysis data)

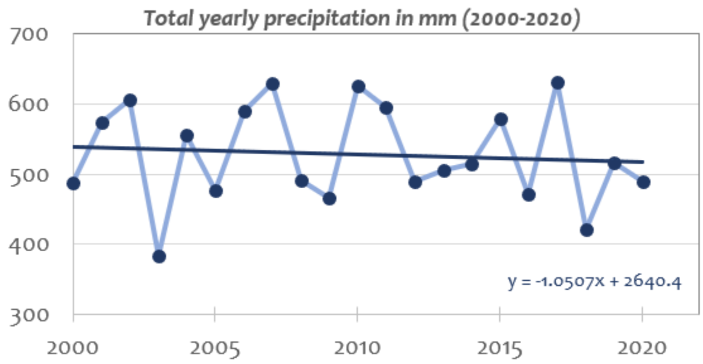


Figure 2 - Projections of summer temperatures change for the island of Fehmarn following RCP4.5 and referenced to average summer temperatures between 1986and 2005. Simulations are obtained from the KNMI Climate Change Atlas service. In total 43 models are used representing the CMIP5 range used in the IPCC AR5 report

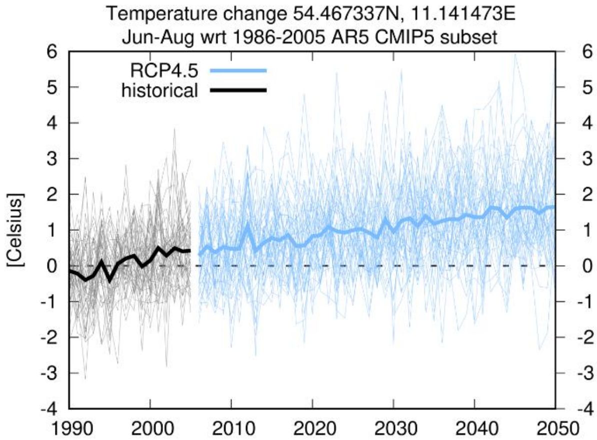


Figure 3 - Example of the distance calculation of coastal features/infrastructure to a given beach segment
(Source: BEF)

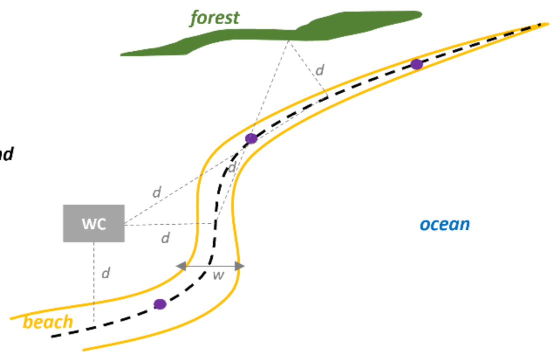


Figure 4 - Distribution of bird species and surf areas at Orther Bucht.

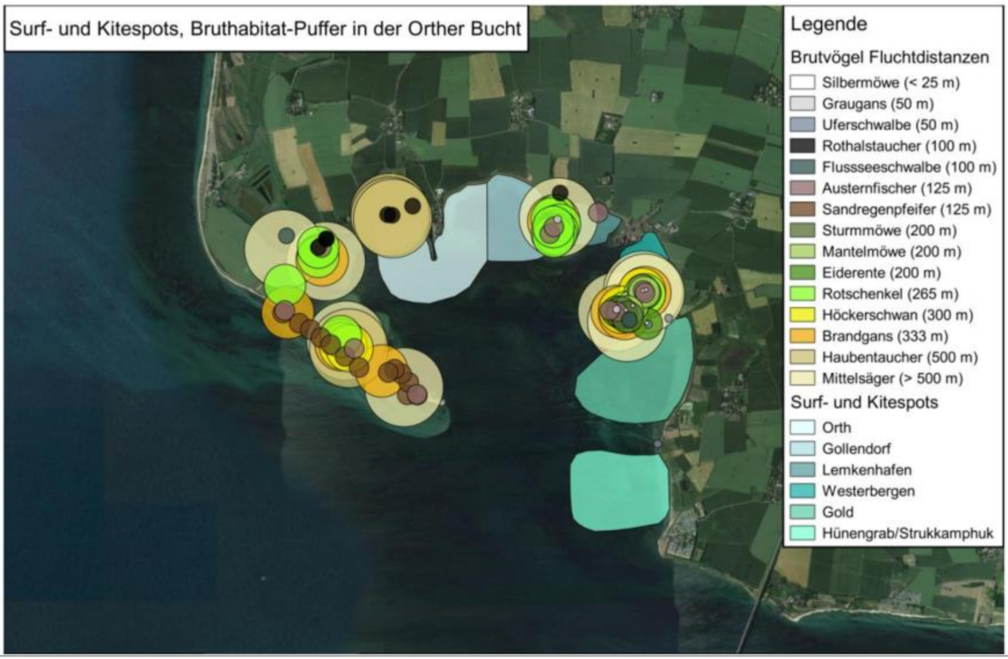


Figure 5 - Coverage macrophytes in surf and natural protection areas at Orther Bucht (Fhemarn, Germany)
(Source: Gesellschaft für Freilandökologie und Naturschutzplanung.)

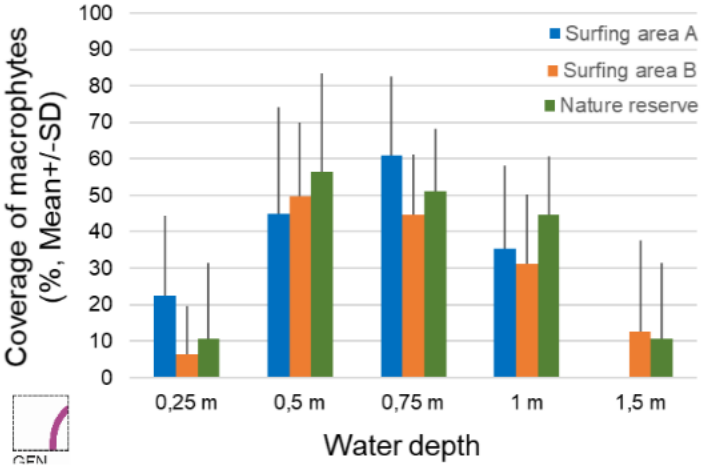


Figure 6 – Daily average temperatures in Fehmarn between 1st July and 30th August 2018
(Source: BEF using AR5 reanalysis data)

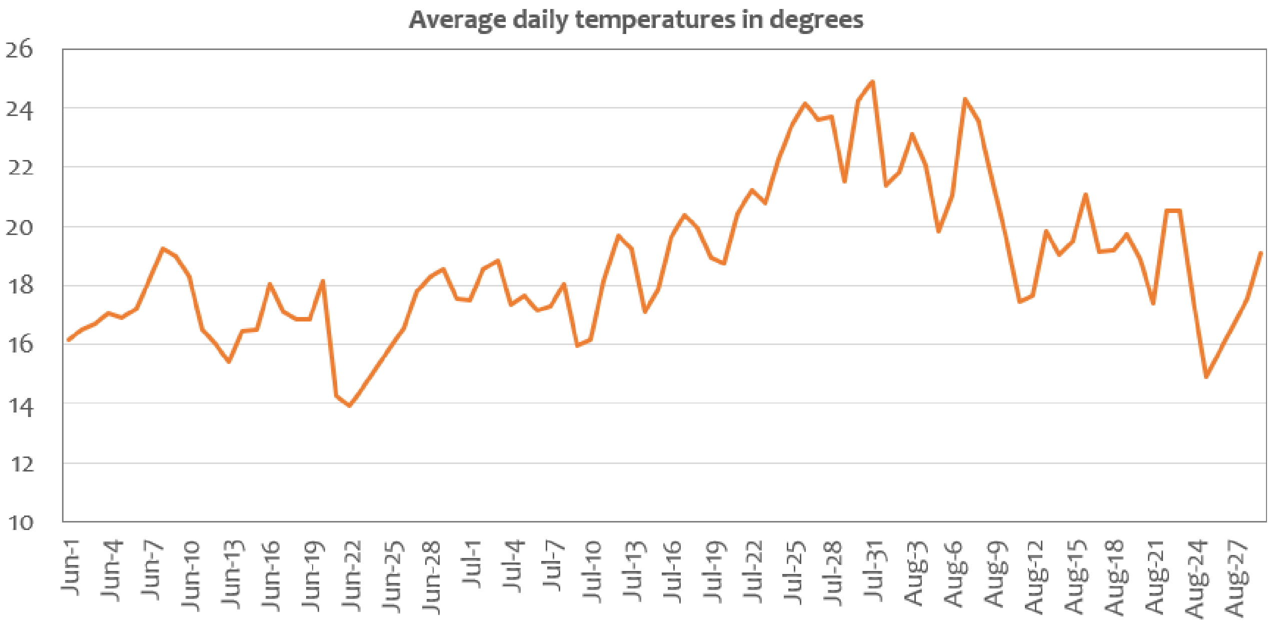
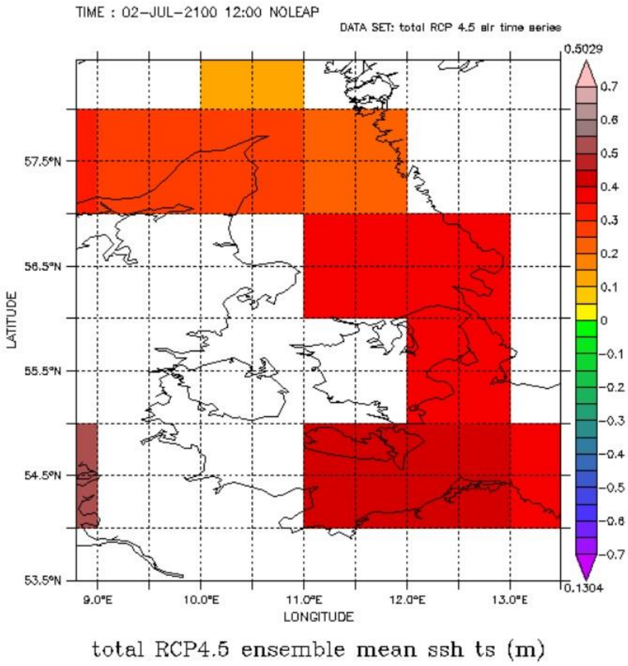


Figure 7 - Mean ensemble projection of sea-level change in the Baltic following RCP4.5 by 2100
(Source: AR5 with data extracted from ICDC University of Hamburg)



Flood model

We have developed a simple flood model in Google Earth Engine to estimate flood risk at the coastline of Fehmarn. The model nevertheless is applicable to any coastal location provided the following information is available:

1. An informed guess of the typical 100yr surge height for a coastal location (value).
2. The incremental level of regional sea-level rise expected by 2100 (value).
3. The local level of Glacial Isostatic Adjustment expected in 2100 (value).
4. Cartographic delimitation of the shoreline to serve as flood source and mask (featureclass).
5. Dike location and height in meters (featureclass).
6. Flooding domains indicating regions with and without dikes (feafureclass).
7. Digital elevation model (image, in this case SRTM30).

The GEE code is available here:

https://code.earthengine.google.com/?scriptPath=users%2Flfccosta%2Fndvi%3AfloodCode

and reproduced below. Note that you will require a GEE account to run the model.

The following feature collections are necessary to load prior to running the code:

```
var dike = ee.FeatureCollection("users/lfccosta/dike"),
    source = ee.FeatureCollection("users/lfccosta/source"),
    mesh = ee.FeatureCollection("users/lfccosta/model-mesh"),
    coast = ee.FeatureCollection("users/lfccosta/fcoast");
```

Followed by the code below:

```
///////////////////////////////////////////////////////////////////////////////////////
//////SEA LEVEL RISE & FLOOD RISK////////////////////////////////////////////////////
//////////////////////////////////////////////////////////////////////////////////////
// This code calculates flood extent and depth at the coastline of Fehmarn
// It was conceived under the Land Sea Act project (https://land-sea.eu/) by the Baltic Environmental Forum (https://www.bef-de.org/)
// The code developer was Luis Costa (luis.costa@bef-de.org)
// In case you wish to use or modify the model you can do so.
// It is nevertheless advisable that you contact Luis Costa beforehand as the model description below might not always be self-explanatory.
// The model was found to provide plausible results for flood heights up to 2.7m.

//Reads SRTM30 elevation data
var elev = ee.Image("NASA/NASADEM_HGT/001")
.select('elevation');

// Imports the coastal segment hit by the hipothetical flood
// in this particular case we import the full Fehmarn coastline
var coastHit = source;
// Sets coastHit to 1 and everything else is 0.
var floodSource = ee.Image().toByte().paint(coastHit, 1);
// Creates the image to calculate the cost path
var floodMask = floodSource.selfMask();

//Converts Dikes to image
var dikeToimage = dike
  .reduceToImage({
    properties: ['height'],
    reducer: ee.Reducer.first()
});
//Converts model domains to image
var meshToimage = mesh
  .reduceToImage({
    properties: ['decay'],
    reducer: ee.Reducer.first()
});

// Remap original dike height values to zero
// this will be used to "nullify" the elevation data at dike location
var burnDike = dikeToimage.not().unmask(1);
// this will be used to restore the dike height on the previously burnt location
var addDike = dikeToimage.unmask(0);

// Burn the dike path into elevation
var elevMinusDike = elev.multiply(burnDike);
// Adds the dike height back to the elevation data
var elevUpdate = elevMinusDike.add(addDike);

// Sets parameters for calculating the flood and probabilities
//--------------------------------------------------------------------
var gia = 0;
var surge = 1.8;
var slr= 0.7;
var slrFlood = gia+surge+slr;
print('Surge height',slrFlood);

// Turns all pixels below the flooding threshold 0 and above 1
var elevRemap = elevUpdate.updateMask(elevUpdate.gte(slrFlood)).gt(slrFlood).selfMask().unmask(0);

// Preforms cumulative path to simulate water penetration
// given that dikes are set to zero, the cumulative cost path is the shortest at the point of dike contact
var toFlood = elevRemap.cumulativeCost({
  source: floodMask,
  maxDistance: 3* 1000,  // to km
  geodeticDistance: false
});

// Remaps the simulated water penetration to 1
var toFloodRemap = toFlood.remap([0,1],[1,0]);
// Flood extent simulation raster to cover the Fehmarn Island only
var floodExtsim = toFlood.clip(coast);
// Create mask of flood extent
var floodMask = floodExtsim.eq(0);
// Update the food extent simulation masking out the non-flooded values
var floodSim = floodExtsim.updateMask(floodMask);

// Determine flood depths in the absense of dikes and surge height limitation
var floodDepth = elev.subtract(floodSim.add(slrFlood));
// Factors of surge height along the unprotected domains of the model mesh
var meshTodecay = ee.Image(1).where(meshToimage.lte(1), meshToimage);
// Determines the model domains where protection exists and can be "overtopped" by surge
var meshToTop = ee.Image(slrFlood).where(meshToimage.gt(1), meshToimage);
// Remove the % flood height equivalent of the dike height if overtopping takes place
var meshSurge = ee.Image(1).subtract(meshToTop.divide(slrFlood));
var meshOne = ee.Image(1).where(meshSurge.neq(0), meshSurge);
var meshFinal = ee.Image(meshOne).where(meshOne.lt(0),0);


// Combines both the overtopping and no-protection domain floodin a single flood raster
var floodDecay = floodDepth.multiply(meshTodecay);
var floodOverTop = floodDecay.multiply(meshFinal);
var floodFinal = floodOverTop.updateMask(floodOverTop.lt(-0.3));

//Maps results
// Flood extent and depth
Map.addLayer(floodFinal, {min: -5, max: 1, palette: ['#023858','#74a9cf','#3690c0']}, 'Flood depth', false);
// Location of dikes
Map.addLayer(dike.draw({color: '#e7298a', strokeWidth: 5}), {}, 'Dike', false);
```

Questionnaires

Water expert

Coastal expert