INNOVA
Climate Service Provision

Beach Wrack Fact Sheet

KIEL BAY: PROJECTED CLIMATE CHANGES AND IMPACTS ON BEACH WRACK

This Beach Wrack Fact Sheet for INNOVA focuses on projected climate change and the impacts on beach wrack for the Kiel Bay area. It is structured in two parts, with the first part displaying projected climate changes for Schleswig-Holstein based on information from the Climate Fact Sheet Schleswig-Holstein (Pfeifer et al. 2020). Several parameters (like temperature, precipitation, or wind) are displayed in relation to a reference period of today’s climate.

The second part looks at the impacts for beach wrack based on possible climate changes. It is based on different parameters directly affected by climate change (like temperature, salinity, waves) but also addresses effects, that could impact beach wrack but are only indirectly linked with climate change (like eutrophication or changes in the food web).

Further information on the Kiel Bay hub can be found in the E-Zines from INNOVA. The first Kiel Bay E-Zine described the region of the innovation hub and introduced the aspect of beach wrack with different approaches how communities deal with this natural issue. The second Kiel Bay E-Zine was addressed to the beach wrack and seagrass in an international and circular economy context.

PROJECTED CLIMATE CHANGES

The information on possible climatic conditions are based on the Climate Fact Sheet for Schleswig-Holstein produced by the Climate Service Center Germany (GERICS; Pfeifer et al. 2020).
The fact sheet provides information on projected climate change for Schleswig-Holstein and is based on 85 regional climate projections. The fact sheet is valid for the whole federal state and is not specific for the Baltic Sea region. It presents 17 different parameters (see section on background information for parameter definitions) for climate change and their change towards the end of the 21st century in comparison with a reference climate period of 1971 to 2000today climate.

The table below provides an overview of the different parameters. Robust changes are marked in colour (with robust increase marked in red and robust decreases marked in blue). Robustness is defined based on the agreement of the simulations on the direction of the changes and on the significance of each individual projection (see Pfeifer et al. 2020). Three different Representative Concentration Pathways (RCPs) are showcased in the Fact Sheet: RCP8.5 represents a business-as-usual scenario with high CO_2 emissions, RCP4.5 a medium scenario, and RCP2.6 a climate protection scenario with lower CO_2 emissions. For each RCP, different climate model runs, based on different combinations of global and regional climate models are displayed in the Climate Fact Sheet.

Results

For example, all scenarios show a robust increase in *temperature* for the time span of 2070-2099. Depending on the different emission scenarios, the annual increases of temperature are between 2.5 and 4.8 °C for RCP8.5; between 1.2 and 3.1 °C for RCP4.5 and are between 0.2 and 2.1 °C for RCP2.6.

The projected changes for *precipitation* show different results for the end of the century. While for RCP 8.5, a robust trend of increase (with a range from -1.2 to 33.2 %) is shown, the trends for the other two RCPs are not that robust and show a range from 0.2 to 18.0 % for RCP4.5 and a range from -11.6 to 10.4 % for RCP2.6.

For changes in *windspeed* by the end of the 21st century, annual changes range from -0.2 to 0.18 m/s for RCP8.5, from -0.18 to 0.04 m/s for RCP4.5, and from -0.21 to 0.1 m/s for RCP2.6. However, none of these changes are robust.

Looking at *temperatures below 0°C*, today Schleswig-Holstein has around 70 days with frost per year. By the time span of 2070-2099, they can decrease in a range from 23 to 95 days for RCP8.5 or from 16 to 57 days for RCP 4.5. For the RCP2.6 the range covers a decrease of 45 days up to a increase of three days.

More detailed information on each of the parameters can be found in the Climate Fact Sheet, which can be found here: https://www.climate-service-center.de/products_and_publications/fact_sheets/climate_fact_sheets/detail/088906/index.php.de

	Climate change for the end of the 21st century		
Parameter	High Emissions Scenario (RCP8.5)	Medium Emissions Scenario (RCP4.5)	Low emissions scenario (RCP2.6)
Temperature	Increase	Increase	Increase
Summer days	Increase	Increase	Increase
Hot days	Increase	Increase	Tendency towards increase
Tropical nights	Increase	Increase	Increase
Frost days	Decrease	Decrease	Decrease
Late frost days	Decrease	Decrease	Decrease
Ice days	Decrease	Decrease	Decrease
Days above 5°C	Increase	Increase	Increase
Maximum duration of heatwaves	Increase	Increase	Tendency towards increase
Precipitation	Increase	Tendency towards increase	Tendency towards increase
Dry days	no changes	no changes	no changes
Precipitation over 20 mm/day	Increase	Increase	Tendency towards increase
95th percentile of precipitation	Increase	Increase	Increase
99th percentile of precipitation	Increase	Increase	Tendency towards increase
Climatic water balance	Tendency towards decrease	no changes	no changes
Wind speed	no changes	Tendency towards decrease	Tendency towards decrease
Sultriness	Increase	Increase	Increase

Table based on Pfeifer et al. 2020.

IMPACTS ON BEACH WRACK

The term beach wrack describes a mix of seagrass and algae deposited on beaches. At least 90% of beach wrack on German coasts consists of biomass. During strong currents, storms or wave exposures, seagrass and algae are torn off the seabed and washed along coasts as beach wrack (Mossbauer et al. 2012; Duarte 2004). The occurrence of beach wrack is irregular and seasonal, as it depends on wind patterns, currents and tides.

Different studies show, that beach wrack at the Baltic Sea is mainly of local origin (Suursaar et al. 2014). At the Kiel Bay, beach wrack mainly consists of two components: Seagrass (*Zostera marina)* and an seaweed called Bladderwrack (*Fucus vesiculosus*). *Zostera* and bladderwrack grow in the shallow water of the Baltic Sea. Generally, their spatial distributions are determined by their ability to adapt to low salinity, variations in sea level, wave exposure, light and oxygen availability, grazing, predation and competition for space (Viitasalo et al. 2015). With a possible climate change, most (if not all) of the mentioned parameters are most likely to change as well. This second part of this paper takes a closer look at possible changes to some of the parameters and their impacts on beach wrack based on literature review.

SEA TEMPERATURE

Projected climate changes

Projected changes in water temperature range from 2 – 4°C in the Baltic until the end of the century (relative to a baseline of 1978–2007 and based on different regional Baltic Sea model simulations). A north–south gradient is causing the range of temperature changes, with relatively higher increase in water temperature in norther Baltic areas. Additionally, an increased warming in shallower sub-basins is projected than in deep-water. Studies also show, that shelf sea regions warm substantially more than the open ocean, by 1.5–4 °C depending on location (Meier 2015: 244; based on mini-ensembles, "which is forced by the SRES A1B and A2 scenarios").

The IPCC states in their Special Report on Ocean and Cryosphere (SROCC) (Collins et al. 2019), that marine heatwaves (MHV) will occur more frequently with climate change. Heatwaves were defined by Hobday et al. (2016) as "prolonged discrete anomalously warm water event that can be described by its duration, intensity, rate of evolution, and spatial extent." For a study, Pansch et al. (2018) defined a water temperature of over 25°C as a heat wave for the western Baltic Sea.

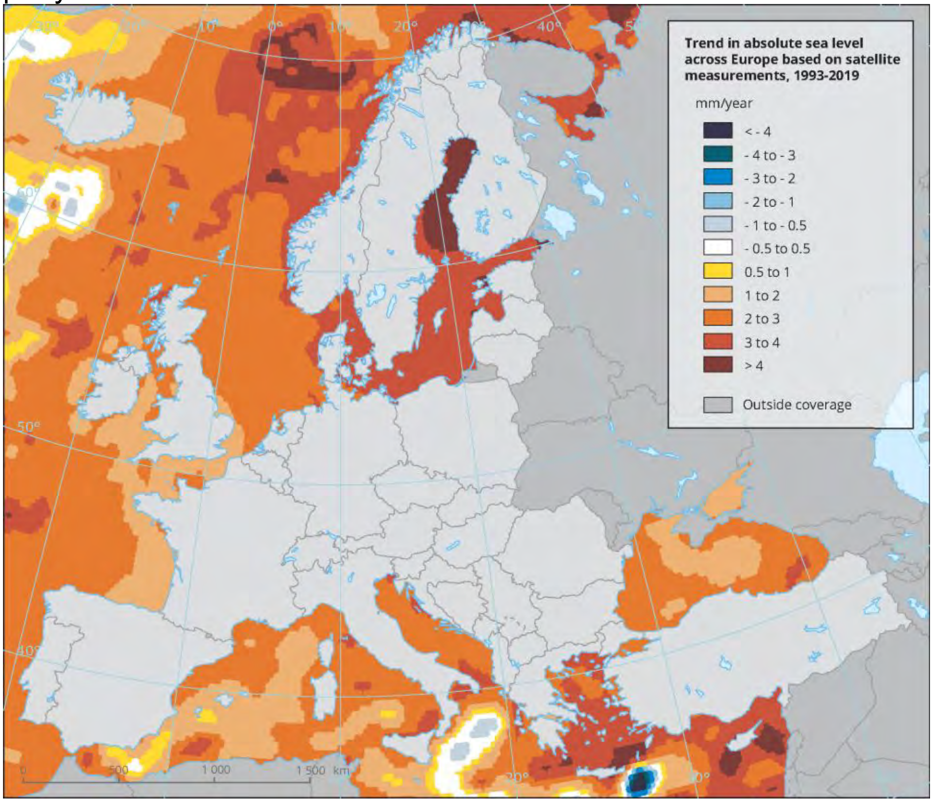
Implication for Beach Wrack:

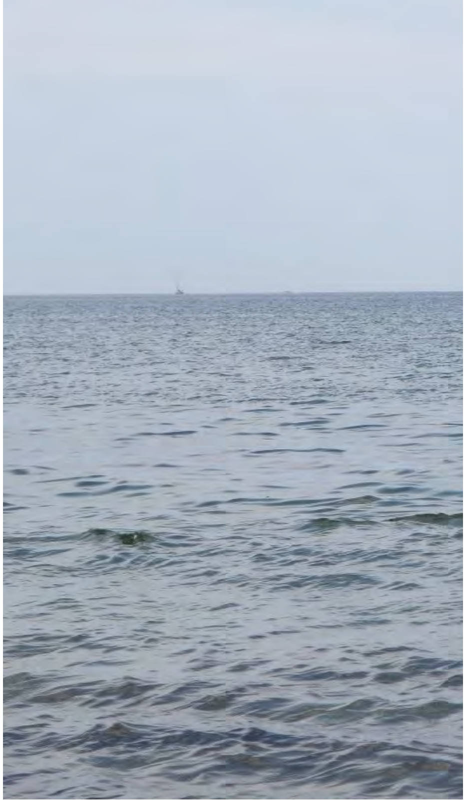
Water temperature plays a decisive role for aquatic organisms, since they developed physiological adaptations to certain water temperature levels, the so-called temperature tolerance. Graiff et al. (2015) studied the temperature tolerance for bladderwrack (Fucus vesiculosus). Bladderwrack has rather wide temperature for growth (ranging from 5 to 26 °C) with optimal growth rates from 15 to 20 °C. Water temperatures above 20°C already represent a stress factor for bladderwrack (Bobsien 2015), for example due to reduced antiherbivore defense mechanisms (Weinberger et al. 2011). ***With current temperatures in the Baltic Sea, F. vesiculosus is "already living close to its upper thermal tolerance limit" (Graiff et al. 2015) and rising sea temperatures may lead to severe conditions for the bladderwrack****. Optimal water temperatures for growth and survival are between 10 and 20°C.* ***For seagrass stocks from the western Baltic Sea, 25°C is considered the critical temperature limit. The productivity of the plants then decreases and mortality increases*** *(Bobsien 2015). An experiment by Höffle et al. (2011) showed a high mortality rate of Zostera in water temperature of 27°C.*

SEA LEVEL RISE & EROSION

Projected climate changes

A recent study (EEA 2019) shows a mean sea level rise for the past two decades (1993-2019) for the southern Baltic Sea from 2 to 4 mm per year (see Figure below). For the Kiel and Eckernförde Bay a rise for 2 to 3 mm per year.





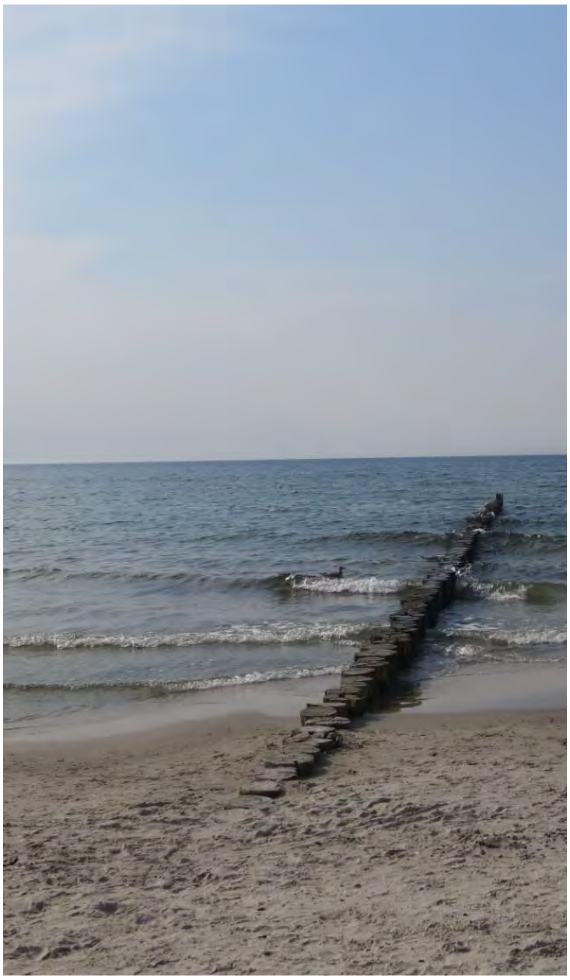
Source: EEA 2019 (https://www.eea.europa.eu/data-and-maps/figures/trend-in-absolute-sea-level/trend-in-absolute-sea-level/109212_Fig02-Map-CLIM012-Trend-in-absolute-sea-level-across-Europe_v05.eps.75dpi.gif/download)

The EEA also presents data for a projected change in relative sea level for the period 2081-2100). Depending on RCP, a rise between 0.2 to 0.4 m (for RCP 2.6) and over 0.6 m (for RCP 8.5) in the area of the Kiel and Eckernförde Bay is possible.

Implication for Beach Wrack:

There are no studies found with a focus on sea-level rise (SLR) and its implication for beach wrack. However, indirect interlinkages between SLR and beach wrack are reported. A SLR will cause erosion of beaches, which will cause increased turbidity in water and leads to reduced light incidence. The erosion will also lead to shifting sediment deposits. If bladderwrack is covered completely by sediments, it dies off (Bobsien 2014). The same is true for Zostera, as a study by Mills and Fonseca (2003) showed that almost 100% of the plants died when 75% of the leaf length were buried. ***Both reduced sunlight and the smothering effect of sediment may slow down growth rates of both seagrasses and algae, and ultimately die off.***

CHANGES IN WIND & WAVE PATTERNS



Projected climate changes

The wind climate over the Baltic Sea region is on average closely linked to the atmospheric circulation and cyclonic activity over the North Atlantic (Rutgersson et al. 2014). Groll et al. (2017) expect an increase median wind speed in the whole Baltic Sea. In a basically tide-free environment, such as the western Baltic Sea, “changes in the wind climate considerably affect the changes in the wave climate” (Groll et al. 2017)
The IPCC SROCC (Collins et al. 2019) states that an increase of the mean significant wave height has to be expected with high confidence under the RCP 4.5 and 8.5 for the Baltic Sea. Changes in wave patters result not only because of “higher wind speeds but also from a shift to more westerly winds, which leads to different fetch and thus to different significant wave height and direction” (Groll et al. 2017).

Implication for Beach Wrack:
No studies were found that considered the implications of climate-induced changes in wind and wave patterns on beach wrack. However, Hammann & Zimmer (2014) concluded, that spatial and temporal distribution of beach wrack is “unpredictable and depends on wind and wind-driven waves”. The amount of landed beach wrack depends on the frequency and abruptness of changes in wind speed. ***It can be concluded that the deposition of beach wrack on the beach will also increase with more frequent and stronger winds.***

SALINITY

Projected climate changes

Results from the BACC II report (Viitasalo et al. 2015) indicate, that changes in salinity are expected to be the greatest in the southwestern part of the Baltic Sea due to a shift in the fronts within the transition zone. In general, a reduction of salinity is projected, due to an increase of river run-off (in the margins of 15–22 % increase, depending on hydrological models). Meier (2015) states, that salinity projections remain uncertain because of uncertainties in run-off projection. However, “studies based on dynamical modelling suggest that in a future climate, Baltic Sea salinity will decrease or remain unchanged compared to the present-day climate”. Also, Vuorinen et al. (2015) assume, based on different scenarios a decrease in the salinity gradient with many different ecological consequences. Jonsson et al. (2018) assume a general decrease of ca 1.5–2 PSU in most of the Baltic Sea, with a decrease of up to 2 – 2.5 PSU in the Kiel Bay area. Bobsien (2014) states a PSU for the Kiel Bay area of ca. 10-15 PSU.

Implication for Beach Wrack:
Jonsson et al. (2018) studied the implication of lower salinity for Bladderwrack (Fucus vesiculosus) caused by gradients due to climate change. In general, a decrease in the salinity gradient will imply a decrease in the abundance of bladderwrack. The authors (ebd.) stated, that in a worst-case scenario, “F. vesiculosus may disappear from large parts of the Baltic Sea”. However, changes in the Kiel Bay area might not be as dramatic as for more northern and eastern part of the Baltic Sea. BACC II authors state, that there is no clear link between “climate-induced changes in salinity and long-term changes in Fucus populations” (Viitasalo et al. 2015).
For Zosterna marina, Bobsien (2014) reviews that the optimal salt content lies between 10 and 25 PSU with its northern and north-eastern geographical distribution at about 5 PSU. With the projected changes in salinity and the current PSU levels, the minimum PSU levels for Z. marina might not be reached for the Kiel Bay area. ***In summary, the assumed changes in the salinity gradient in the Bay of Kiel will be of such magnitude that only marginal effects on bladderwrack and Zostera can be assumed. Therefore, these changes should not have a significant effect on the beach wrack.***

INDIRECT LINKAGES

EUTROPHICATION

Projected climate changes

The BACC II report (Viitasalo et al. 2015) state, that modelling results show a potential worsening of eutrophication with climate change. This is explained by an increase in freshwater discharge and resulting nutrient loads from land. Agriculture is a main driver in nutrient discharge to the Baltic Sea (Refsgaard et al. 2019). Bartosova et al. (2019) conclude that nutrient loading will rise due to climate change, but also state that changes in the socioeconomic drivers can lead to a decrease of nutrient loadings in similar magnitude or worsen the loadings depending on the socio-economic pathways. However, leaving socio-economic changes aside and assuming a business as usual, an increase in eutrophication due to climate change is to be expected for the Baltic Sea.

Implication for Beach Wrack:
Eutrophication is an important key factor driving the growth of seagrass and algae's, because it directly affects light conditions, oxygen content and concentrations of toxic substances in water. At present, eutrophication is the greatest threat to the bladderwrack and seaweed stocks in the Baltic Sea (Bobsien 2014). Long-term and large-scale decline of seagrass were "generally recorded in the most nutrient rich areas" (Boström et al. 2014: 425). ***Negative effects of eutrophication are therefore expected to increase with climate change, which in longer turn may result in lesser amount of Zostera and bladderwrack in the beach wrack.***

OXYGEN DEFICIENCY

Projected climate changes

Closely linked to warming sea temperature and eutrophication are areas of oxygen deficiency, so-called hypoxic and anoxic zones. An area of ca. 70,000 km^2 with hypoxia condition where recorded in 2016 (Meier et al. 2019). In 2019, anoxic conditions affected ~24% of the Baltic bottom areas and about 33% suffered from hypoxia (Hansson et al. 2020). The Baltic Sea is experiencing dead bottom zones with anoxic environments due to "(1) excessive nutrient loads from land, (2) limited water exchange with the world ocean and (3) perhaps other drivers like global warming" (Meier et al. 2017). The authors conclude in their study, that climate change will probably lead to an increase of anoxic zone in the Baltic Sea.

Implication for Beach Wrack:
While the 'dead-zones' merely occur in deep waters where seagrass and bladder wrack not reside, they still have effects on the shallow Baltic waters. Changed wind and current patterns could lead to oxygen-poor deep water reaching previously untouched shallow water areas (Bobsien 2014). ***Anoxic and hypoxic conditions can be severe for seagrass.*** *Holmer and Bondgard (2001) stated, based on experiments, that growth and survival of seagrass were negatively affected by poor oxygen conditions and the presence of sulfides in the water column. Baden et al. (2003) reported that loss of seagrass beds in Denmark were "primarily due to summer anoxia and accompanying sulfide release from the sediment."*

CHANGES IN THE FOOD WEB

One impact of climate change for coastal areas of the Baltic Sea can be changes in the food web. Higher temperatures, eutrophication and other factors can lead to changes in the food web relations. Bobsien (2014) exemplified possible effects of changes in the food web for Bladderwrack and Seagrass. The common periwinkle (*Littorina littorea*) and the isopod *Idotea balthica* (so called Mezo-Grazer) both are able to graze the growth of epiphytes on adult Bladderwrack and Seagrass so that sufficient light is available for photosynthesis and they are not covered with quickly growing algae.

How the food web can change with a changing climate has not been studied in detail. In general, BACC authors (Viitasalo et al. 2015) state, that in their review, only “very few studies have explicitly investigated the mechanisms by which climatic variations can affect shallow benthic and algal communities in the Baltic Sea” (ebd. 367). Bobsien (2014) concludes in his study, **that from eutrophication, over-fishing, raising water temperatures, declining PH-values and less oxygen, epiphytes could profit and become a threat to Zostera and bladderwrack.**

CONCLUSION

The climate changes projected up to 2100 are expected to have various effects on the bladderwrack and seagrass stocks in the Baltic Sea (Bobsien, 2014; Korpinen et al. 2012). This will have direct effects on the composition and amount of beach wrack landing on the Baltic Sea shores.

Key Facts: implications for beach wrack

SEA LEVEL RISE & EROSION: *Both reduced sunlight and the smothering effect of sediment may slow down growth rates of both seagrasses and algae, and ultimately die off.*

SALINITY: *The assumed changes in the salinity gradient in the Bay of Kiel will be of such magnitude that only marginal effects on bladderwrack and Zostera can be assumed. Therefore, these changes should not have a significant effect on the beach wrack.*

EUTROPHICATION: *Negative effects of eutrophication are therefore expected to increase with climate change, which in longer turn may result in lesser amount of Zostera and bladderwrack in the beach wrack.*

OXYGEN DEFICIENCY: *Anoxic and hypoxic conditions can be severe for seagrass.*

The water temperature plays a central role among the environmental factors because it influences elementary physicochemical as well as biochemical metabolic processes. Water temperatures above 30°C exceed the physiological tolerance limits and represent an extraordinary burden for the bladderwrack and seaweed stocks in the Baltic Sea. In addition, high water temperatures increase the sensitivity to other stress factors. The plants react particularly sensitively at high water temperatures in the interaction of light deficiency, oxygen deficiency and toxic components.

Eutrophication is another important key factor that directly affects light conditions, oxygen content and concentrations of toxic substances in water. Eutrophication is one of the main threats to the bladderwrack and seagrass stocks in the Baltic Sea. Climate changes are expected to increase the negative effects of eutrophication. Strict nutrient reductions in the Baltic Sea catchment area could improve the water quality and thus the living conditions of bladderwrack and seagrass in the long term. Other parameters, such as salinity, eutrophication, changes in food web, are more or less influenced by climate change and are probably additional stress factors for seaweed and bladderwrack.

On the other hand, seagrass and bladderwrack from the Baltic Sea tolerate to some degree fluctuations of individual abiotic parameters and are considered relatively adaptable to changes in environmental conditions (Bobsien 2014). This makes it difficult to assess the impact of the climatic factors and their influence on beach wreck. With the several interrelations between the climatic parameters affecting seagrass and bladderwrack, it is however unclear, to what extent they are able to adapt to these changes.

Therefore, no future trends can be stated as to the extent to which changing climate parameters such as temperature rise or sea level rise will affect the beach wrack. Due to the manifold relationships between the parameters, a trend showing an increase in the amount of beach wrack under a changing climate as well as a decrease in the amount of beach wrack would be conceivable. Similarly, a change in the composition of the beach wrack is conceivable under a changing climate.

LITERATURE

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BACKGROUND INFORMATION

The projected climate changes presented in this Beach Wrack Fact Sheet are based on regional climate projections, which are taken from the GERICS Climate Fact Sheets (see Pfeifer et al. 2020)

Definitions of parameters

PARAMETER	Definition (based on GERICS Climate Fact Sheets)
Temperature	Defined as the temperature in 2 m height above surface.
Summer days	Number of days per year with daily maximum temperatures of at least 25 °C
Hot days	Number of days per year with daily maximum temperatures of at least 30 °C
Tropical nights	Number of days per year with daily minimum temperatures of at least 20 °C
Frost days	Number of days per year with daily minimum temperatures below 0 °C
Late frost days	Number of days per year with a daily minimum temperature lower than 0 °C from 1 April.
Ice days	Number of days per year with a daily maximum temperature lower than 0 °C.
Days above 5°C	Number of days per year with a daily average temperature above 5 °C
Maximum duration of heatwaves	Maximum duration [in days] of periods of consecutive days with a daily maximum temperature above 30 °C.
Precipitation	The absolute precipitation sum (rain and snow) in mm.
Dry days	Number of days per year with daily precipitation (rain and snow) lower than 1 mm
Precipitation over 20mm/day	Number of days per year with daily precipitation (rain and snow) higher than 20 mm
95th percentile of precipitation	Value of total daily precipitation that is exceeded on five percent of all wet days per year
99th percentile of precipitation	Value of total daily precipitation that is exceeded on one percent of all wet days per year
Climatic water balance	Difference between annual precipitation and annual evaporation in mm/day
Wind speed	Mean annual wind speed in m/s
Sultriness	Number of days per year with daily values of vapor pressure greater than 18.8 hPa. The vapor pressure is calculated based on daily values of the near-surface air temperature and the relative humidity using the Magnus Formula.

INNOVA BEACH WRACK FACT SHEET.

By Nico Stelljes (Ecologic Institute)
Additional input by Jo-Ting Huang-Lachmann, Louis Celliers, and Susanne Pfeifer (GERICS)

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