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A model approach to estimate the potential for mussel beds in a Wadden Sea area of the German North Sea coast

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In the awareness of the increasing conciousness regarding the sensitivity, vulnerability, and complexity of near coastal marine ecosystems, including tidal flats, it is imperative to improve the understanding of its individual elements. One of these elements are organisms habitating the seabed, such as mussels.
Bivalves - specifically blue mussels (Mytilus edulis) and pacific oysters (Magallana gigas) - besides other smaller organisms are an integral part of the seabed fauna. On the one hand they serve as a basic food resource for a large number of higher trophic level predator. On the other hand they affect the surface structure, stability and composition of the seabed.
To better understand the large fluctuations the mussel stocks underwent during the last decades, it is
of great benefit to know the environmental conditions of their habitats. Based on the analysis of different physical parameters at known mussel beds, prototypical automated algorithms were developed and used to identify other tidal flat regions with favorable conditions for epibenthic mussels. The input parameters originate from different morphological, hydrodynamical, sedimentological and hydrochemical numerical models. Morphological factors include morphological activity and gradient conditions of the ground surface, hydrodynamical factors include stream velocities, bottom shear stress, wave orbital velocities, energy of wave breaking and
duration of tidal flats falling dry during low tide, sedimentological factors include sediment composition and hydrochemical factors include salinity. These parameters were available as products of the mFUND project EasyGSH-DB and were supplemented with additional evaluations. It is expected that the approach of habitat modeling will allow to determine the possibility of initial and long-term settlements of epibenthic mussels by ruling out intertidal or subtidal seabed areas where environmental parameter combinations do not fulfill the necessary requirements.

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Session GM6.1
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A model approach to estimate the potential for mussel beds in a Wadden Sea area of the German North Sea coast

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blue mussel bed

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Abstract / Introduction

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In the awareness of the increasing conciousness regarding the sensitivity, vulnerability, and complexity of near coastal marine ecosystems, including tidal flats, it is imperative to improve the understanding of its individual elements. One of these elements are organisms habitating the seabed, such as mussels. Bivalves - specifically blue mussels (Mytilus edulis) and pacific oysters (Magallana gigas) - besides other smaller organisms are an integral part of the seabed fauna. On the one hand they serve as a basic food resource for a large number of higher trophic level predator. On the other hand they affect the surface structure, stability and composition of the seabed as well as stream conditions and properties, as they are also investigated in the KFKI project "Biva-Watt". To better understand the large fluctuations the mussel stocks underwent during the last decades, it is of great benefit to know the environmental conditions of their habitats.

Abstract / Introduction

Based on the analysis of different physical parameters at known mussel beds, prototypical automated algorithms were developed and used to identify other tidal flat regions with favorable conditions for epibenthic mussels. The input parameters originate from different morphological, hydrodynamical, sedimentological and hydrochemical numerical models. Morphological factors include morphological activity and gradient conditions of the ground surface, hydrodynamical factors include stream velocities, bottom shear stress, wave orbital velocities, energy of wave breaking and duration of tidal flats falling dry during low tide, sedimentological factors include sediment composition and hydrochemical factors include salinity. These parameters were available as products of the mFUND project EasyGSH-DB and were supplemented with additional evaluations. It is expected that the approach of habitat modeling will allow to determine the possibility of initial and long-term settlements of epibenthic mussels by ruling out intertidal or subtidal seabed areas where environmental parameter combinations do not fulfill the necessary requirements.

Introduction

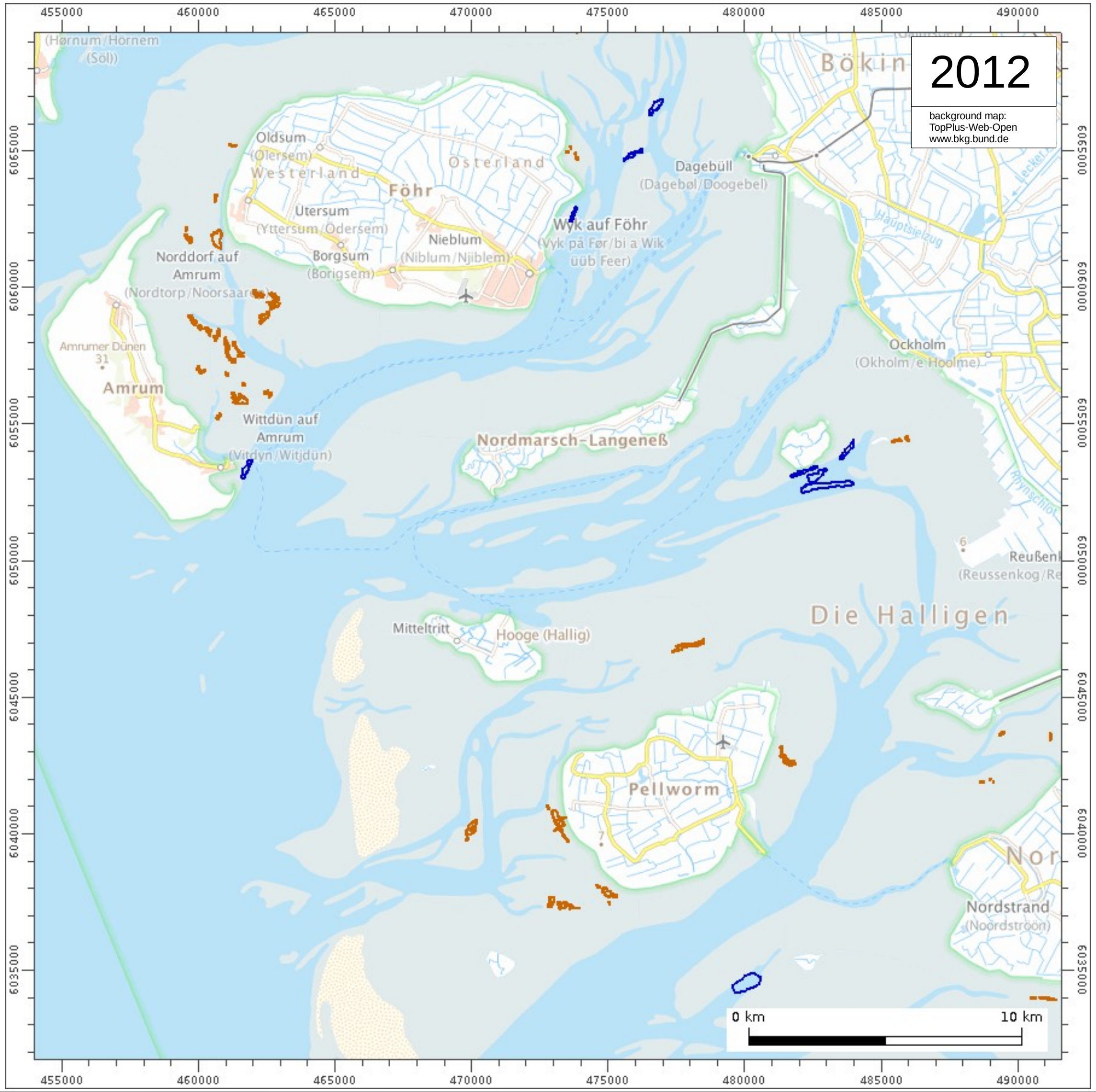
The following slides focus on the identification of blue mussel beds and oyster reefs in laser scan data in the Schleswig-Holstein Wadden Sea in the North of Germany. Furthermore, the analysis of typical environmental conditions, which can be determined for known and observed mussel communities on the basis of the different products of EasyGSH-DB, are examined. In cooperation with the "Forschungs- und Technologiezentrum Westküste" (FZK) in Büsum the collected environmental factors will subsequently be used as a framework for the preparation of a potential map for mussel settlements.

Analysis objectives and data basis

The most comprehensive data basis for the analysis of known eu- (polygons from the "Nationalparkverwaltung im Landesbetrieb für Küstenschutz, Nationalpark und Meeresschutz Schleswig-Holstein" - LKN-SH) and sublittoral (polygons from the "FZK") mussel communities is provided by the year 2012. The following slides classify the above mentioned mussel areas in their geographical and morphological context in the Schleswig-Holstein Wadden Sea.

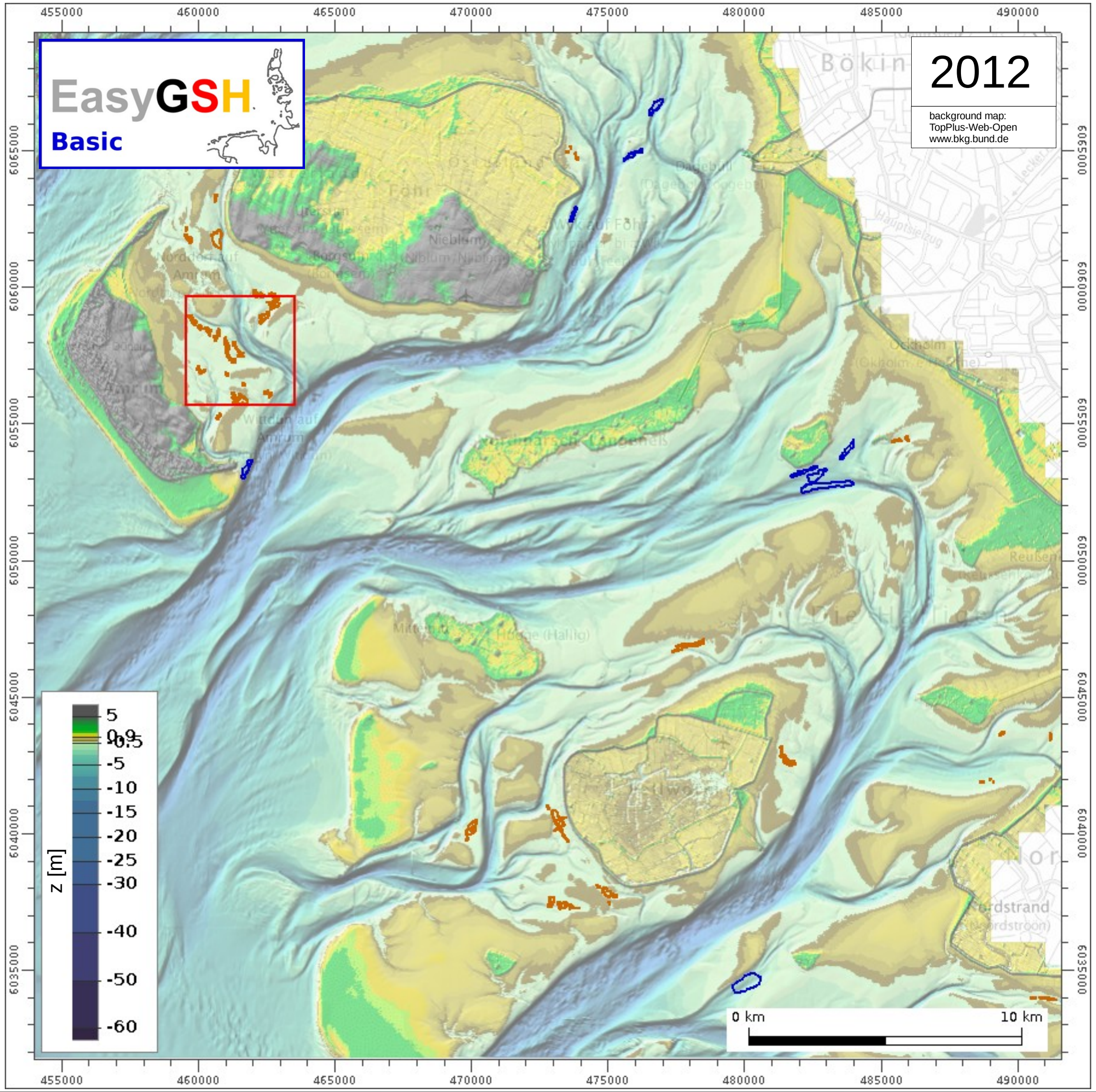
The reference to laser scan data of the LKN-SH from 2014 and to height variance calculations based on these data allow the identification of areas of mussel colonization by means of surface structures that differ from their surroundings. This can be used for validation of mapped mussel areas as well as an alternative to common mapping methods.

Mapped mussel populations near „Föhr“ (2012)



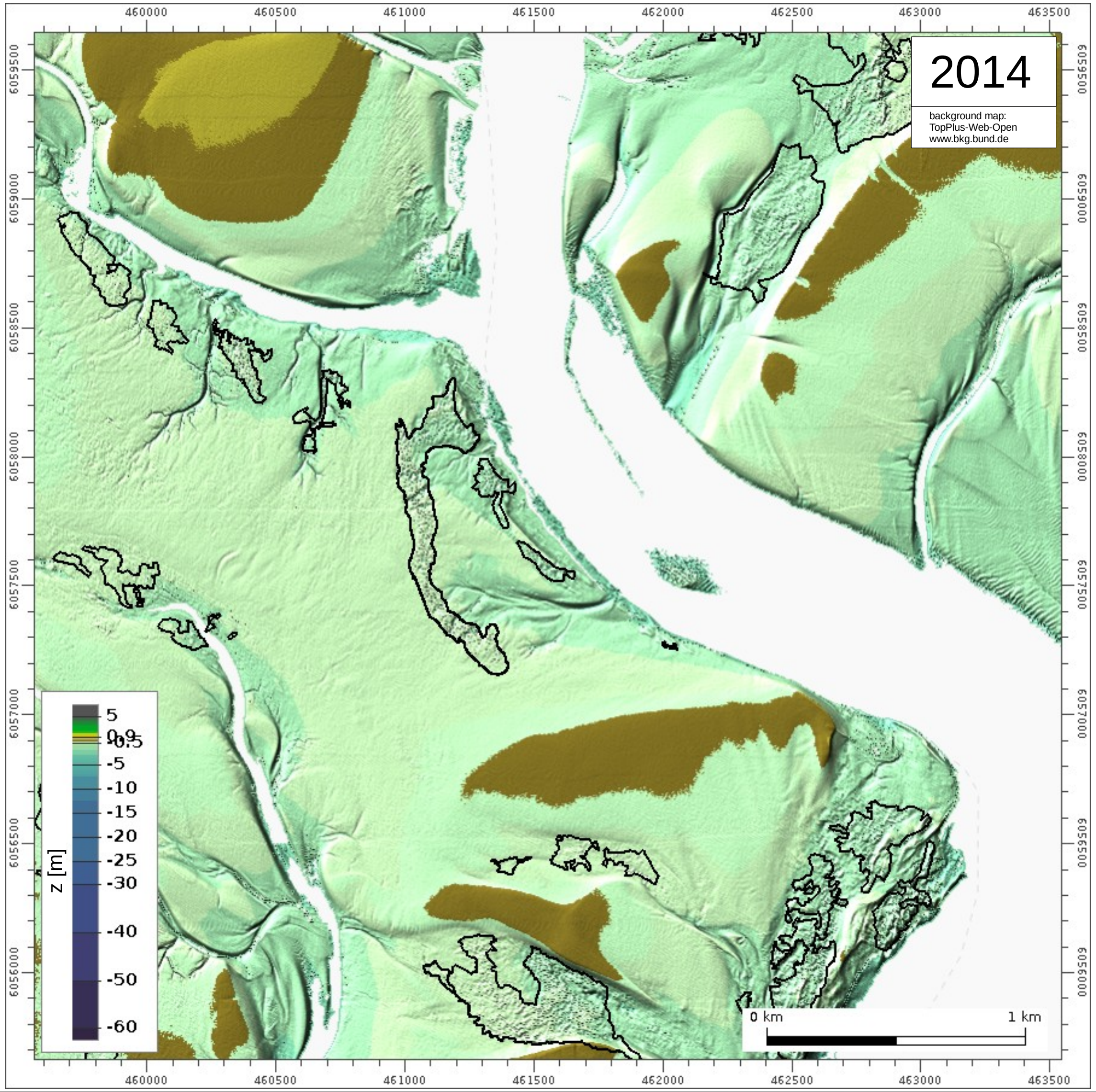
known / observed eu- (brown - LKN-SH) and sublittoral (blue - FZK) mussel occurrences in the Schleswig-Holstein Wadden Sea

Bathymetry (2012)



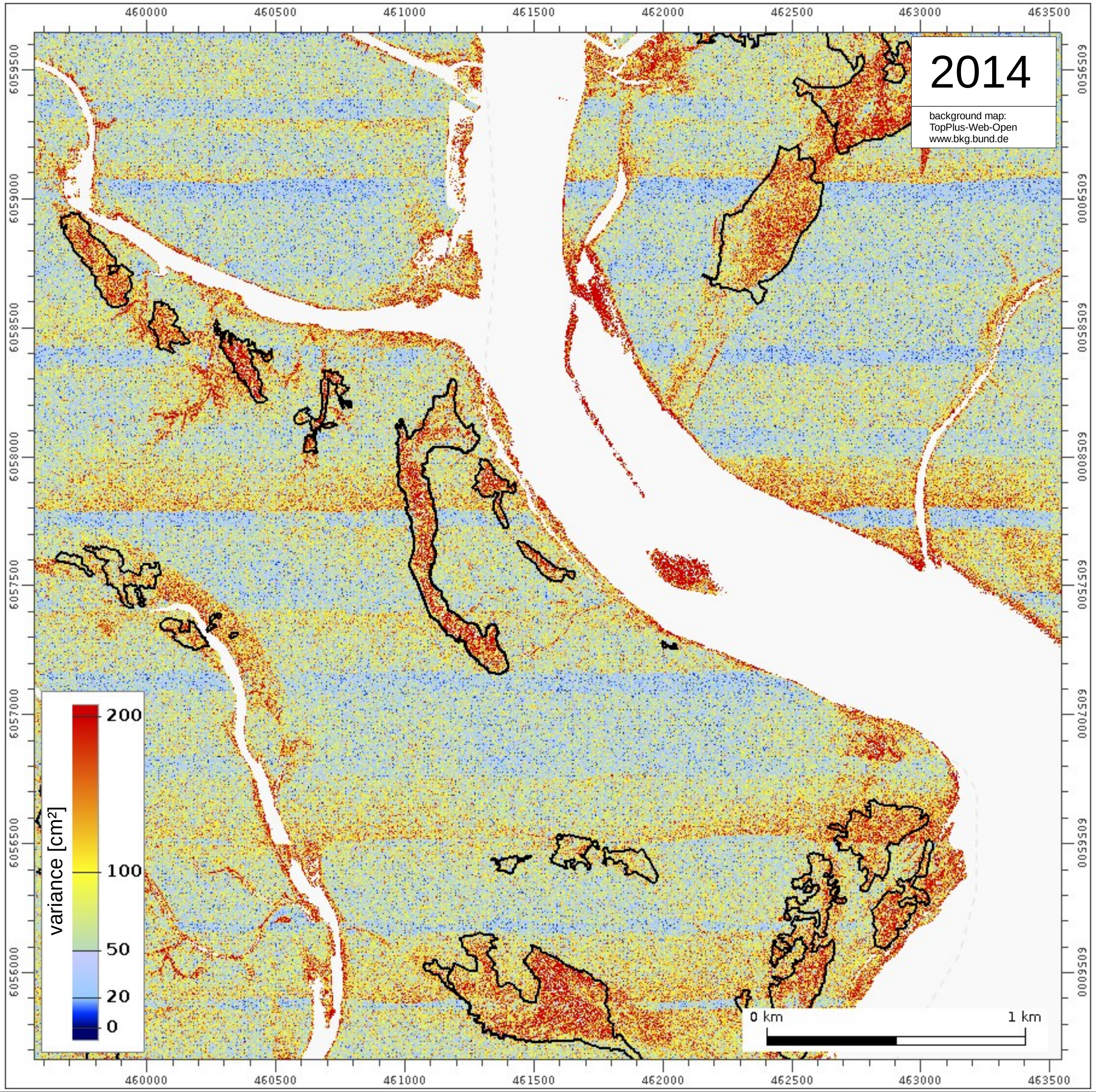
annual bathymetric depth distributions on basis of the Functional Seabed Model (FSM) - developed by smile consult GmbH - provide information on the morphological background in which shellfish occur

Mussel bed identification in ALS data (2014)



mussel beds of 2014 (LKN-SH) identifiable in data of the laser scan flight of the LKN-SH of 2014

Mussel bed identification in ALS data (2014)



mussel beds of 2014 (LKN-SH) identifiable in data of the laser scan flight of the LKN-SH of 2014

variance of z-values gives information about possible mussel bed areas

Environmental parameters and data basis

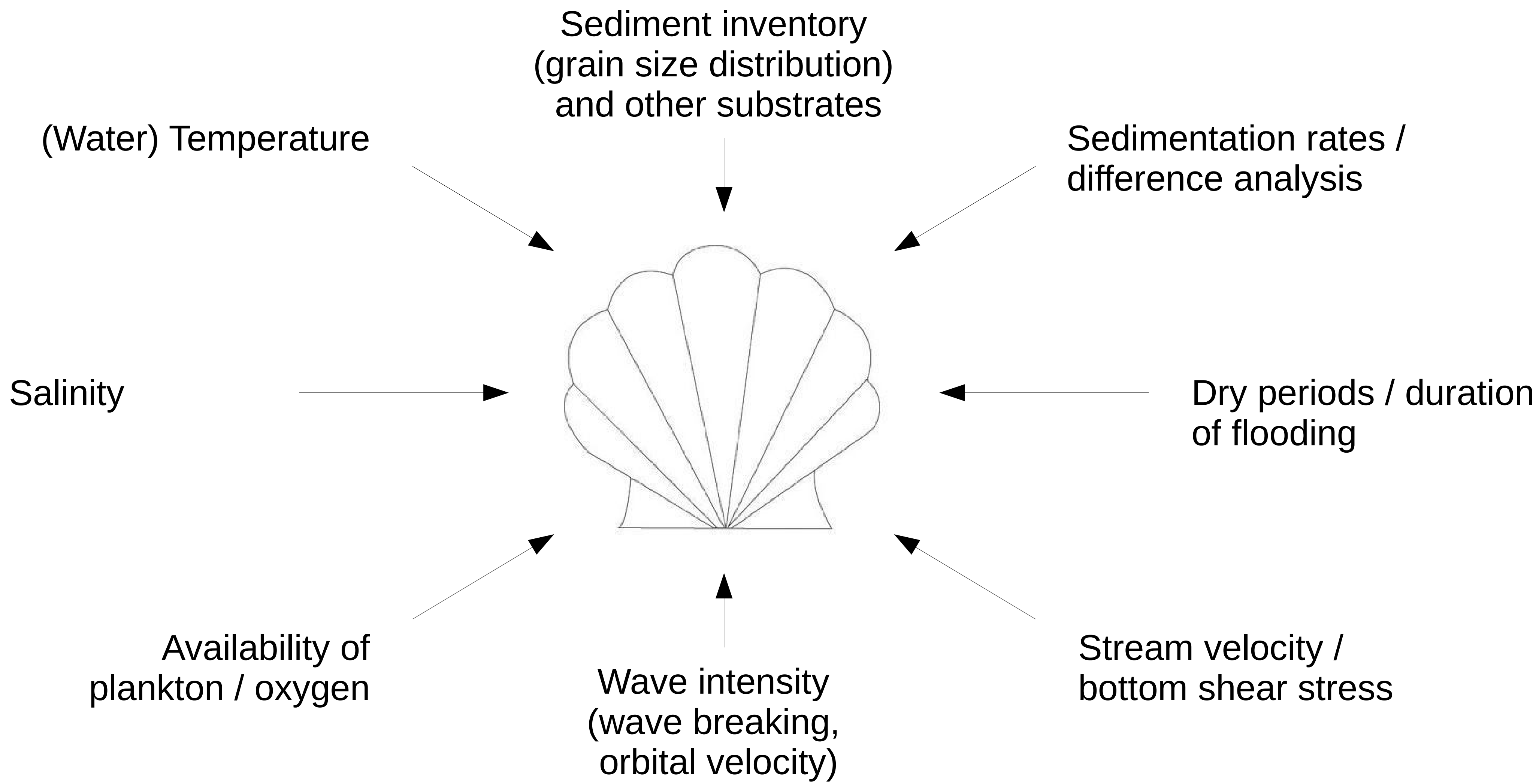
Both the establishment and the survival of mussels is linked to a number of influencing factors, so-called environmental parameters, which prevent the survival of bivalves outside certain limits, while within these limits they favour a habitat. Despite their importance literature contains only vague to no numerical values regarding possible influencing environmental parameters, especially concerning their magnitude.

The following slides therefore illustrate how such environmental parameters are derived for known mussel communities on the basis of the wide range of products from the EasyGSH-DB project. For this purpose, all existing mussel areas are examined for a minimum and maximum value as well as a median value for each influencing factor and thus value ranges are defined which allow for mussel existences. All limiting factors are shown in bold type below.

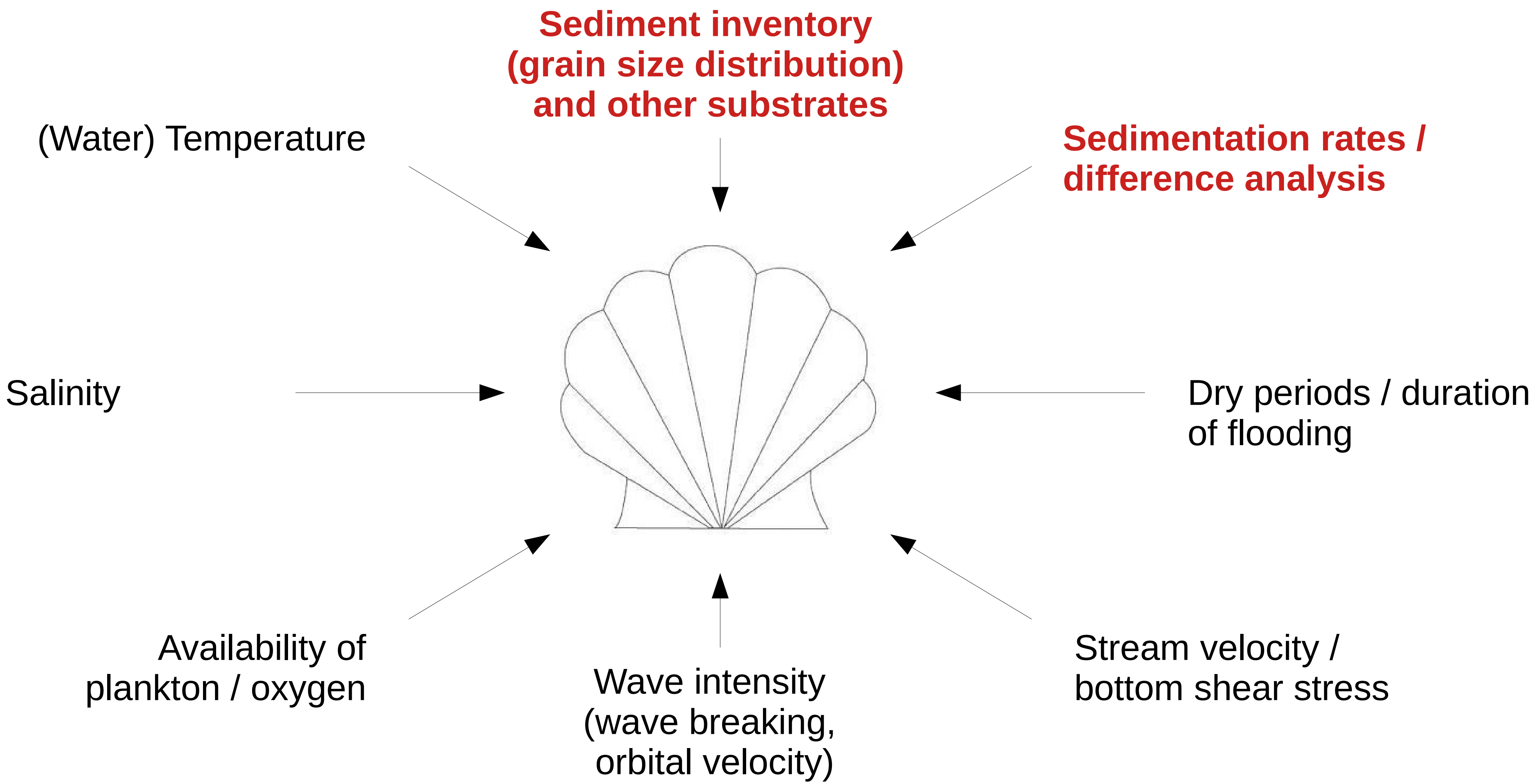
Environmental parameters and data basis

As an example, for duration of flooding the analysis show that mussels must be flooded for at least 314 of a total of 745 minutes per tide to ensure their survival. In addition, the product range also provides analysis possibilities with regard to sediment composition and grain size distribution (see Sievers et al., 2020) erosion and sedimentation rates, flow velocities and bottom shear stresses, as well as salinity. In addition, calculations of wave orbital velocities and wave intensities from Marina - a model system for the simulation of hydro- and morphodynamics in rivers, lakes, estuaries and coastal areas - are used for analysis.

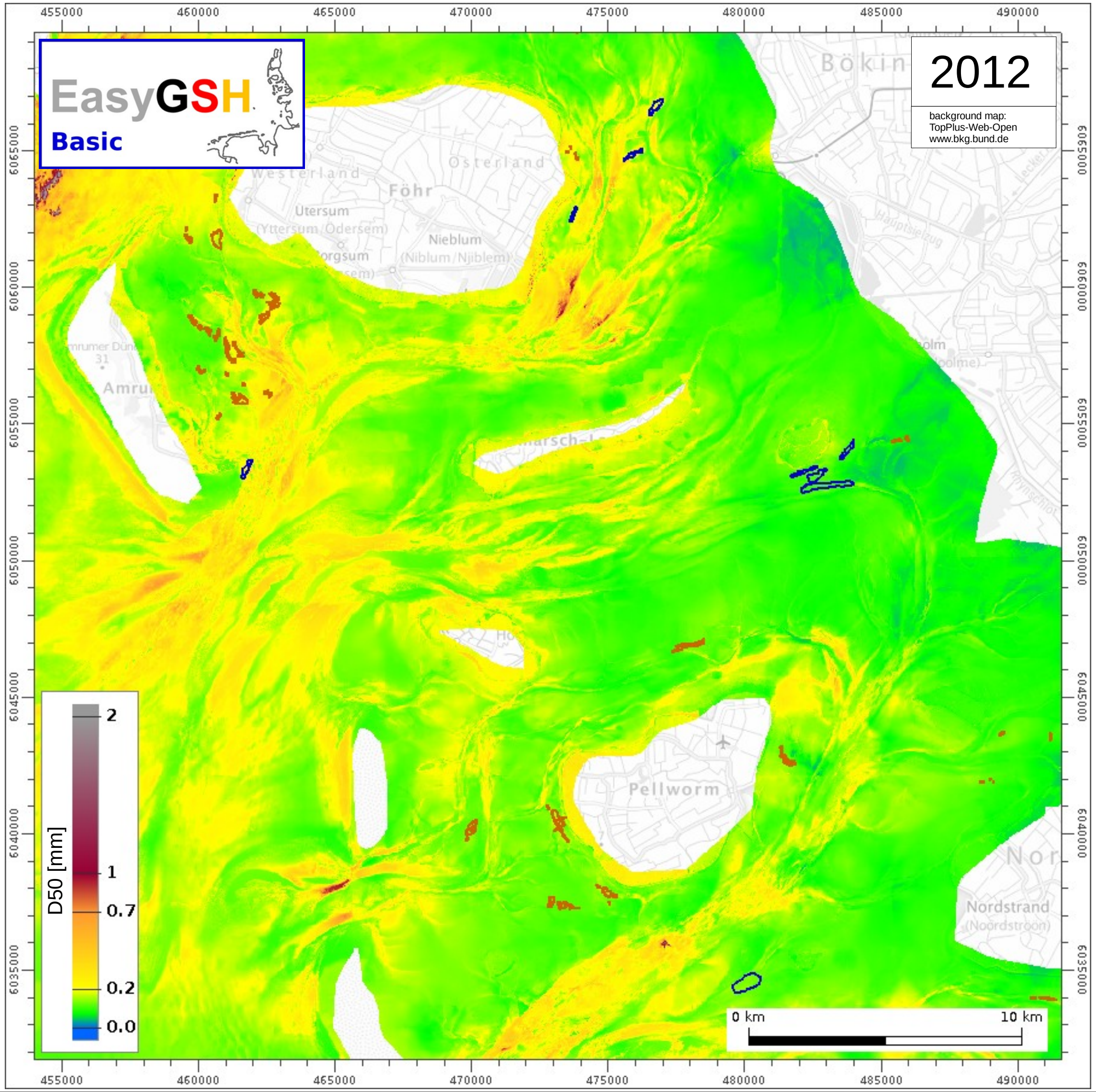
Parameters influencing mussel settlement / growth



Parameters influencing mussel settlement / growth



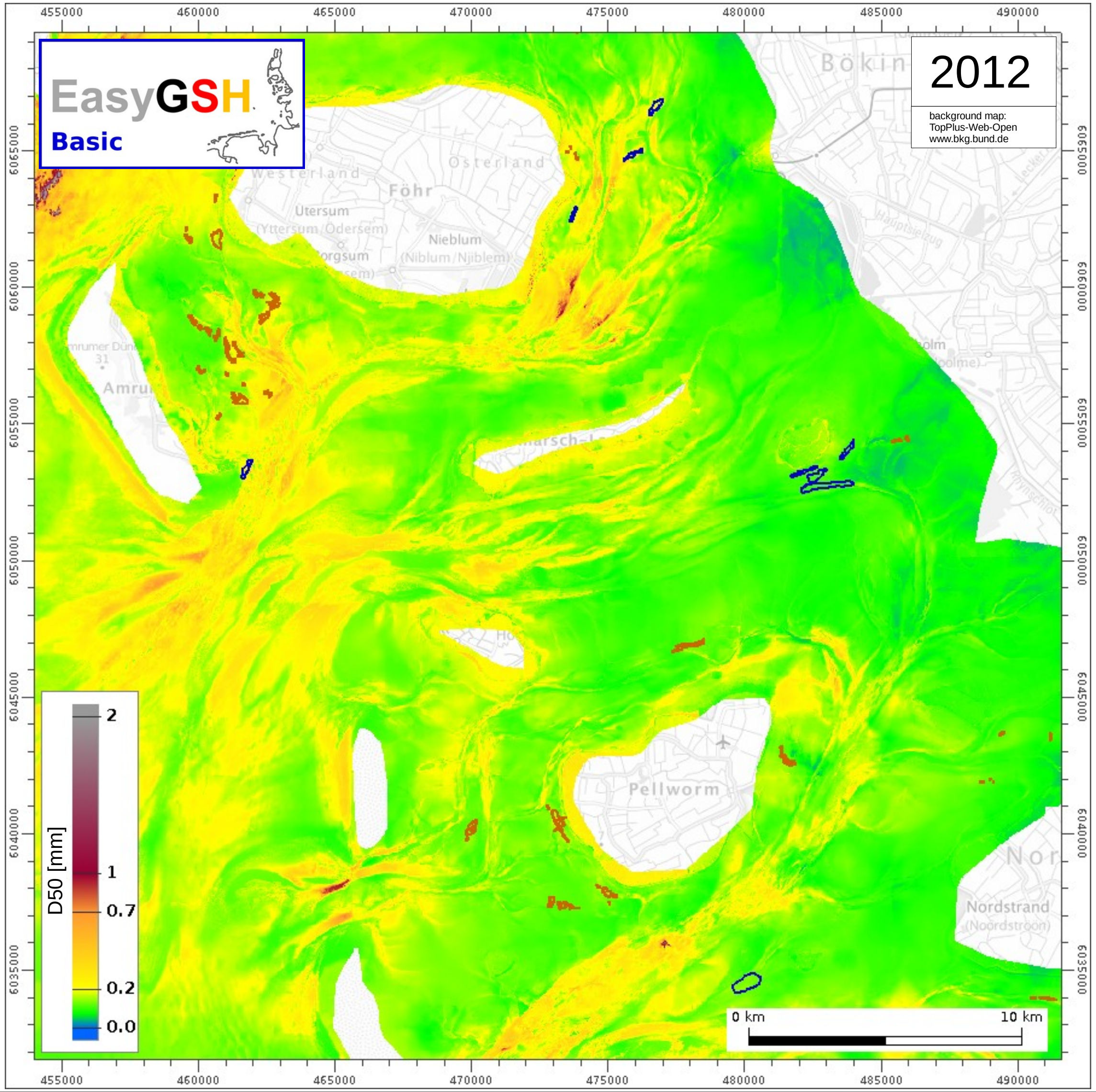
Sediment distribution / sediment inventory



D50 (median grain size)

→ extremely fine sediments reduce clinging / anchoring / stability of the mussels

Sediment distribution / sediment inventory



In areas of known mussel occurences minimum and maximum values for D50 were determined:

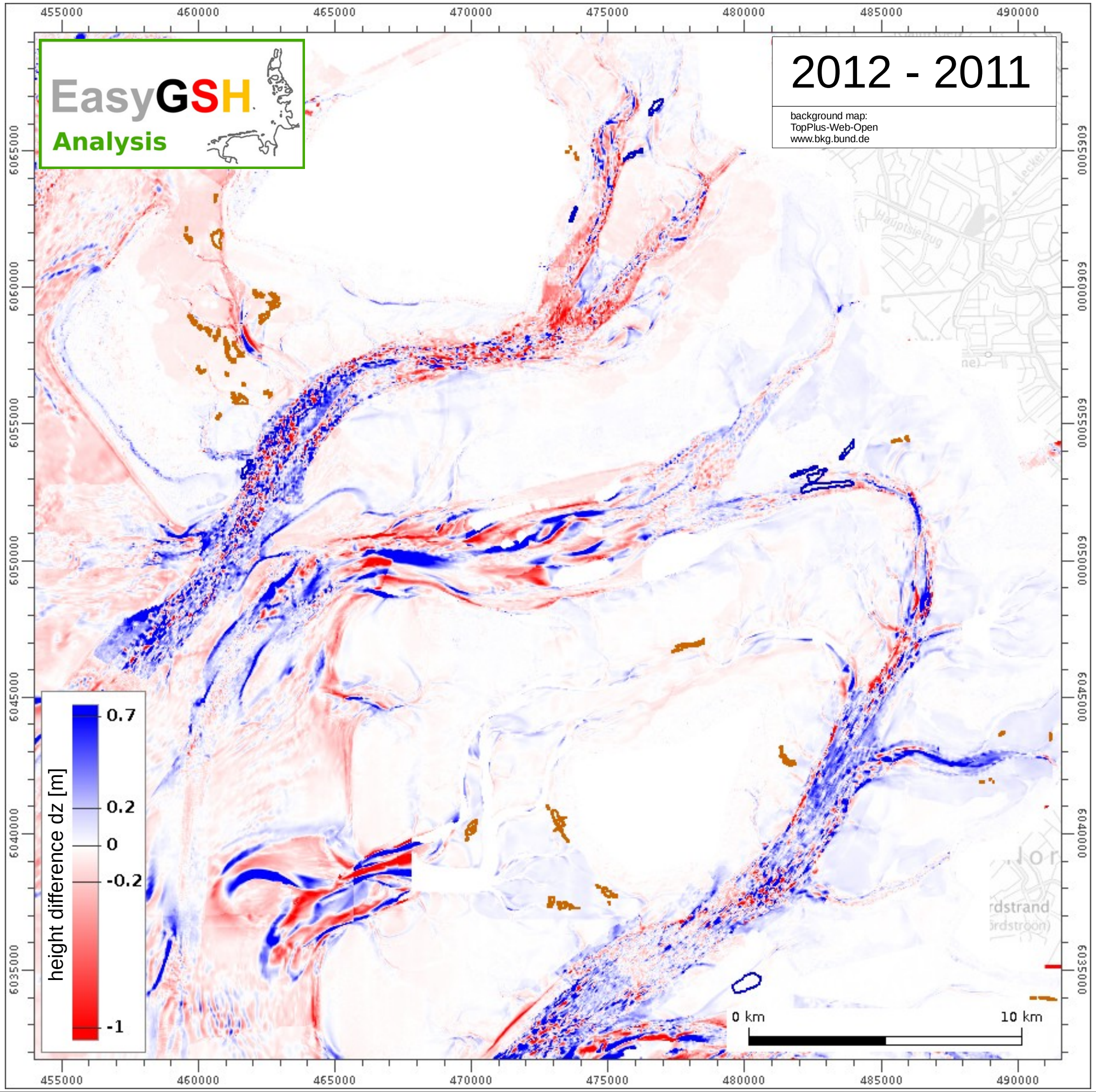
Eulittoral mussel occurences:

Min. 0.079 mm (fine sand)
Median 0.175 mm (fine sand)
Max. 0.652 mm (coarse sand)

Sublittoral mussel occurences:

Min. 0.104 mm (fine sand)
Median 0.166 mm (fine sand)
Max. 0.377 mm (medium sand)

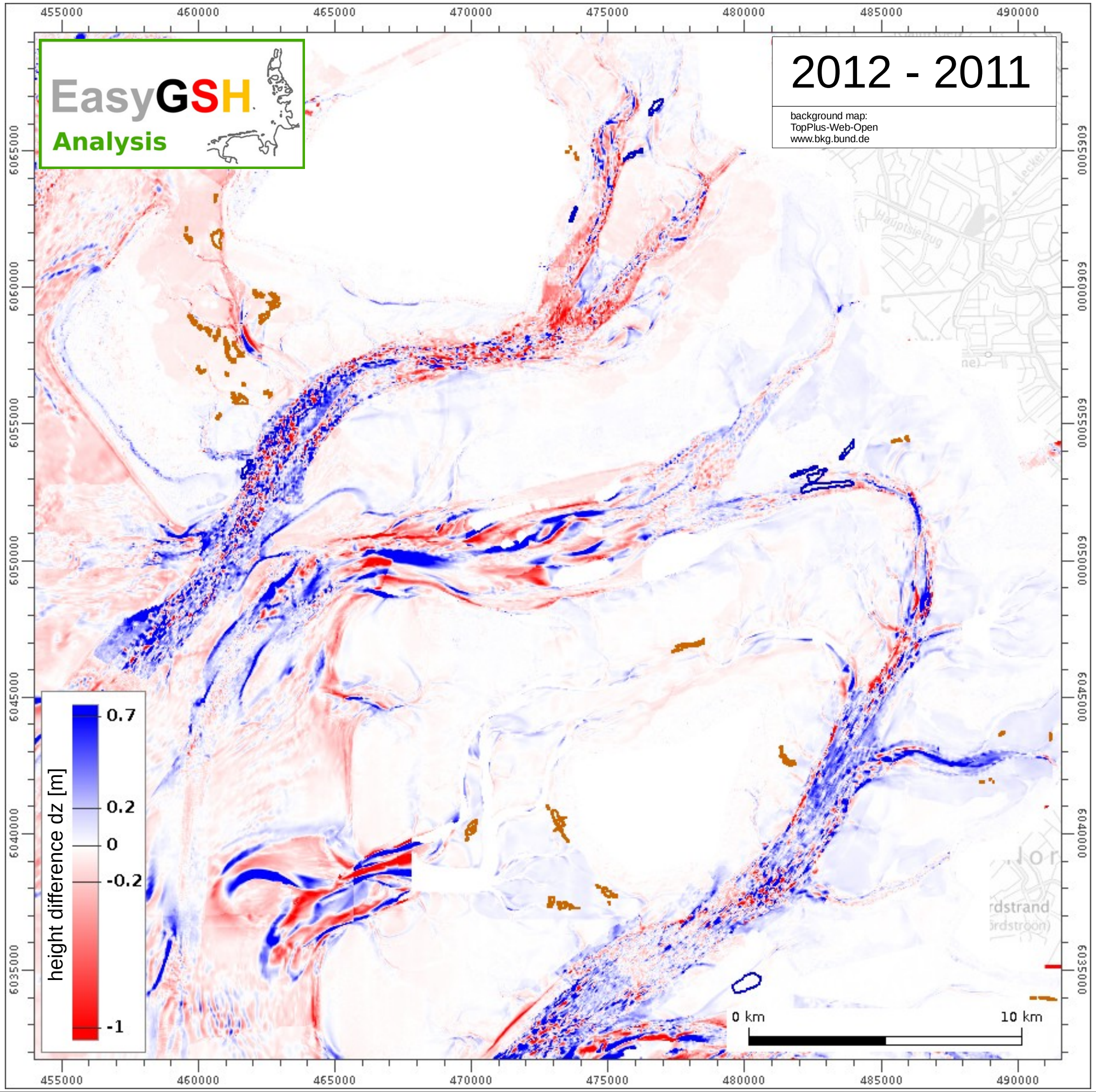
Sediment distribution / sediment inventory



Erosion / sedimentation rates

→ cover mussels with sediment or erosion of existing shellfish communities and / or their settlement substrate

Sediment distribution / sediment inventory



In areas of known mussel occurences maximum values for sedimentation and erosion rates were determined:

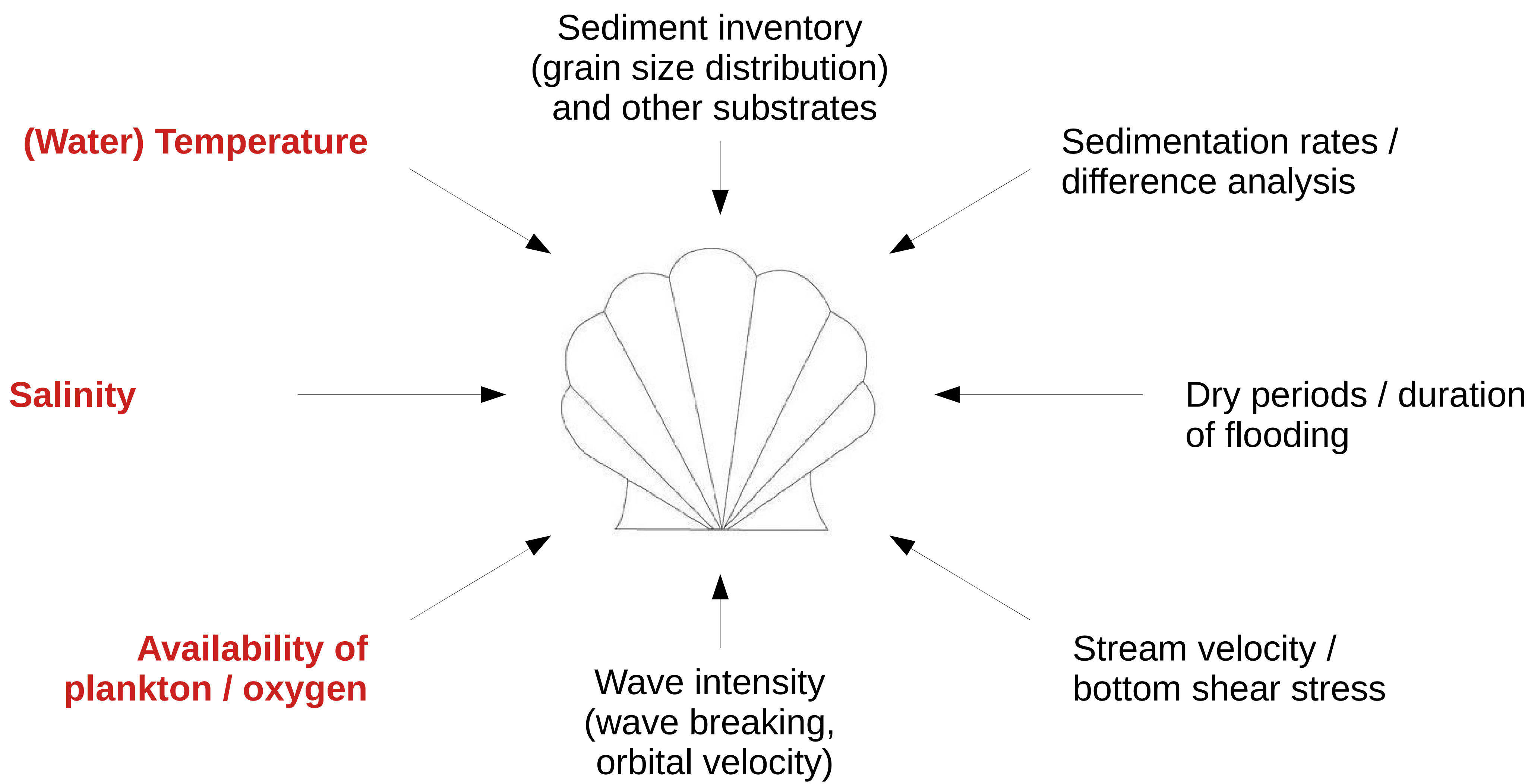
<u>Eulittoral mussel occurences:</u>

Min. erosion rate: -0.2 m / year
Max. sedimentation rate: 0.7 m / year

<u>Sublittoral mussel occurences:</u>

Min. erosion rate: -0.2 m / year
Max. sedimentation rate: 0.6 m / year

Influencing factors mussel settlement / growth



Temperature, salinity, availability of oxygen / plankton

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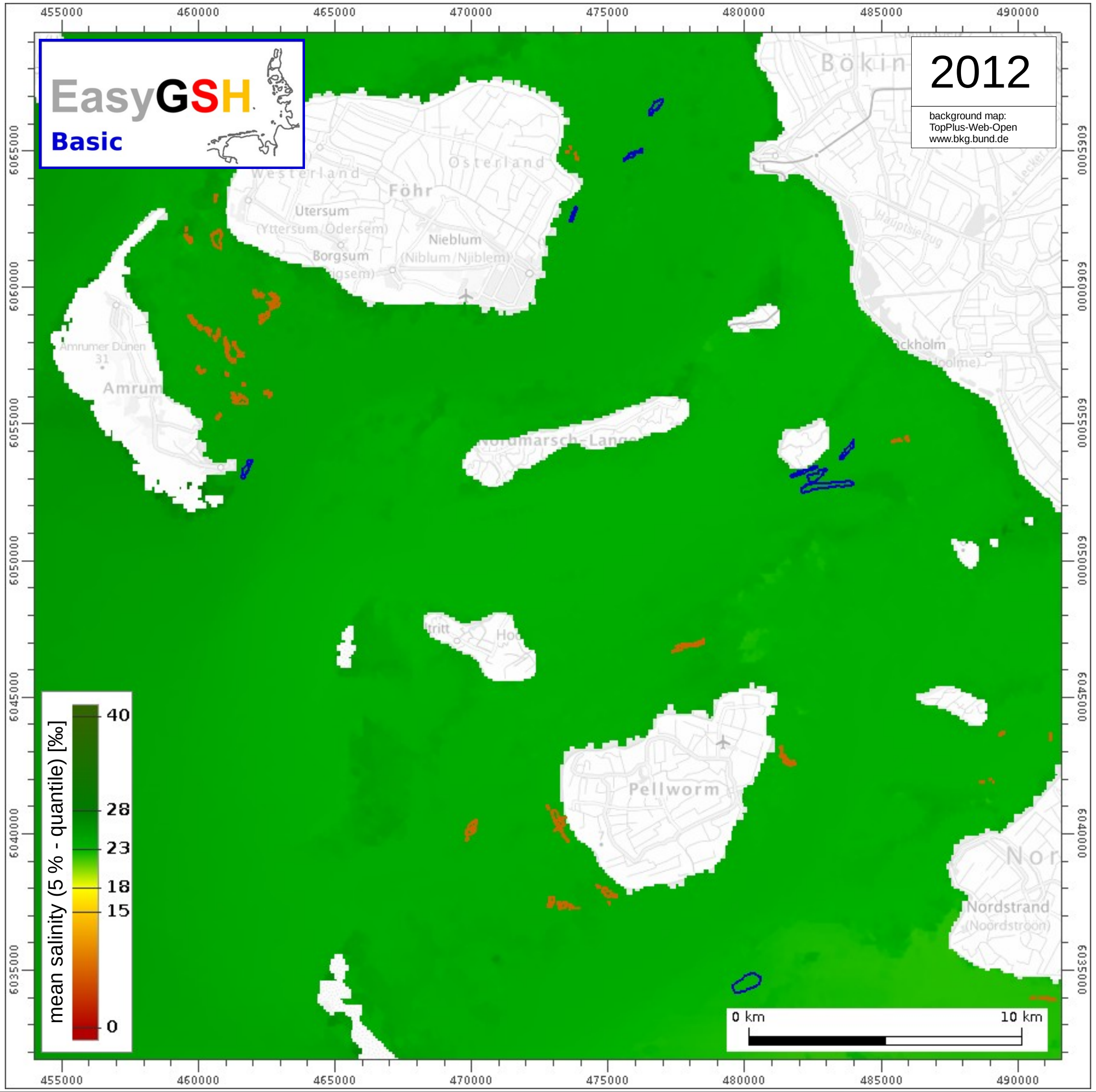
Species / Parameter	Blue mussel (Mytilus edulis)	Pacific oyster (Magallana Gigas)
(Water-) Temperature	• in summer water temperatures of min. 4 °C are necessary • at water temperatures >18 °C the strength of the byssus threads decreases	• very temperature tolerant (-2 °C - 35 °C) • spat only at temperatures between 17 °C and 28 °C (optimum 19 °C - 23 °C)
Salinity	• prefer 18 - 40 ‰ • at less than 15 ‰ slower growth and thinner shells (more vulnerable to predators)	• preferably between 20 and 35 ‰, spatting ideally between 23 and 28 ‰ • salinities of 18 ‰ already result in a 98 % mortality of sexual products
Availability of oxygen / plankton	• sufficient oxygen and plankton are available down to depths of 10 m	• sufficient oxygen and plankton are available down to depths of 40 m

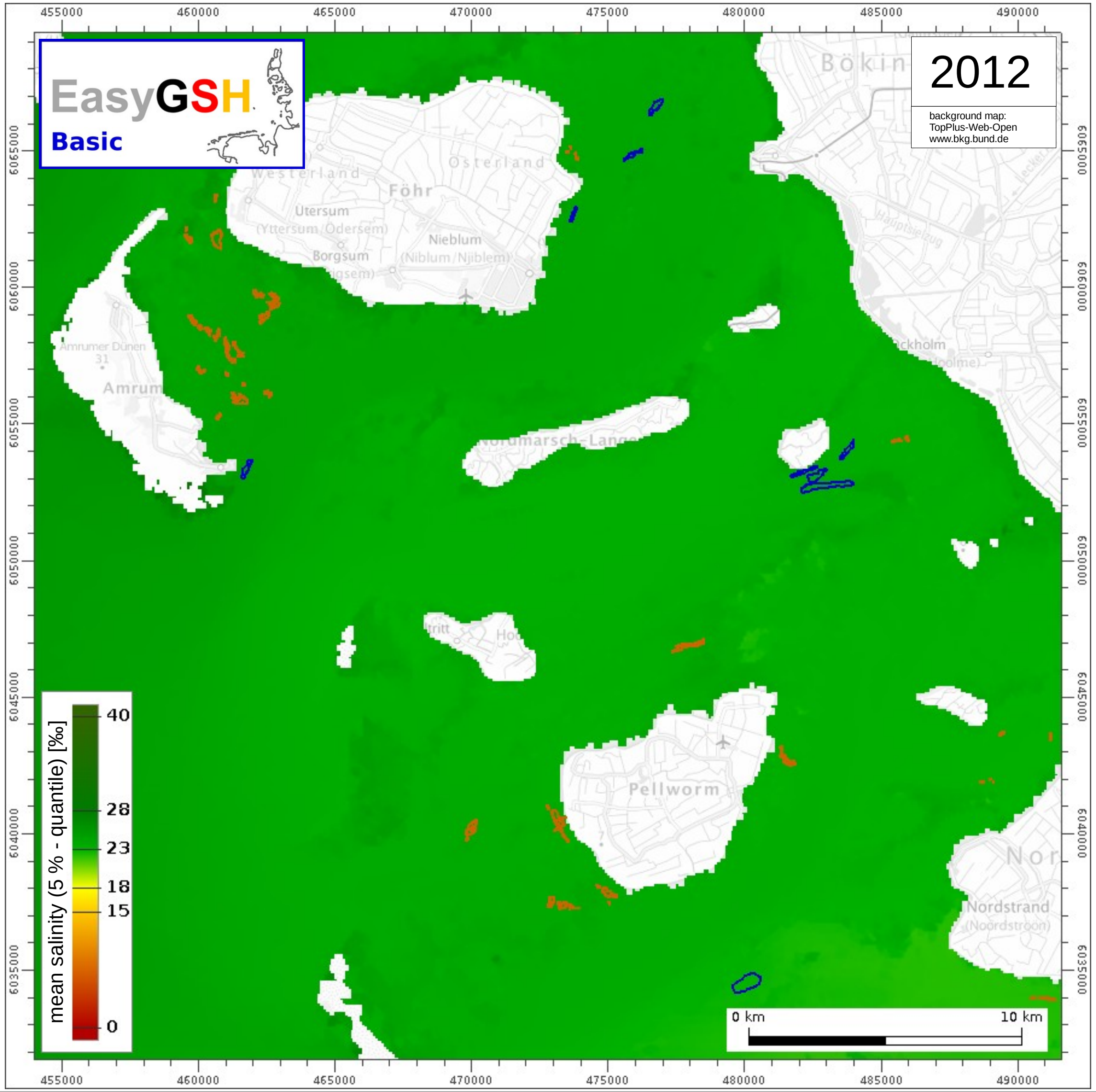
Average salinity per tide



Salinity:

→ low salinities cause slower growth and reduced shell thickness (increased vulnerability to predators), as well as a high mortality rate of larvae

Average salinity per tide



In areas of known mussel occurences mean values for salinity (5 % - quantile) were determined:

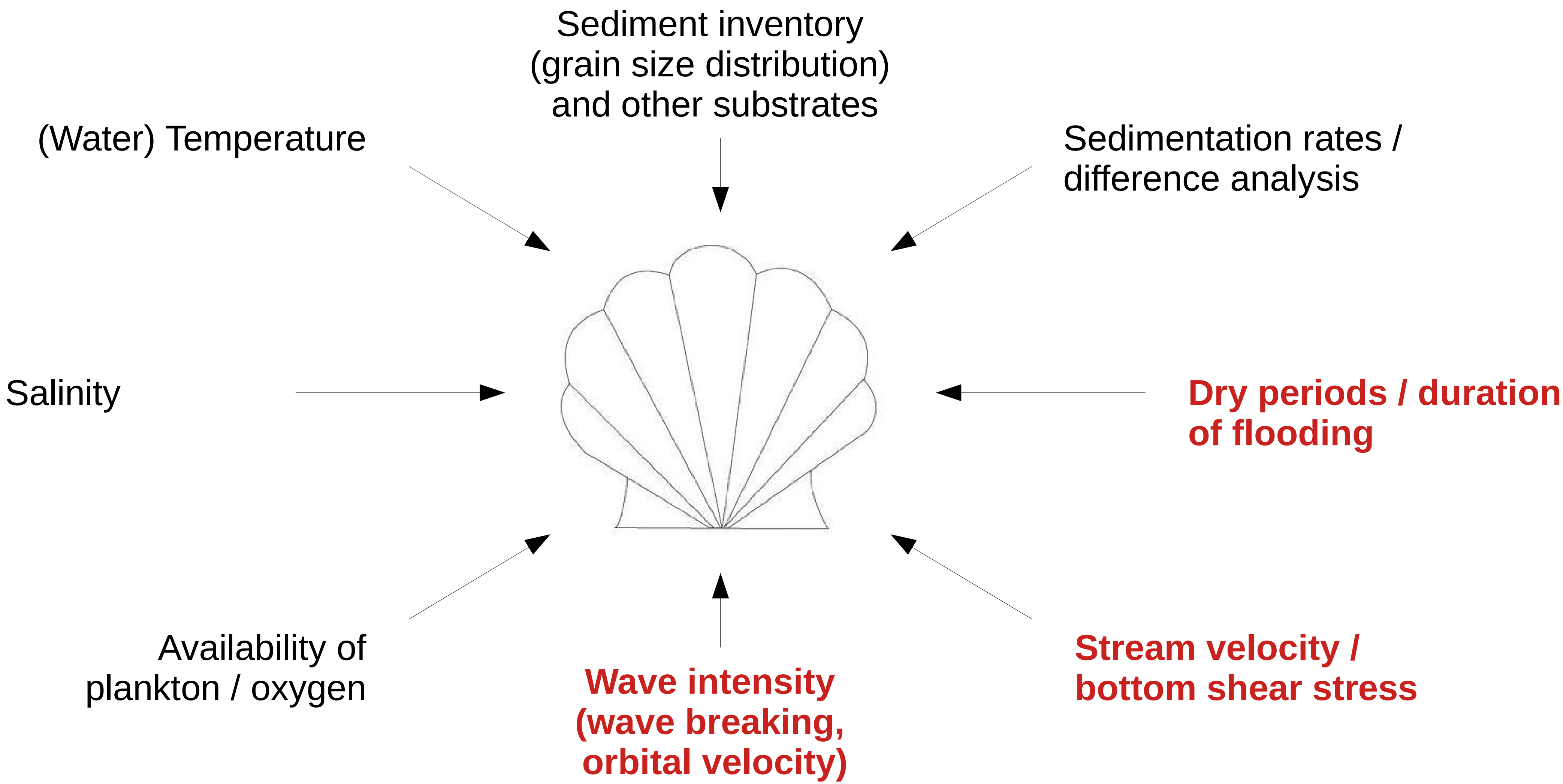
Eulittoral mussel occurences:

Min. 18.676 ‰
Median 24.379 ‰

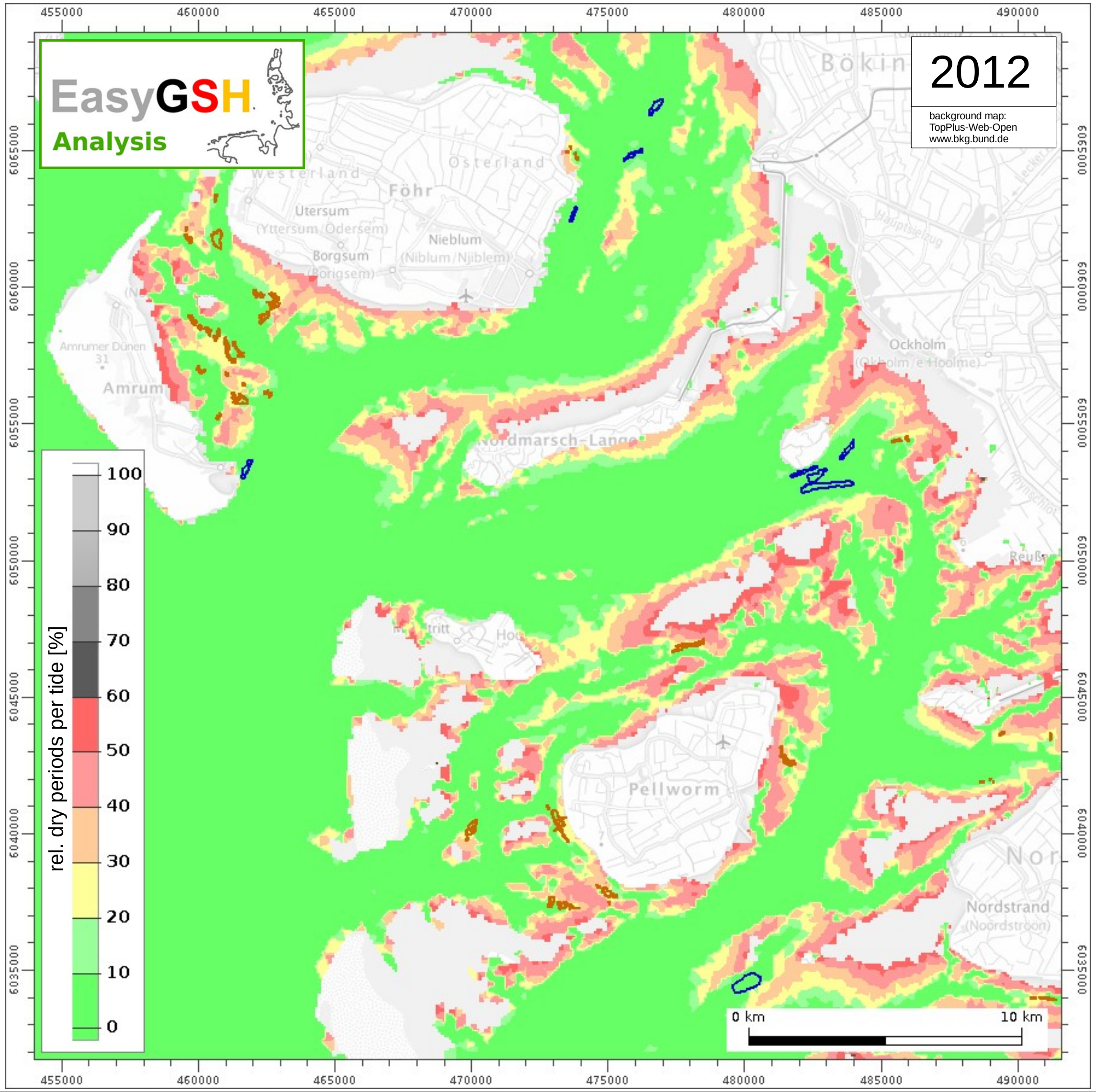
Sublittoral mussel occurences:

Min. 22.863 ‰
Median 23.598 ‰

Parameters influencing mussel settlement / growth



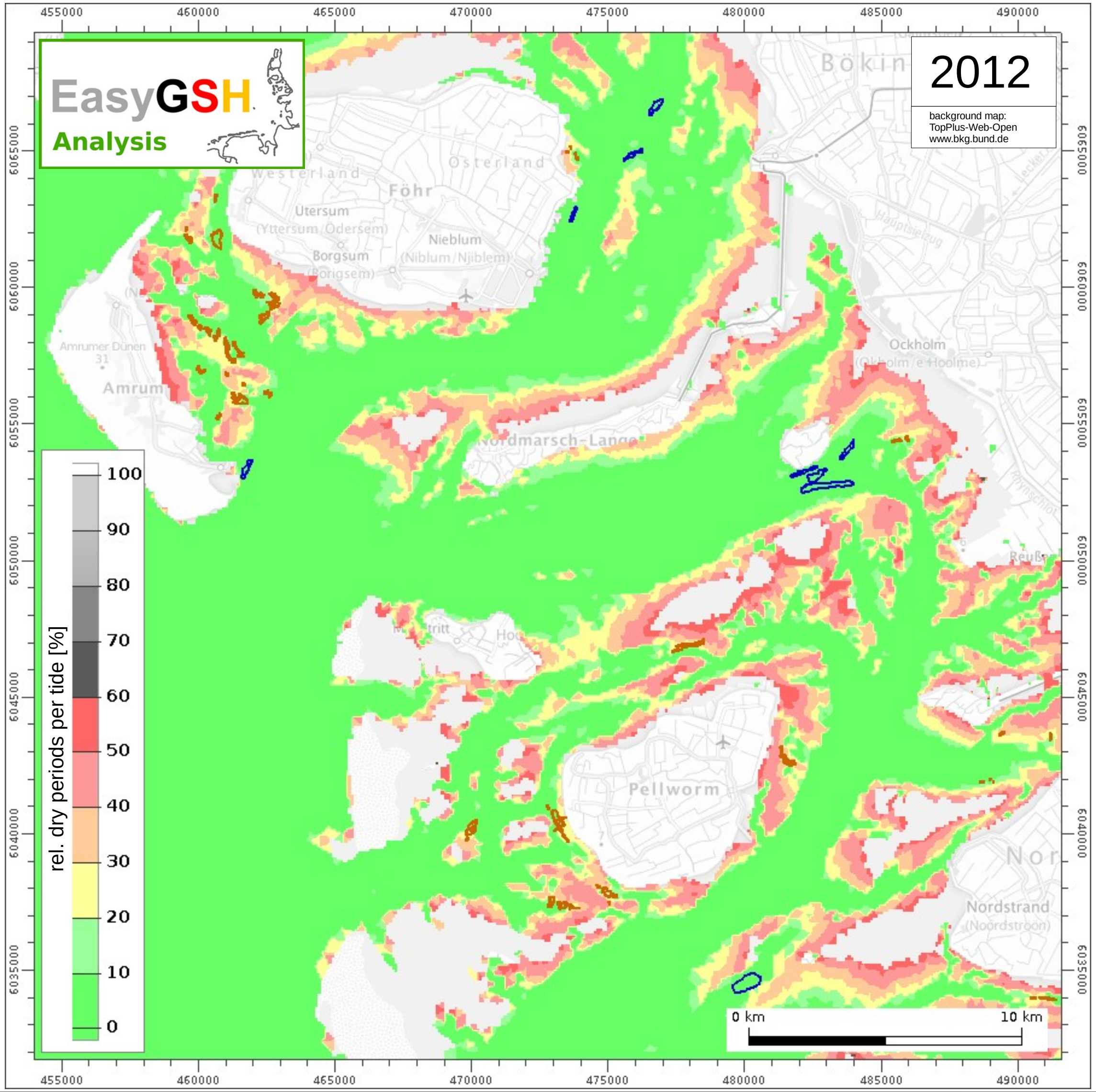
Dry periods per tide



Dry periods per Tide:

→ vulnerability to predators, in cold months planing due to ice floes

Dry periods per tide



In areas of known mussel occurences mean values for dry periods were determined:

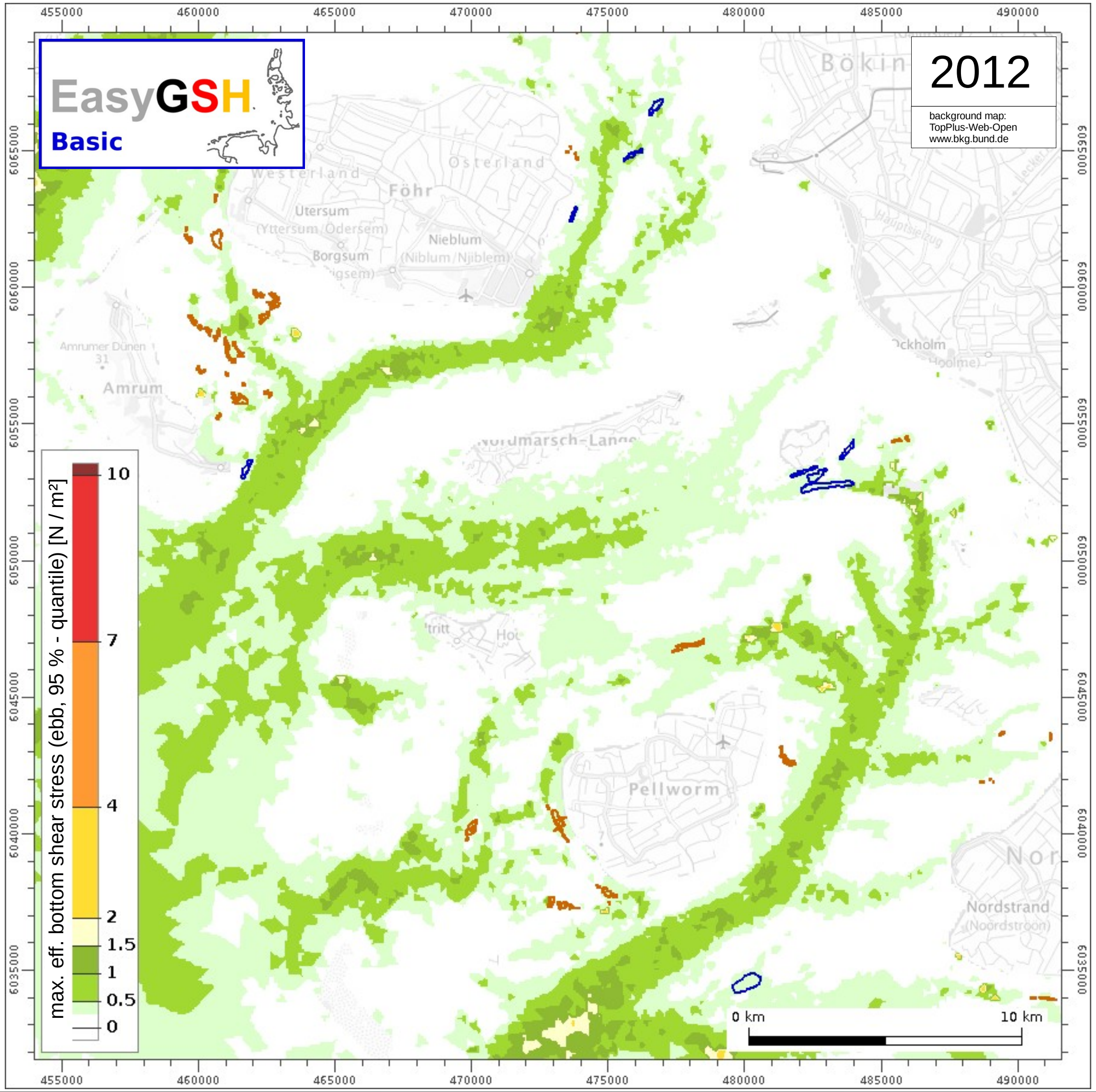
Eulittoral mussel occurences:

Median 14.163 %
Max. 42.210 %

Sublittoral mussel occurences:

Median 0.00 %
Max. 0.00 %

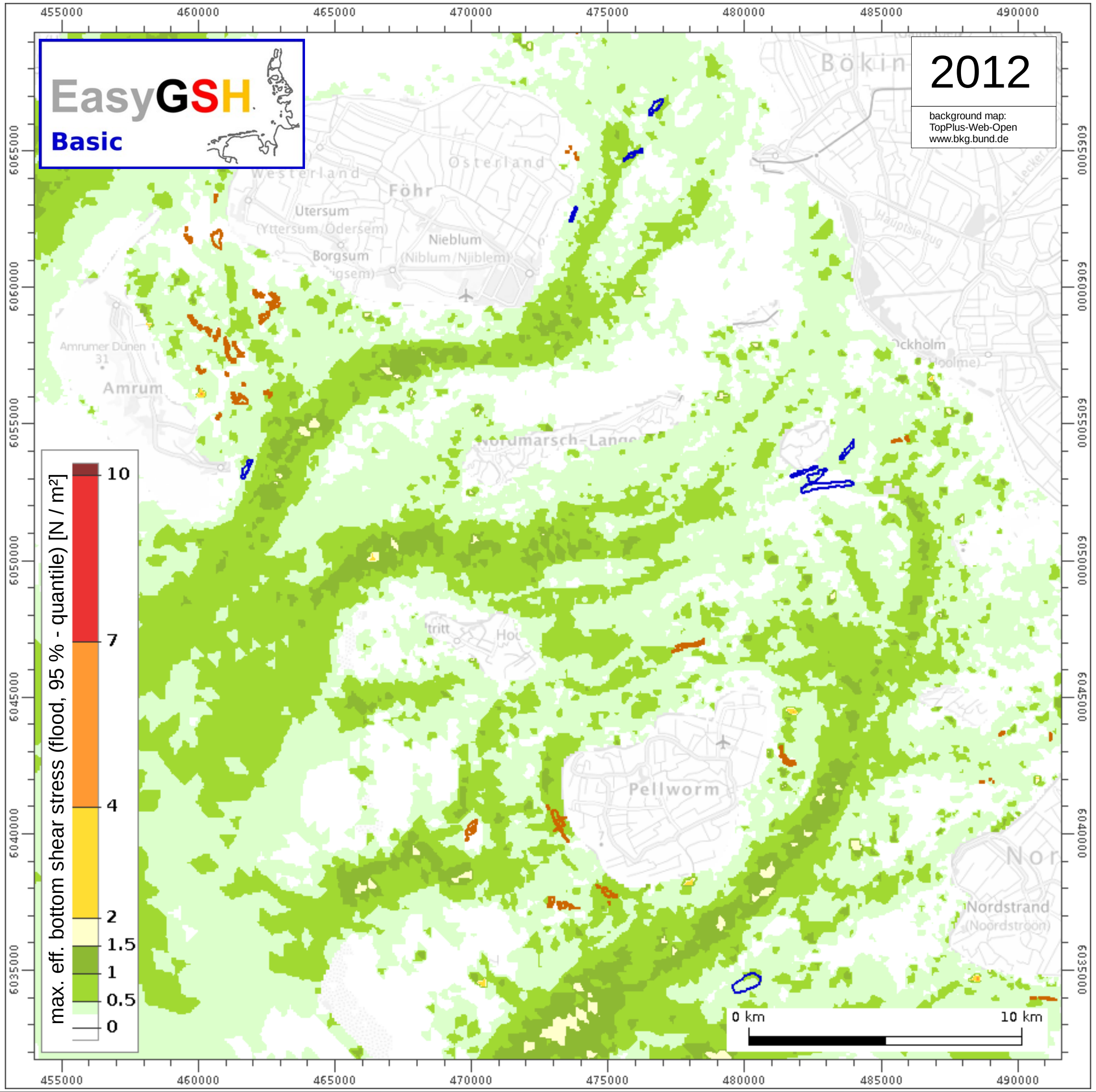
Bottom shear stresses



Maximum effective bottom shear stress (95 % - quantile):

→ excessive shear stresses prevent new settlement or erode existing shellfish stocks or their sediment base
→ periods of low shear stresses favour settling (established mussel deposits more resistant to higher stresses)
→ shear stresses indicate streams and stream velocities, which are an integral part of food and oxygen supply

Bottom shear stresses



In areas of known mussel occurences maximum values for effective bottom shear stress were determined:

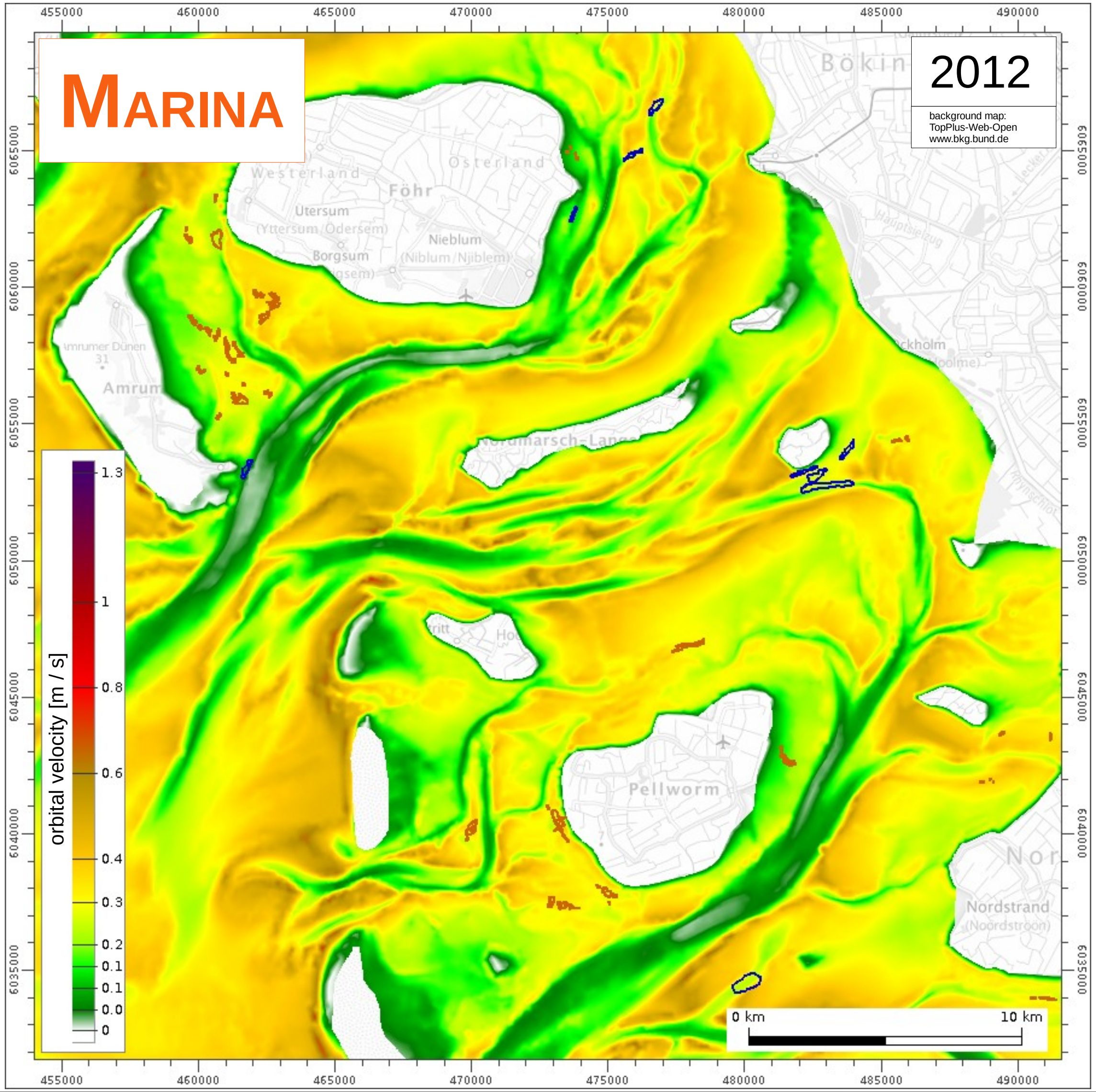
Eulittoral mussel occurences:

Min. 0.026 N / m²
Median 0.213 N / m²
Max. 1.309 N / m²

Sublittoral mussel occurences:

Min. 0.123 N / m²
Median 0.355 N / m²
Max. 0.794 N / m²

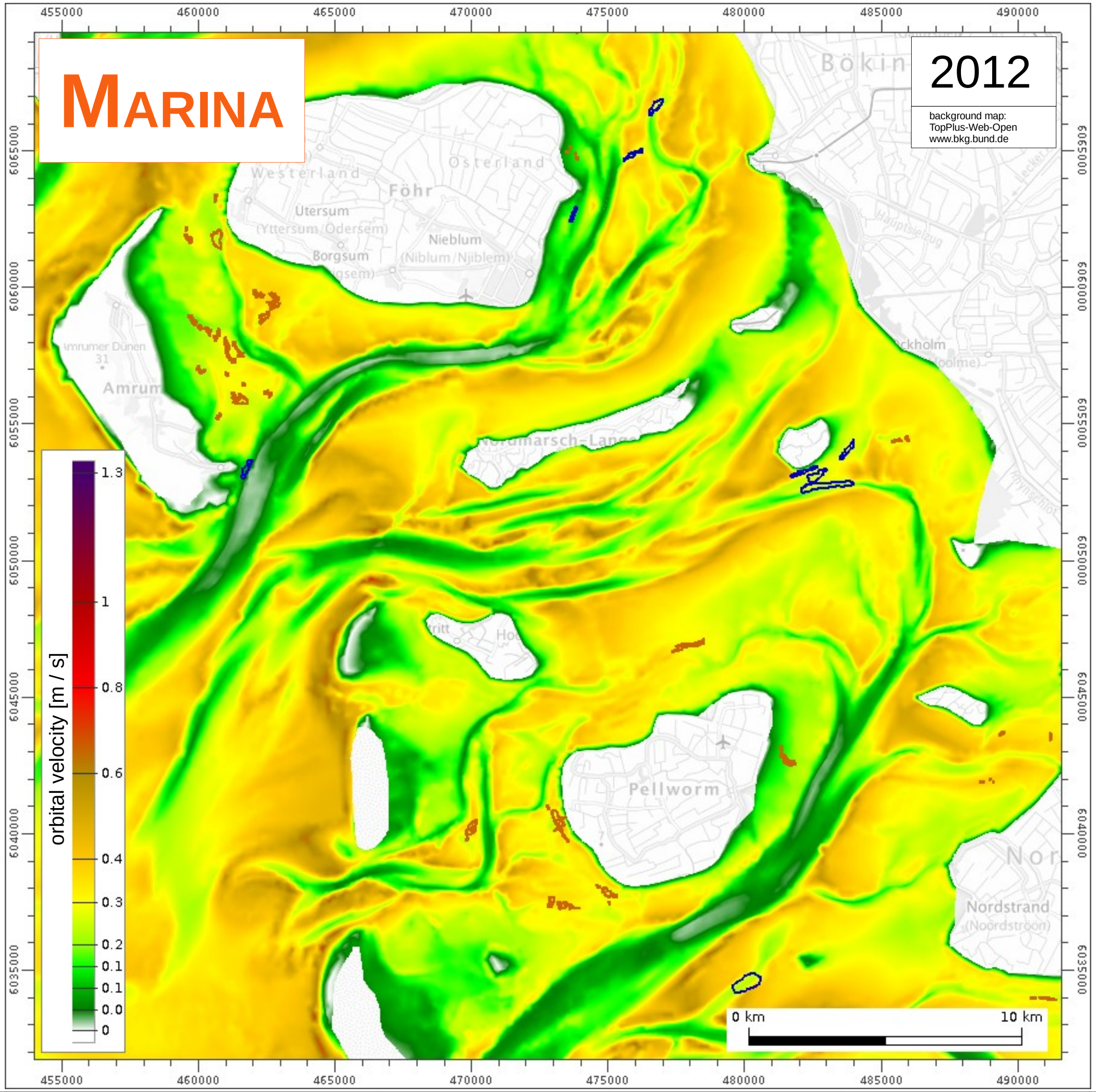
Orbital velocities



Orbital velocities:

→ analogous to stream velocities and bottom shear stresses

Orbital velocities



In areas of known mussel occurences values for orbital velocities were determined:

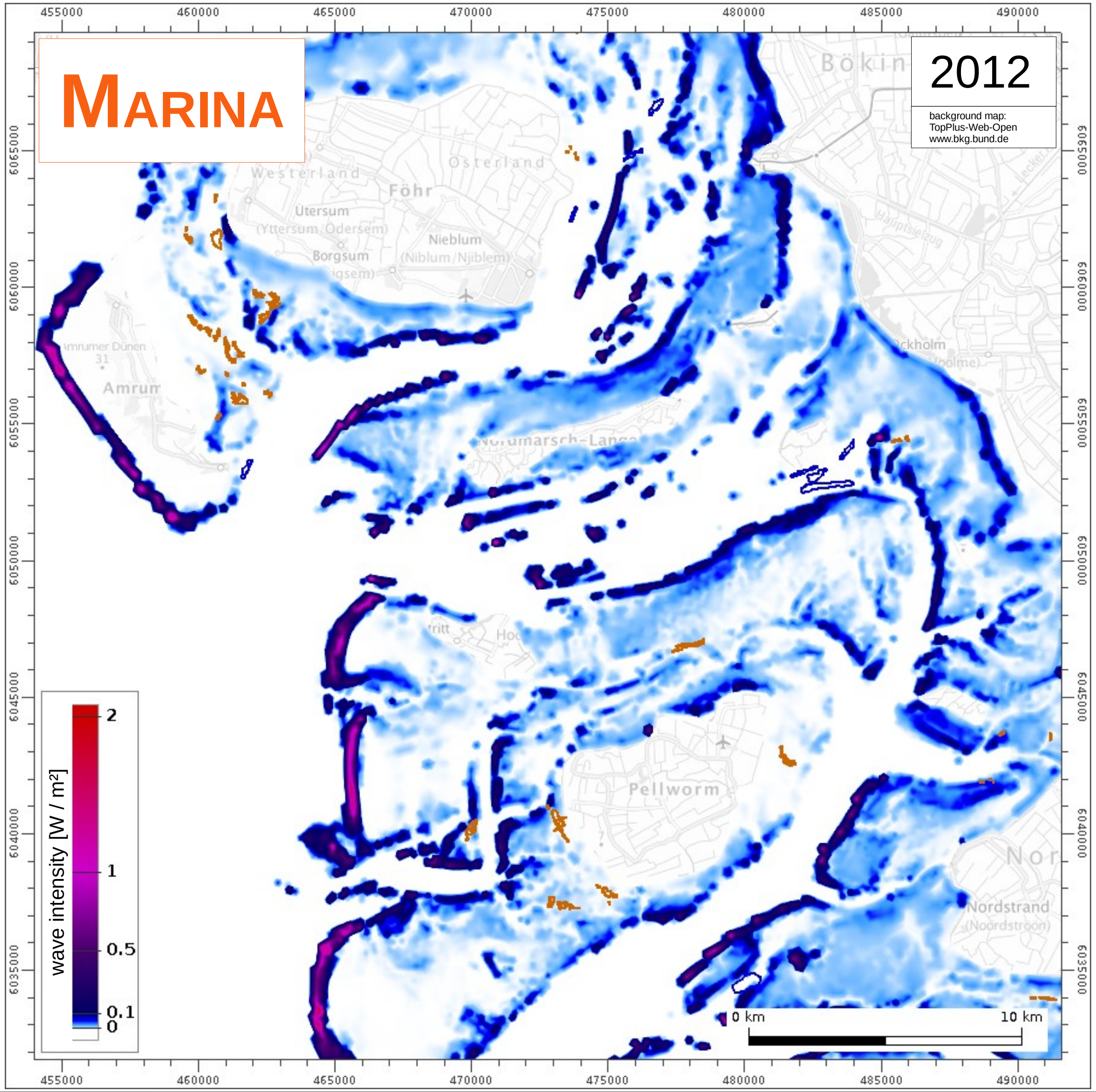
Eulittoral mussel occurences:

Min. 0.074 m / s
Median 0.290 m / s
Max. 0.504 m / s

Sublittoral mussel occurences:

Min. 0.097 m / s
Median 0.256 m / s
Max. 0.417 m / s

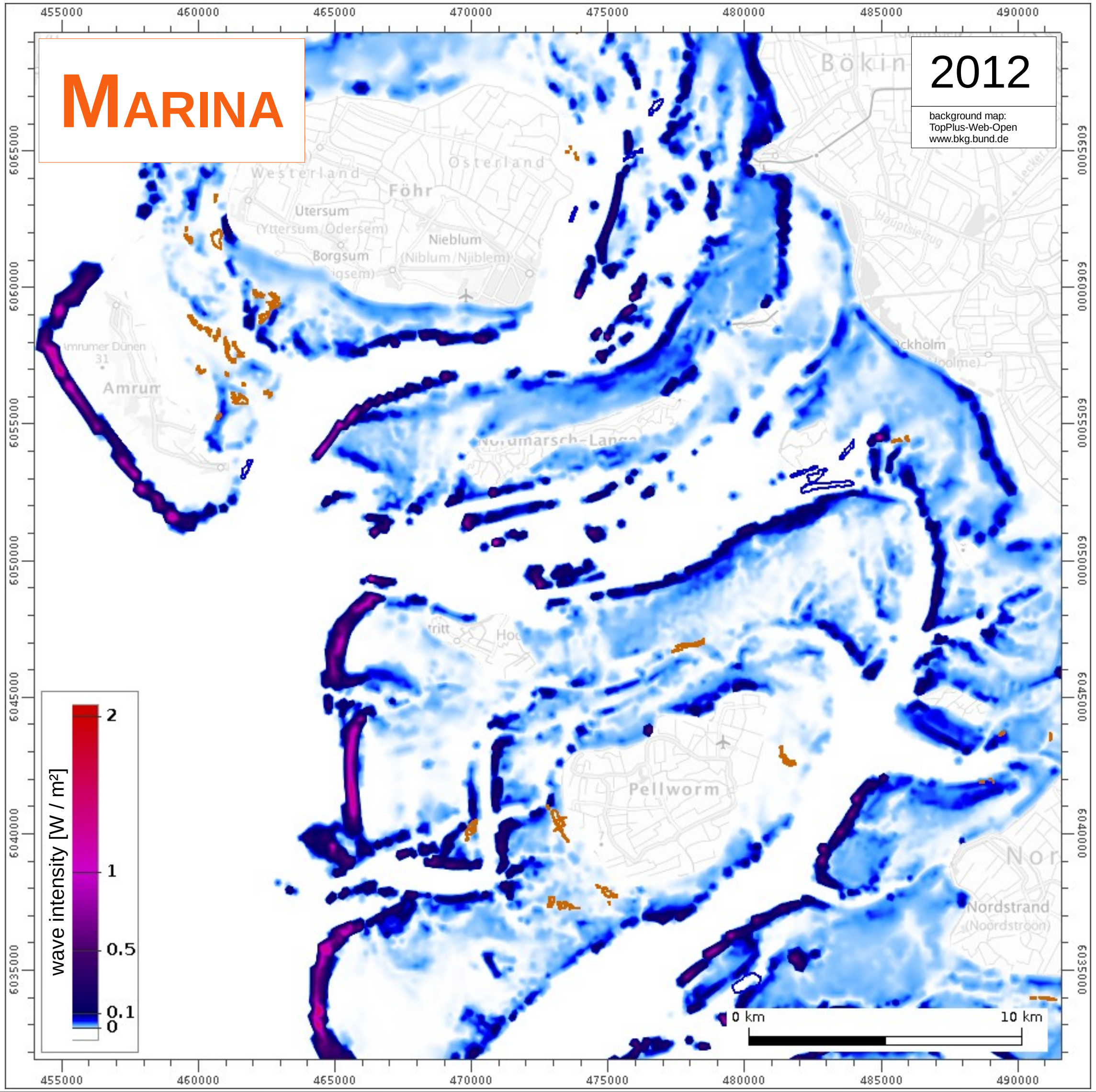
Wave breaking / wave intensity



Wave intensities:

→ high wave intensity / wave breaking leads to a strong energy transfer to the ground surface, which could erode existing shellfish and / or prevent settlements

Wave breaking / wave intensity



In areas of known mussel occurences mean values for wave breaking (annual mean value) were determined:

Eulittoral mussel occurences:

Median 0.001 W / m²
Max. 0.21 W / m²

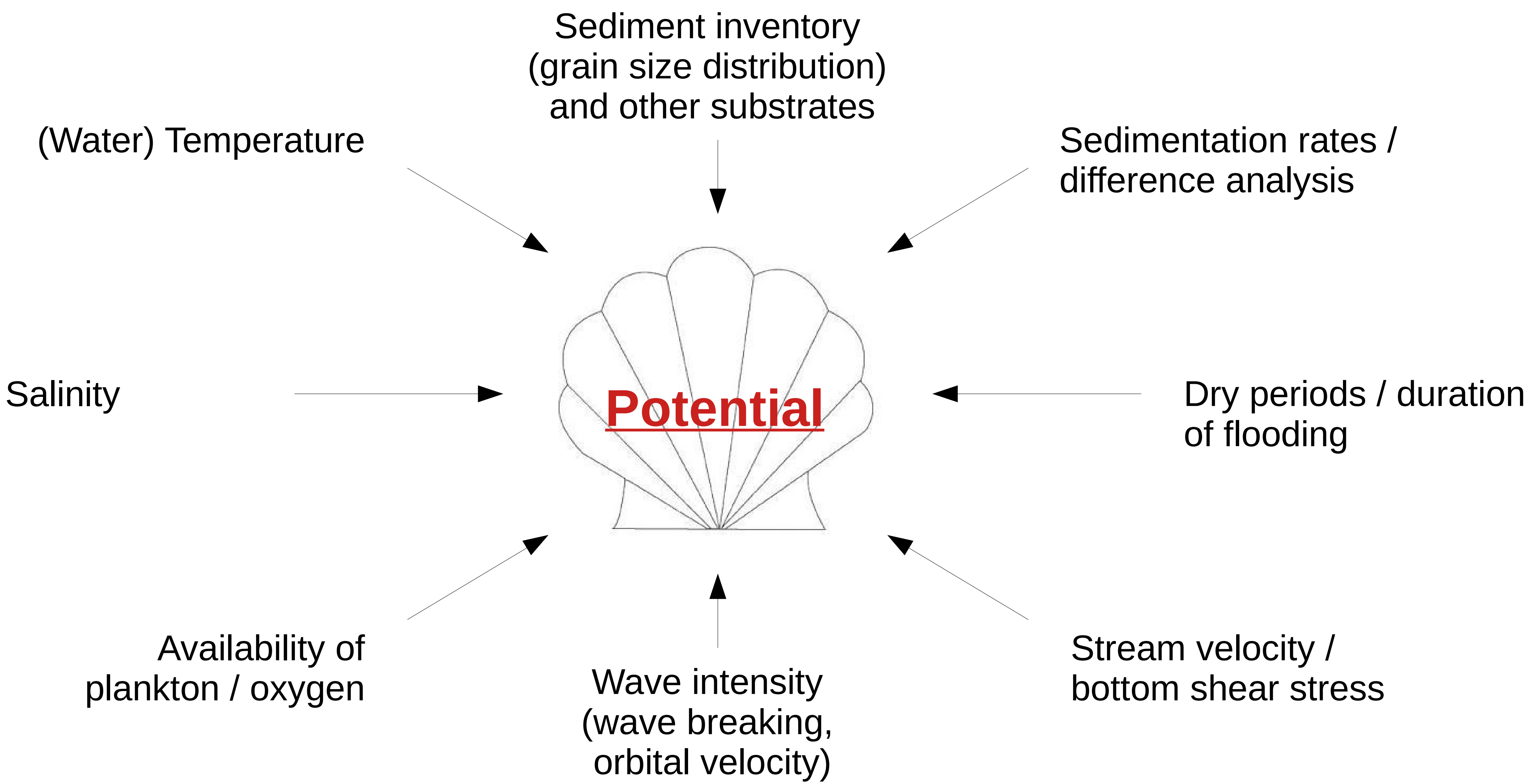
Sublittoral mussel occurences:

Median 0.00 W / m²
Max. 0.00 W / m²

Analysis of mussel potential

On the basis of the limits for environmental parameters compiled from the EasyGSH-DB products, it is possible to initially exclude areas for mussel occurrences in which one or more parameters do not match the conditions necessary for mussel communities. Such a map is to be understood as "binary map" (mussel potential = 1, no mussel potential =0) without weighting of the individual parameters.

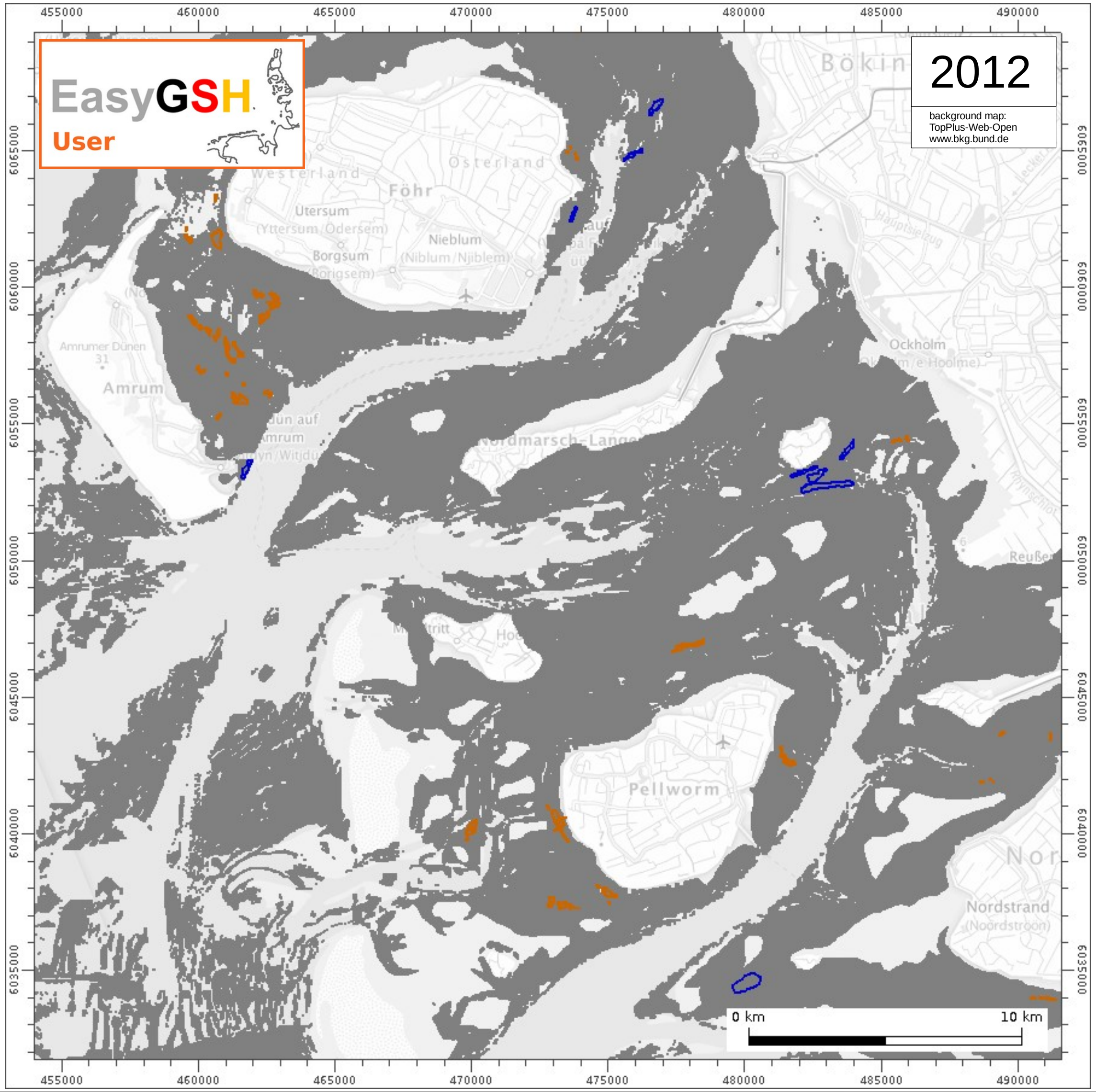
Parameters influencing mussel settlement / growth



Environmental parameters - overview

	Eulittoral mussel beds			Sublittoral mussel beds		
Environmental parameters	*Minimum*	*Maximum*	*Median*	*Minimum*	*Maximum*	*Median*
Erosion / sedimentation rate [m / year]	**-0.2**	**0.7**	-	**-0.2**	**0.6**	-
Sediment distribution d50 [mm]	**0.079**	0.652	0.175	**0.104**	0.377	0.166
rel. duration of falling dry per Tide [%]	0	**42.210**	14.163	0	0	0
Orbital velocity [m / s]	**0.074**	**0.504**	0.290	**0.097**	**0.417**	0.256
Bottom shear stress [N / m²]	**0.026**	**1.309**	0.213	**0.123**	**0.794**	0.355
Wave intensity / wave breaking [W / m²]	0	**0.21**	0.001	0	0	0
Salinity [‰]	**18.676**	27.717	24.379	**22.863**	24.754	23.598

Potential analysis - potential areas



On the basis of the various environmental parameters modelled, the exclusion methodology (limits as a condition for mussel occurrence) allows the identification of areas, displayed in grey, for which all the above conditions are met.

For the environmental factors considered and their determined limits, these are to be understood as potential areas where mussels occur / could be found (prototypical “binary map of mussel potential”).

Analysis of mussel potential

In order to be able to assign individual potentials to the various environmental parameters in form of numerical values between zero and one, membership functions (combination of sin- and cos- functions as well as exponential functions) are created based on the determined minimum, maximum, and median values. By means of these membership functions, individual potentials can be determined for each value of an environmental parameter, which are then combined by using the geometric mean to form an overall potential for each point within the study area which is valid for the study year. This results in a map of potential for mussel communities, in which the determined value is to be understood as a characteristic value for favourable / unfavourable overall environmental conditions.

Environmental parameters - overview

	Eulittoral mussel beds			Sublittoral mussel beds		
Environmental parameters	*Minimum*	*Maximum*	*Median*	*Minimum*	*Maximum*	*Median*
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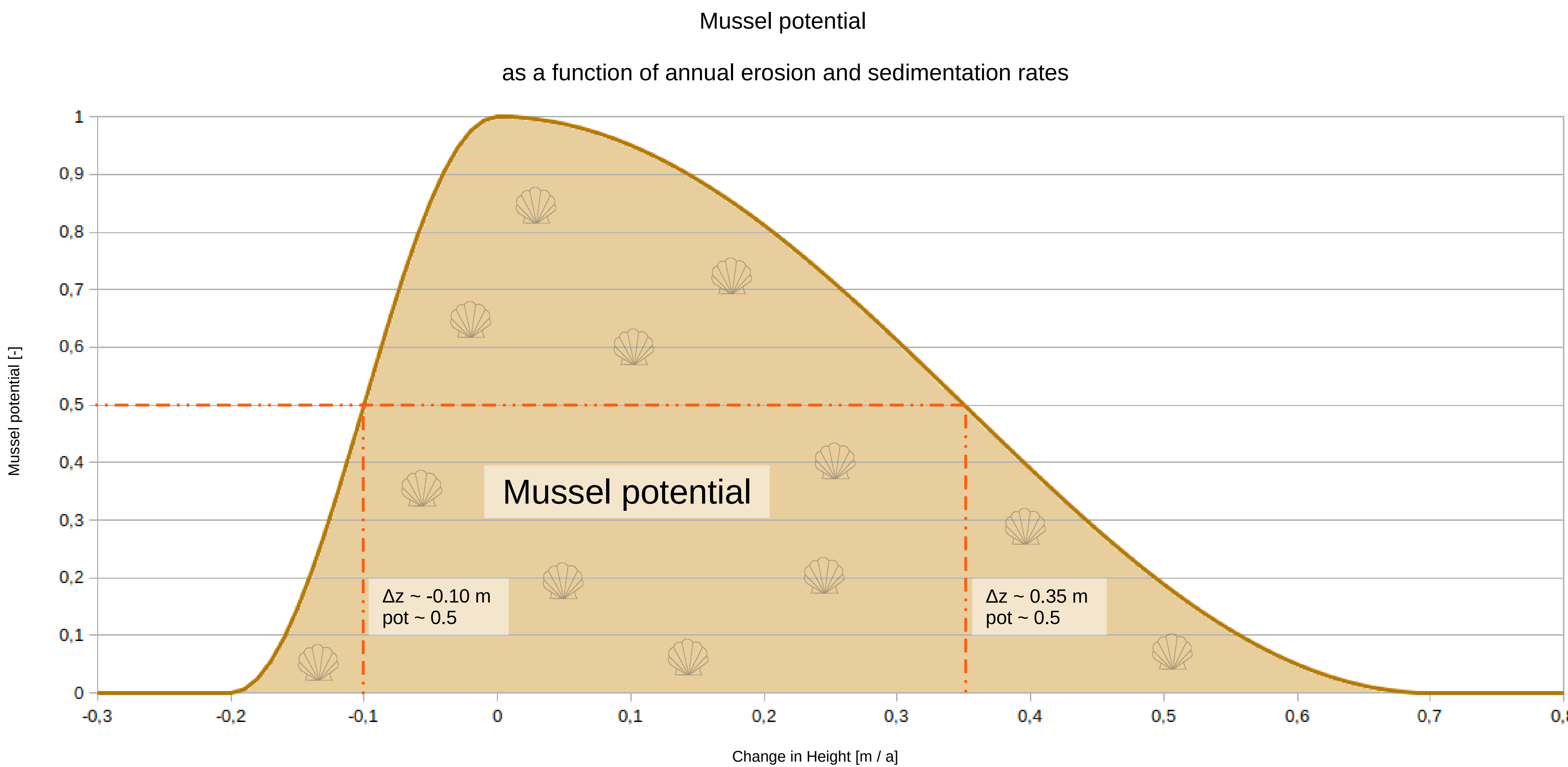
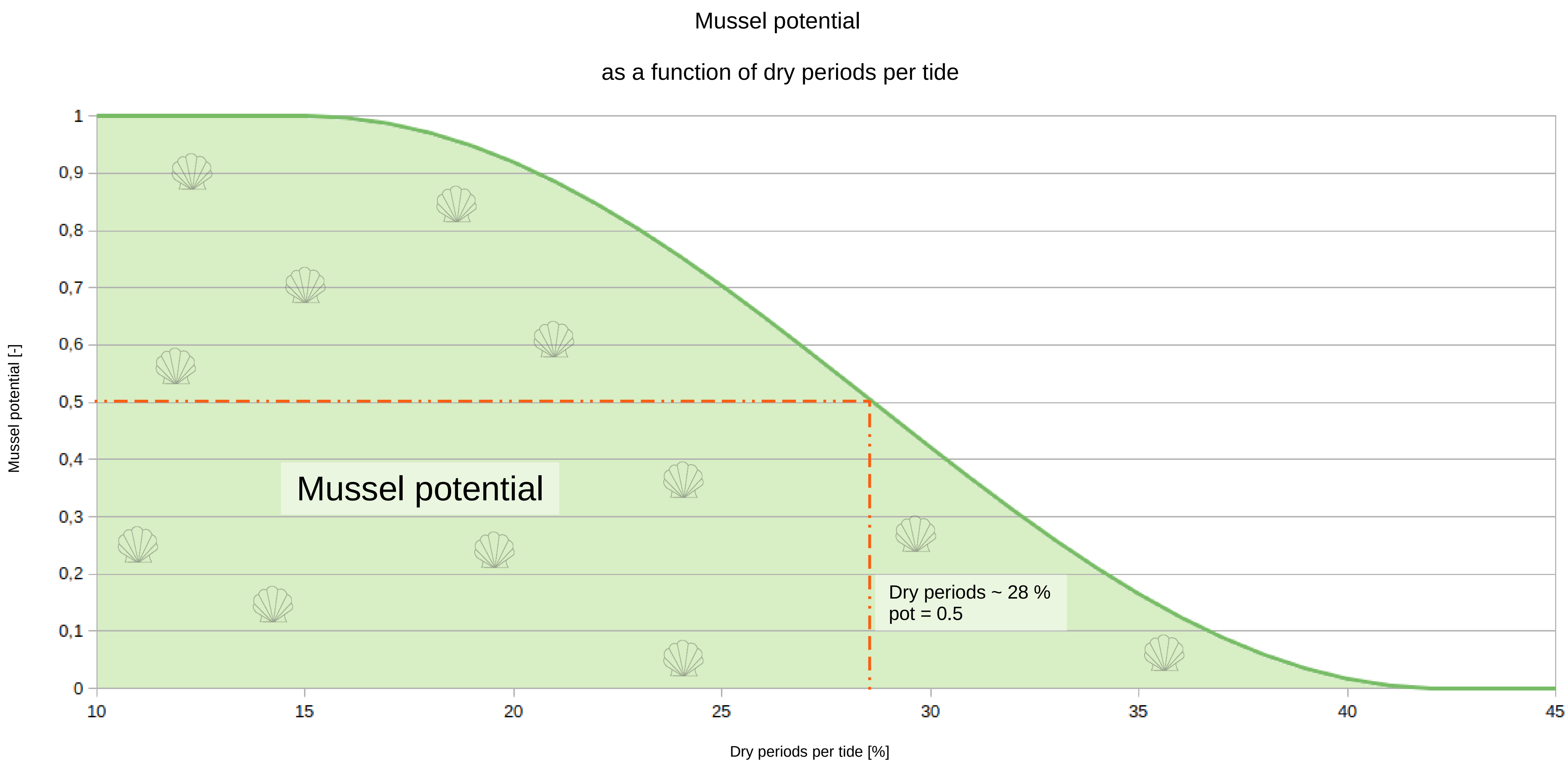
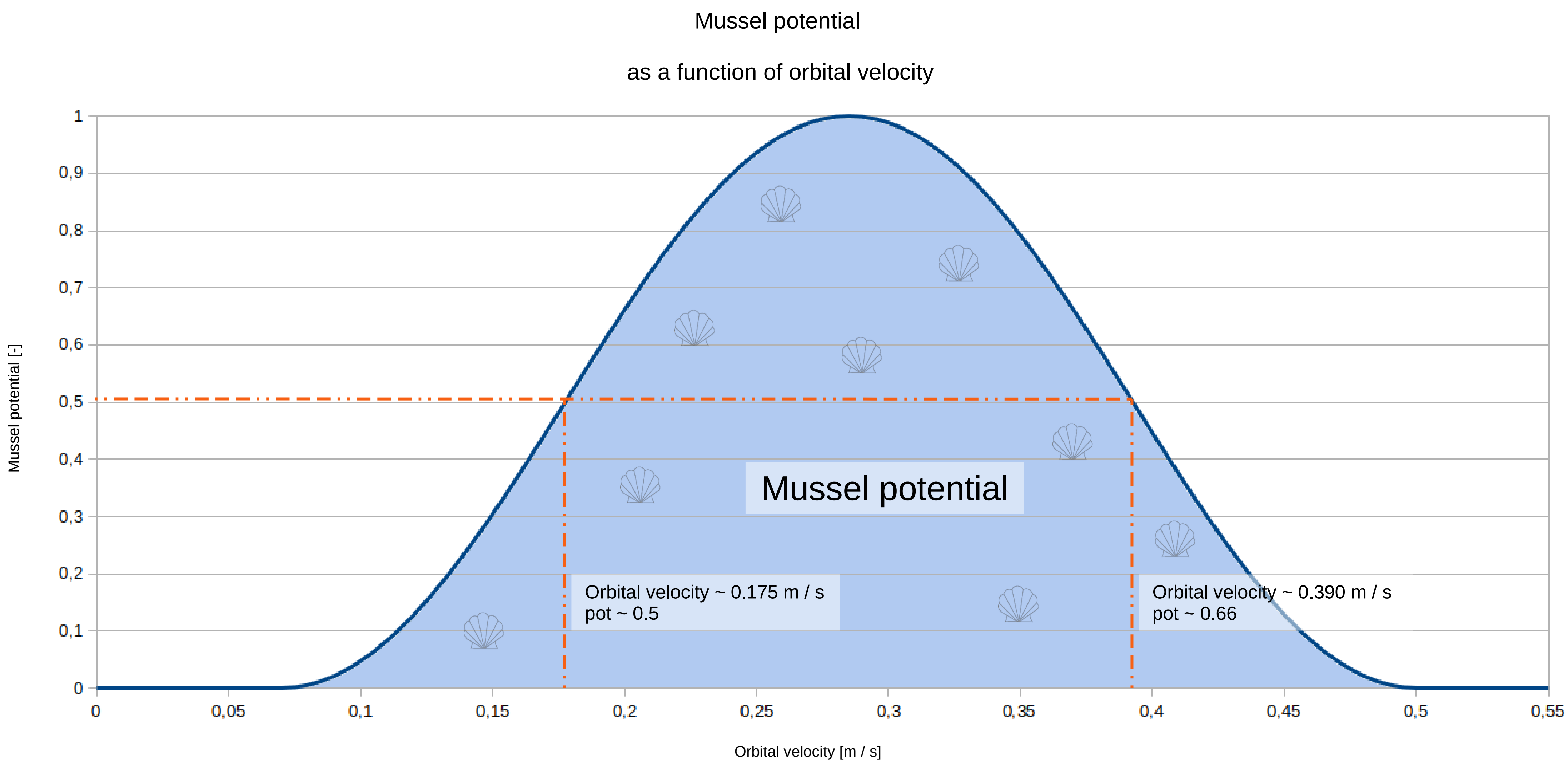
Individual potentials of environmental parameters



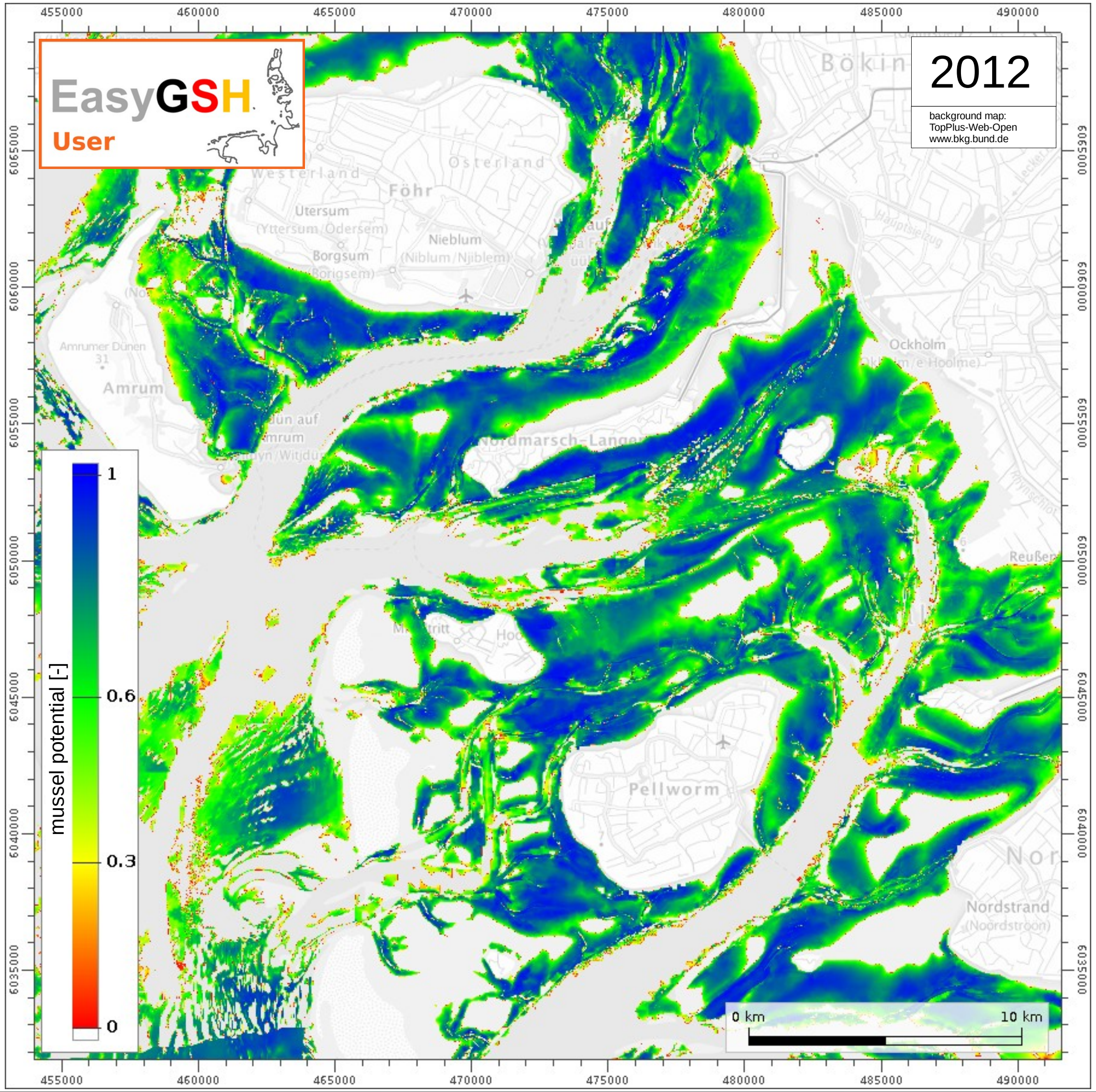
Individual potentials of environmental parameters



Individual potentials of environmental parameters



Map of potential for mussel beds

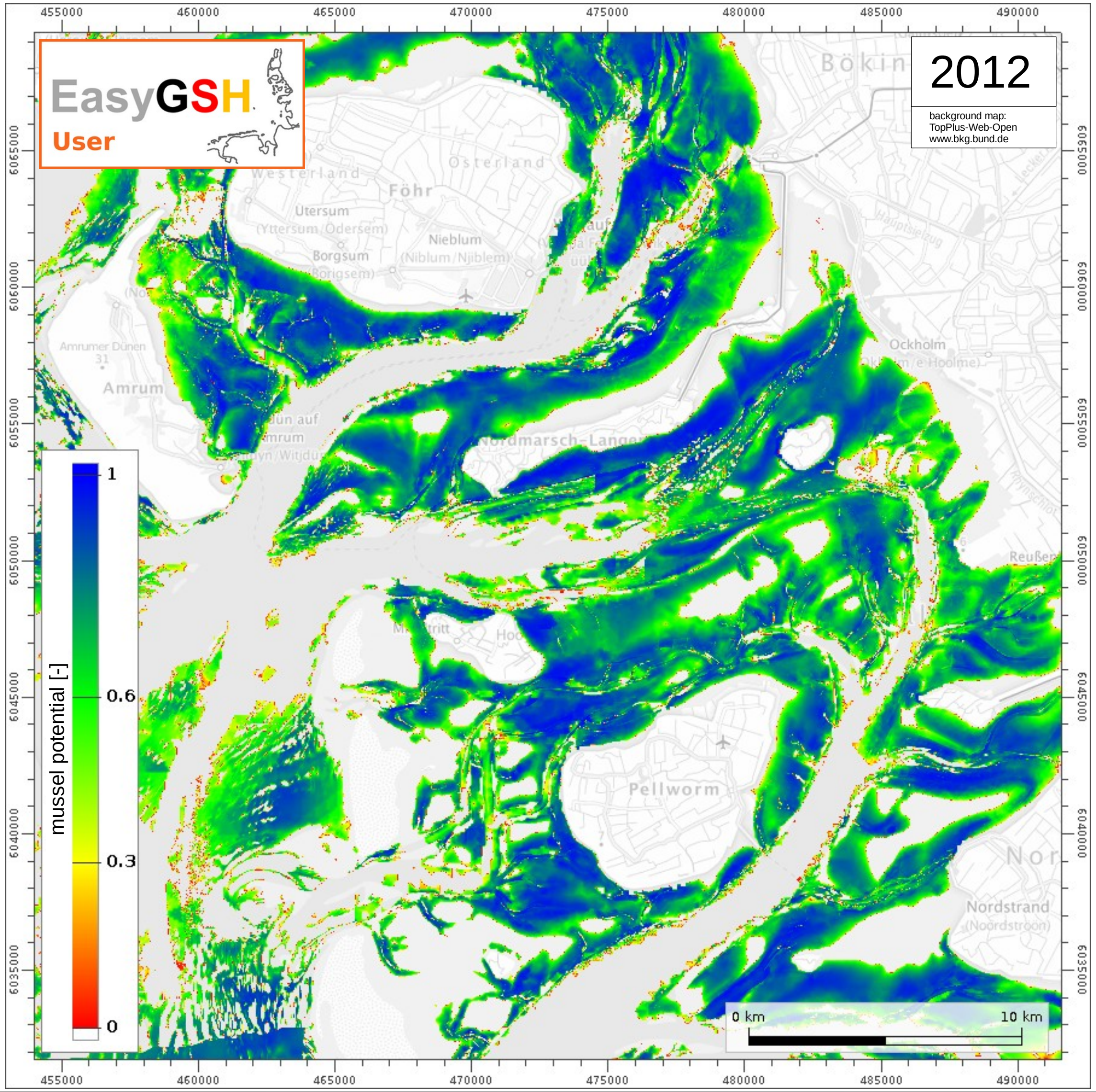


Calculation of an overall potential using the geometric mean of the independent individual potentials per environmental factor

$$Pot_{tot} = \sqrt[n]{Pot_1 * Pot_2 * Pot_3 * ... * Pot_n}$$

$$with \ \ n = number\ of\ individual\ potentials$$

Map of potential for mussel beds



Outlook:

- observation / determination of the individual environmental parameters for several years
- differentiation between mussel beds, oyster reefs and mixed deposits
- consideration of other potential settlement substrates (shell deposits, peat, ...) and their influence on the determined environmental parameters

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Project homepage www.easygsh-db.org
Download portal http://mdi-de.baw.de/easygsh/index.html#download

Cover picture taken by Jan Hitzegrad, TU Braunschweig, Leichtweiß Institut für Wasserbau as part of the KFKI project "BIVA-WATT: Untersuchung der Rauheitswirkung von Austernriffen und Miesmuschelbänken".
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