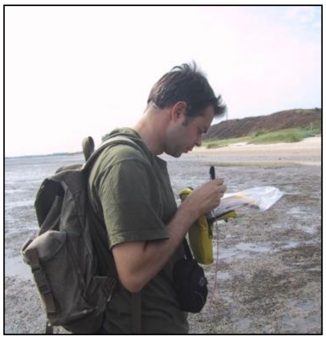
Guidelines for seagrass monitoring and the Ecological Quality Assessment of the Schleswig-Holstein Wadden Sea

Status: April 2014



Ecological Quality Assessment of the Northfrisian Wadden Sea using a macrophytobenthos index

	Ecological Quality classes	0 bad	1 poor	2 moderate	3 good	4 high	weighting %
	class boundaries	0 – 0.19	0.2 – 0.39	0.4 – 0.59	0.6 – 0.79	0.8 – 1.0	
biological quality element: seagrass [6]	coverage of tidal flat area (%) [1]	< 2	2 - 4.9	5 - 9.9	10 - 19.9	20 - 100	50
	share of ≥ 60 % cover density (%) [2]	< 6	6 - 11.9	12 - 24.9	25 - 49.9	50 - 100	10
	occurrence of both species (%) [3]	< 20	20 - 39.9	40 - 59.9	60 - 79.9	80 - 100	10
biological quality element: green algae [7]	coverage of tidal flat area (%) [4]	100 - 15	14.9 - 7	6.9 - 3	2.9 - 1	< 1	20
	share of ≥ 60 % cover density (%) [5]	100 - 50	49.9 - 25	24.9 - 12	11.9 - 6	< 6	10

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LLUR order number: 0608.451125

Contents

1 Introduction

Seagrasses are flowering plants and the dominant vegetation of shallow sandy bottoms in coastal areas around the world (den Hartog 1970). They are of high ecological importance for coastal ecosystems as they are one of the most productive coastal vegetation types worldwide and supply valuable ecosystem services (Constanza et al. 1997).

Seagrasses usually occur in communities and can form large and dense beds. Seagrass beds provide habitats and shelter from predators for a diversity of organisms and are spawning and nursery grounds for fish (Fonseca 1996, Polte et al. 2005, Polte and Asmus 2006). Furthermore, they are an important food source for waterfowl, especially for migrating birds like brent geese and wigeon (Nacken and Reise 2000), and support a complex detritus-based food chain (Cunha et al. 2005). Another important function is their ability to filter nutrients as well as stabilising and trapping sediments by reducing the water flow with their leaf canopy (Fonseca 1996).

Seagrass is sensitive and requires good ecological conditions. It is sensitive towards eutrophication, turbidity (which basically means light limitation), hydrodynamics (currents and waves), sediment instability, desiccation as well as changes in temperature and salinity (de Jonge and de Jong 1992, Philippart et al. 1992, Koch 2001, Schanz and Asmus 2003). Therefore, its spatial and temporal occurrence is determined by these factors. Due to its sensitiveness a worldwide decline of seagrass beds can be observed, especially since the early 20th century and human impact is regarded to be the primary reason (den Hartog and Phillips 2001, Green and Short 2003).

In the European Wadden Sea, seagrass is growing on the tidal flats where two species occur: *Zostera noltii* and *Zostera marina* (photo 1). The dwarf eelgrass *Z. noltii* occurs more frequent and is more tolerant to low tide exposure why it mainly grows in the upper intertidal area. The eelgrass *Z. marina* occurs primarily in the mid intertidal but also down to the lower intertidal. Seagrass has a seasonal cycle in the Wadden Sea: germination begins in May, maximum extent and cover of the beds occur in August, and leaves are shed and grazed by migrant waterfowl in late summer / autumn (Vermaat and Verhagen 1996, Nacken and Reise 2000). The roots and the rhizomes remain below the surface. *Z. marina* is largely annual whereas *Z. noltii* is largely perennial (van Katwijk et al. 1998, Zipperle et al. 2009).

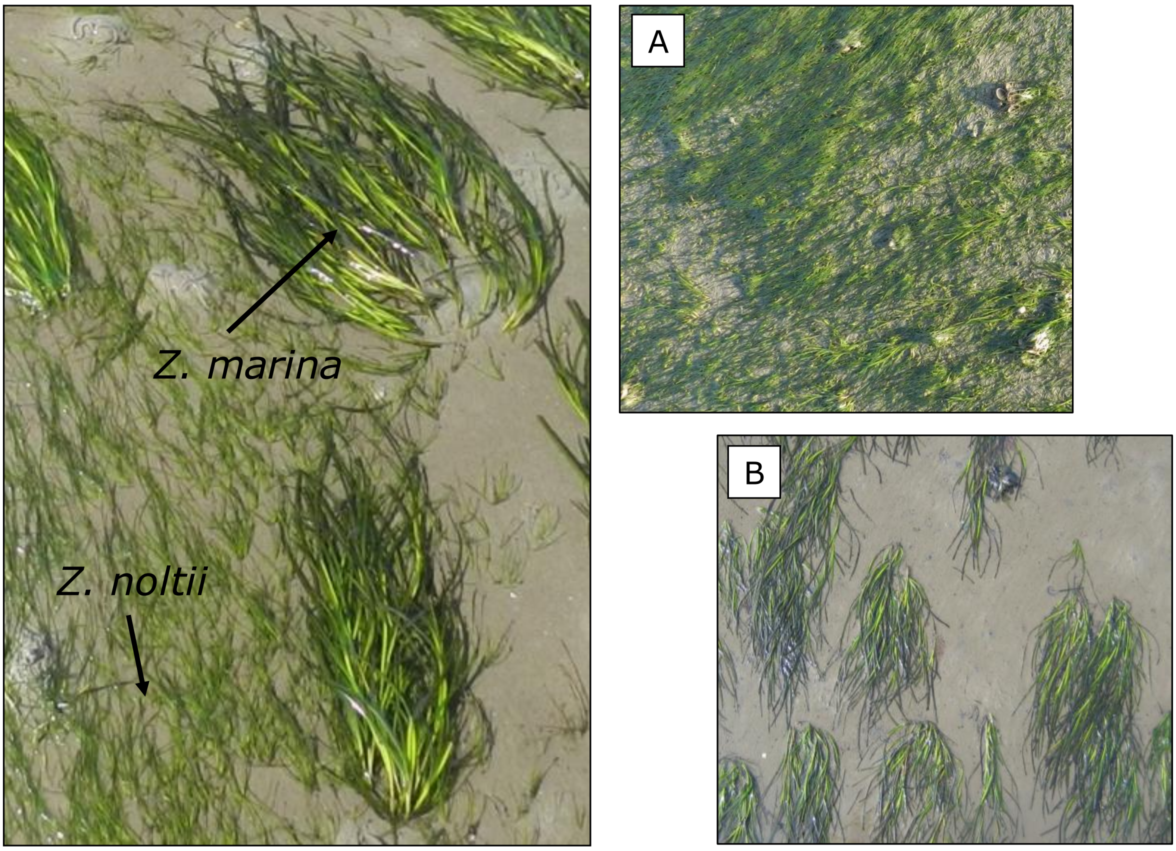


Photo 1: The dwarf eelgrass *Zostera noltii* (A) and the eelgrass *Zostera marina* (B) are the two species of seagrass that occur in the European Wadden Sea. *Zostera noltii* (A) usually forms denser vegetation cover than eelgrass *Zostera marina* (B).

The stock of seagrass in the European Wadden Sea was reduced by two separate crises in the 20th century (Lotze 2005). In the beginning of the 20th century, *Zostera marina* could also be found in the lower subtidal here. From 1931 to 1934 the eelgrass pathogen *Labyrinthula zosterae* is assumed to have caused the so called 'wasting disease' which eliminated seagrasses at both coasts of the Atlantic Ocean (den Hartog 1987). While the *Zostera marina* beds recovered slowly at the neighbouring European coastal regions, it never returned into the subtidal of the Wadden Sea (de Jonge and de Jong 1992). This might have been caused by changing hydrodynamic conditions developing after the seagrass loss, too much turbidity, the loss of sheltered locations as well as the loss of seagrass itself which means the loss of a starting population for recolonization (Giesen et al. 1990, Schanz and Reise 2006).

Another dramatic decrease of seagrass started in the 1960s/1970s, affecting the extant intertidal *Zostera* beds. This time anthropogenic eutrophication is regarded as the primary reason for the decline (van Katwijk et al. 1997, 1999). Eutrophication results in increased water turbidity due to higher phytoplankton growth, a high amount of epiphytes attached to seagrass leaves and a strong development of green algae which often accumulate in areas where seagrass is growing (de Jonge and de Jong 1992, Reise and Siebert 1994, Kolbe et al. 1995, Duarte 1995, Short et al. 1995, den Hartog and Phillips 2001, van Katwijk et al. 2010). Green algae can form thick and dense mats which then smother the seagrass underneath. High nutrient loads may also affect seagrass physiology because its metabolism is adapted to low nutrient conditions (Burkholder et al. 2007). All these effects led to a strong decline of seagrass beds especially in the southern and central Wadden Sea, where the level of eutrophication were higher than in the northern Wadden Sea (van Beusekom et al. 2005). This is because the southern and central Wadden Sea are in proximity to the big estuaries (Elbe, Weser and Ems) which discharge riverine nutrient loads into the Wadden Sea. To combat the effects of eutrophication, measures were taken and the nutrient discharge has been reduced since the mid 1980s. It seems that seagrass beds in the Northfrisian Wadden Sea (northern Wadden Sea), which were per se less affected by eutrophication, have benefited most from this reduction and started to recover about 10 years later. An almost steady and five-fold increase of the seagrass bed area can be observed in this region from the mid 1990s until today (Reise et al. 2005, Reise and Kohlus 2008). Today, seagrass beds dominated by *Zostera noltii* are occurring on more than 15 % of the tidal flat area in the Northfrisian Wadden Sea. They grow mostly at the lee side of islands and high sand bars where they are sheltered against strong hydrodynamics. However, seagrass beds in the southern and central Wadden Sea, where the effects of eutrophication were strongest, still show no clear sign of recovery (van der Graaf et al. 2009).

Besides the facts that seagrass is on the one hand of high ecological importance and on the other hand sensitive to a variety of parameters, particularly to human induced eutrophication (Burkholder et al. 2007, Orth et al. 2006, Short et al. 2011), it also responds quickly to changes of environmental conditions. This in total makes it a suitable indicator for ecosystem health and it is used as such in the EU Water Framework Directive (Foden and Brazier 2007, Krause-Jensen et al. 2005, Romero et al. 2007).

The EU Water Framework Directive has the aim that bodies of surface waters should be protected, enhanced and restored in order to achieve a good status (European Union 2000). This includes coastal waters and in the Schleswig-Holstein Wadden Sea the size, species composition and cover density of intertidal seagrass beds are taken as indicators for the ecological status. These parameters are used primarily to calculate an Ecological Quality Ratio (EQR) which presents the ecological status. However, the EQR is also based on green algae data, which is a suitable indicator for eutrophication too. Seagrass and green algae are responding opposed to eutrophication: as seagrass declines at high eutrophication levels, green algae increase and vice versa at low eutrophication levels. The less green algal mats and the more seagrass beds there are, the better may be the environmental quality of the Wadden Sea. Even though eutrophication is declining since the mid 1990s, it is still regarded to be a major ecological problem for the Wadden Sea and therefore a continuous monitoring is carried out.

There are two major monitoring programs. In one monitoring program seagrass beds and green algae are surveyed area-wide from the air. Three surveyors map their distribution directly by flying in airplane during low tide exposure at heights between 300 to 500 m above the tidal flats (Reise and Kohlus 2008). This aerial mapping is a rapid assessment method which has the major advantage of producing quick results and covering the entire survey area. The drawbacks come with the nature of this method: the positioning is not very accurate, the results are neither very detailed nor high-resolved, seagrass can only be detected with a cover density of more than 20 % and experienced surveyors are required.

As a supplementary counterpart to the aerial mapping field surveys with GPS devices are carried out on foot from mid-July to mid-September when the beds have their seasonal maximum areal extent and density. The results are accurate, precise and have a high-resolution. However, due to the laborious and time-consuming work under challenging conditions, this survey cannot be area-wide and is limited to selected subareas.

This report focuses on the latter monitoring method and can be regarded as a handbook. Recommendations and suggestions how to survey intertidal seagrass beds in the field are given. All guidelines and recommendations are based on extensive field experience. The aim is to present a practical and safe but also accurate and precise way to monitor intertidal seagrass beds and to introduce a method how to assess the ecological status of coastal waters based on this data.

2 Seagrass monitoring in the Schleswig-Holstein Wadden Sea

2.1 Study area

The Wadden Sea is located at the south-eastern shallow fringe of the North Sea and comprises the largest coherent tidal flats of the world. The Schleswig-Holstein Wadden Sea is the major part of the northern Wadden Sea (CWSS 2008). It stretches over a length of 135 km (N-S) from the Elbe estuary to the German-Danish border and has a width (E-W) of 10 – 28 km. The tidal flat area in the Schleswig-Holstein Wadden Sea amounts to about 1455 km^2 (plain tidal flat area obtained from topographic GIS map 2013, issued by National Park Authority, Tönning; made available by Jörn Kohlus). These tidal flats are the habitat for both seagrass species which can form large and dense beds.

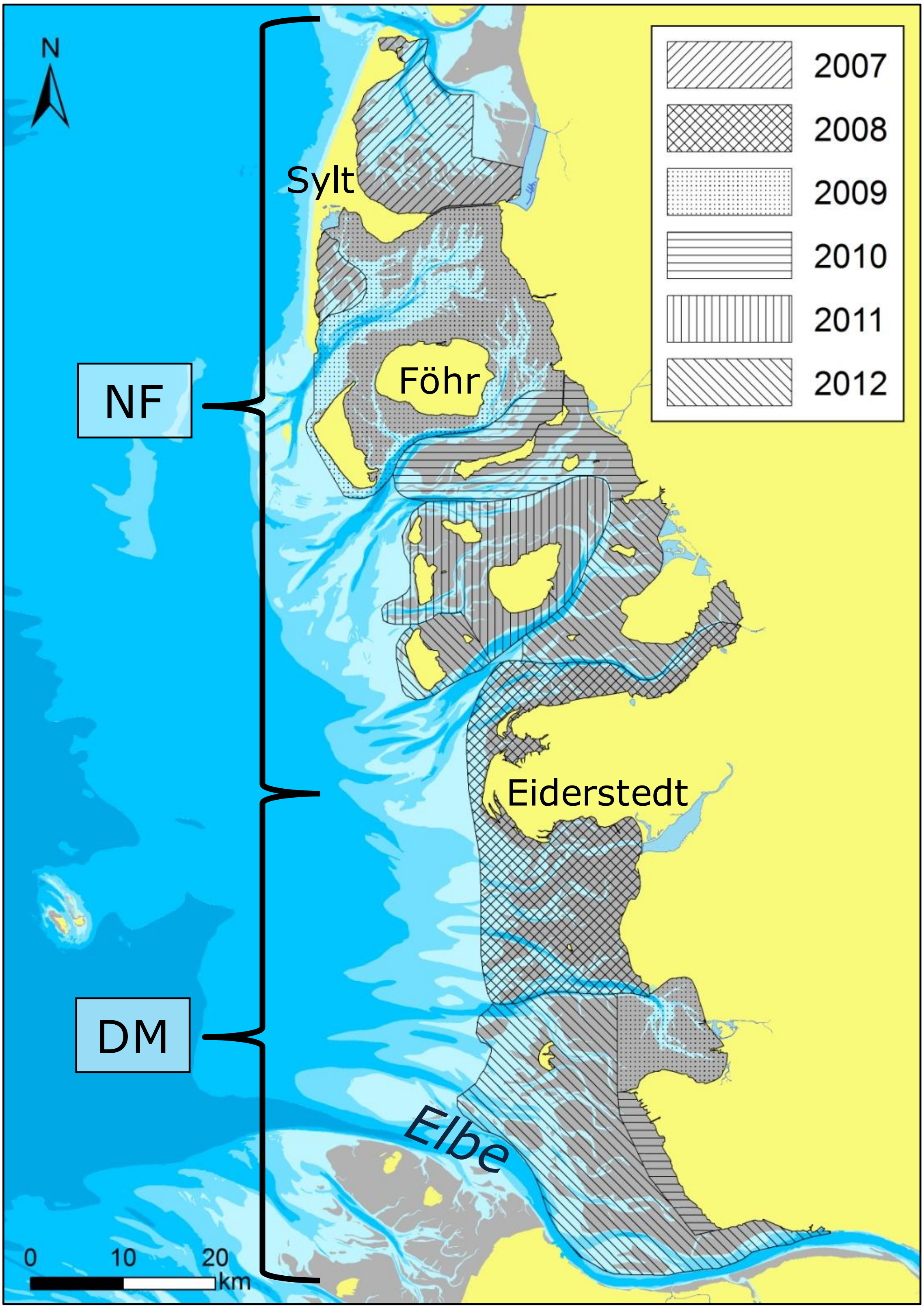
The Schleswig-Holstein Wadden Sea is composed of two major water bodies: the Northfrisian Wadden Sea and the Dithmarscher Wadden Sea (map 1).

The Northfrisian Wadden Sea stretches from Eiderstedt peninsula to the German-Danish border and represents the northern 2/3 of the Schleswig-Holstein Wadden Sea. It is characterized by a low riverine input and a chain of barrier islands and high sands facing westward, protecting the back barrier tidal basins from the prevailing westerly North Sea swell. These natural characteristics seem to facilitate the establishment of seagrass beds in this region. More than 15 % of the tidal flat area is covered with seagrass, which is more than in any other part of the Wadden Sea (Reise et al. 2013).

The Dithmarscher Wadden Sea represents the southern 1/3 of the Schleswig- Holstein Wadden Sea and stretches from Eiderstedt peninsula to the Elbe estuary. Due to its proximity to this big river mouth it is characterized by a high riverine input at which nutrient loads are also included in the river discharge. Furthermore the tidal flats are not protected by barrier islands and high sands which results in exposed conditions. The combination of the lack of sheltered positions and the exposure to strong hydrodynamics as well as high nutrient discharges from the close Elbe estuary makes the habitat conditions for seagrass less favourable. In 2013, just 0.3 % of the tidal flat area in the Dithmarscher Wadden Sea was covered with seagrass.

2.2 Surveying design

The aim of the presented monitoring approach is to detect and record all seagrass stock in the Schleswig-Holstein Wadden Sea by field surveys. As seagrass has a seasonal cycle and in order to make the survey data from different years comparable, the monitoring is limited to the period from mid-July to mid-September when the beds have their seasonal maximum areal extent and density. This gives a rather short time frame for the monitoring which is furthermore limited by the semi-diurnal tides. On the other hand, the survey area is vast (about 1455 km^2) and the terrain difficult with soft and muddy substrate in some parts and the tidal flats are intersected by tidal channels. Therefore it is not possible to survey the entire Schleswig-Holstein Wadden Sea within one year why the area was divided into 6 subareas (see map 1). Each year the entire seagrass stock in one subarea is recorded by on foot field surveys. As the 6 subareas are successively surveyed, all seagrass beds in the entire Schleswig-Holstein Wadden Sea are detected after a period of 6 years. The first survey period started in 2007 and ended in 2012. In most years (2008, 2009, 2010 and 2012) the annual survey covered parts of the Northfrisian and the Dithmarscher Wadden Sea. In 2007 and 2011, the entire mapping took place just in the Northfrisian Wadden Sea due to its larger areal size and the much higher abundance of seagrass here. In order to achieve comparative measurements and to detect the dynamics and changes of the seagrass beds, the second survey period has started in 2013. The course of the monitoring of the subareas is the same as in the prior survey period in order to minimise the time gap between the repetitive measurements (in other words the subarea surveyed first in the first monitoring period is also the first surveyed in the second period etc.).



Map 1: The Northfrisian (NF) and the Dithmarscher Wadden Sea (DM) with the 6 annual survey sites of the first survey period (2007 – 2012).

2.3 Guidelines for seagrass monitoring field work

The monitoring of intertidal seagrass beds presented in this report is conducted by field surveys. The shape, size and position of a seagrass bed are collected by circulating the bed on foot with a GPS device. For logistical and safety reasons at least two surveyors have to do the monitoring simultaneously, each of them equipped with a GPS device.

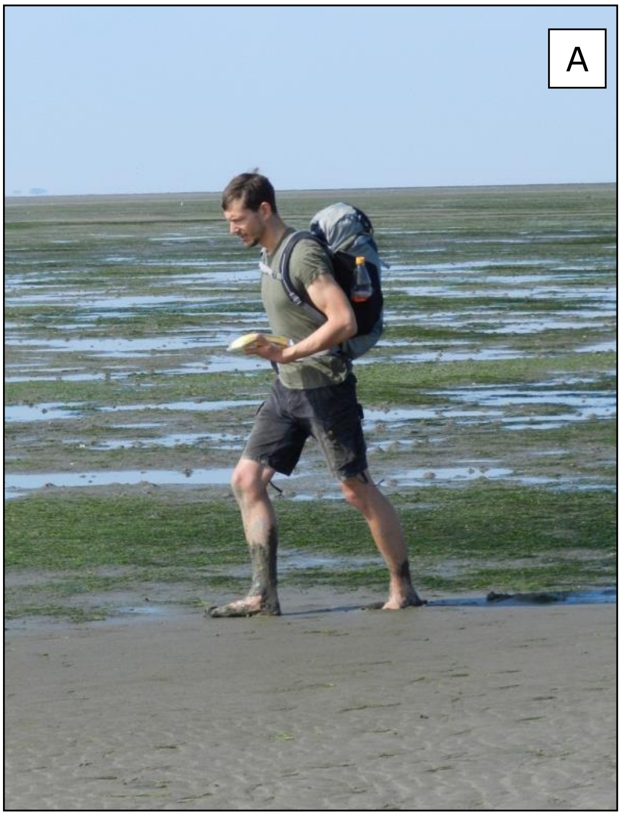


Photo 2: Surveyor mapping seagrass with a GPS device (A). As he is walking along the outer border, the dense seagrass bed can be seen in the back. The borderlines of ≥ 5 %- and ≥ 20 % cover density are circulated on foot (B). In the two photos, the border of the seagrass bed is distinct, clear, and easy to detect.

By definition, a seagrass bed exists when seagrass occurrence has a cover density of ≥ 5 %. At least 5 % of the tidal flat sediments have to be covered with seagrass plants so that the seagrass occurrence can be regarded as a bed. The areal extent of seagrass occurrence with a cover density below 5 % is not mapped.

For each seagrass bed the area with ≥ 5 % and – if applicable - ≥ 20 % cover density has to be mapped. The ≥ 20 % cover density presents the inner denser core of a seagrass bed, while the cover density ≥ 5 % presents the outer, rather sparsely vegetated frame of the bed. To monitor these two cover densities is agreed in the Trilateral Monitoring and Assessment Programme (TMAP). TMAP is the common monitoring programme for the

Wadden Sea carried out by The Netherlands, Germany and Denmark and was implemented based on a decision at the Ministerial Conference in Stade, 1997 (Marencic and de Vlas 2009).

At first, the 5 %- and 20 %-borderlines need to be determined in order to record the areas with ≥ 5 % and ≥ 20 % cover density. As a preparation for the actual monitoring, it is necessary to practice with a measuring frame in order to get a reliable feeling for different seagrass cover densities. Surveyors need to gain experience prior to the actual monitoring as there is no time to use a measuring frame during field work and the estimation of cover densities has to happen by eye. Therefore extensive practising is an indispensable pre-condition for the instant in situ assessment in the field.

At the beginning of a field campaign it is also necessary that the two surveyors synchronise their assessment on all parameters recorded in the field (cover density, species composition, epiphyte cover etc.). It is important that the assessments made by the surveyors are as close and agreeing as possible. Therefore it is recommended that both surveyors map the first seagrass beds simultaneously and agree on their assessments.

The survey of seagrass beds should be commenced as soon as possible before low tide. In the Schleswig-Holstein Wadden Sea this is usually 3 to 2 hours before low tide. It is a recommended to adopt the survey strategy to the falling and rising water level: at the start of the survey when the water level is still high, the landward borderlines should be mapped first. The survey should start near the shore and follow the falling tide. The monitoring of the seaward borderlines which are located in the lower intertidal, should be completed at around low tide. When the tides are rising the mapping should focus again on the landward seagrass border. For safety reasons it is recommended that the two surveyors start mapping in the same area of the seagrass bed and circulate it parallel.

The GPS devices should be set that they automatically record a position every 5 seconds. This ensures that the shape and size of the seagrass bed are mapped precisely and the data files have a size that can be handled.

Determination of a seagrass bed border

The best practice to determine a borderline for the areas of ≥ 5 % or ≥ 20 % cover density is to cross the seagrass bed starting from outside the bed. The bed should be approached perpendicular to its vegetation border. As soon as the seagrass cover reaches a density of

5 %, the borderline for the area with ≥ 5 % cover density is found. Now, one surveyor circulates the seagrass bed following this borderline (fig. 1). The best practice to follow the course of the border is to try to go along a line where you have seagrass with a cover density of more than 5 % to your left and a cover density of less than 5 % to your right (or vice versa).

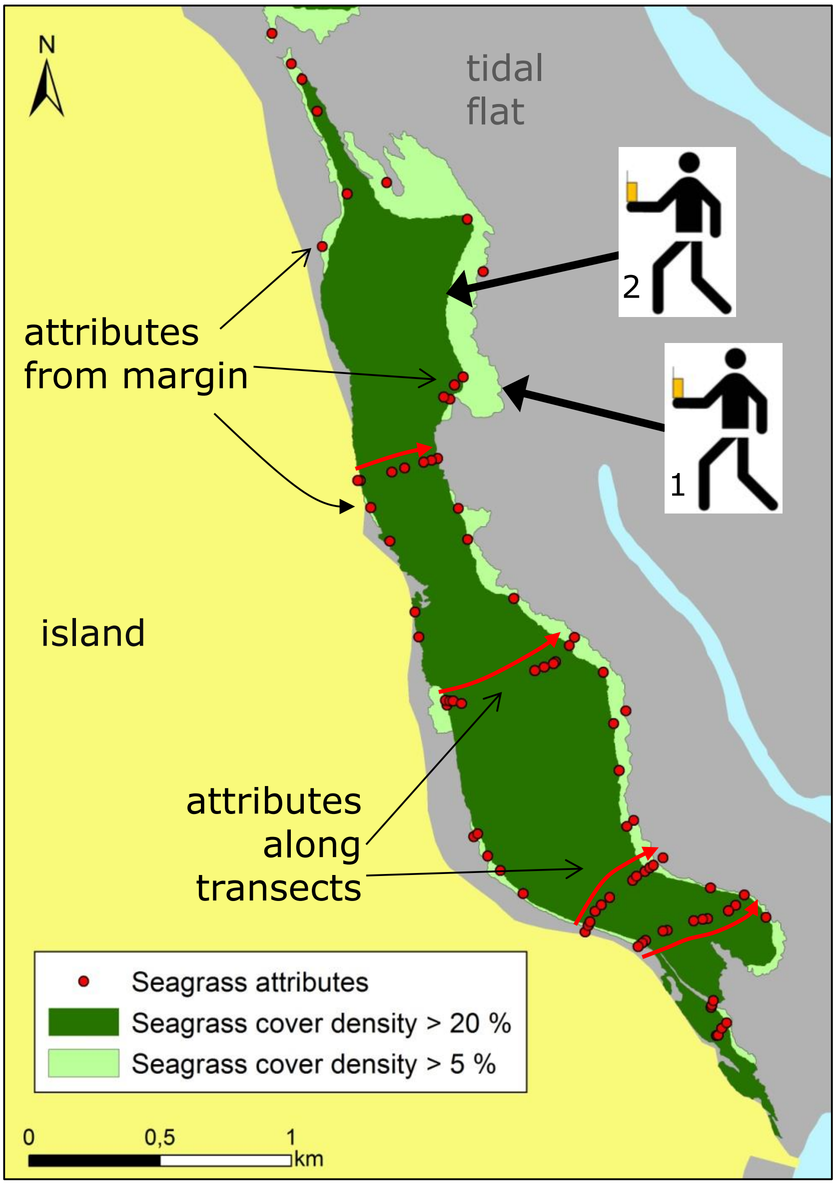


Fig. 1: Surveyor 1 circulates the seagrass bed along its borderline for the area with ≥ 5 % cover density while surveyor 2 does the same for the boundary of the area with ≥ 20 % cover density. Seagrass bed attributes were taken at the red points. Some attributes refer to the ecological status at the margins of the seagrass bed. Data from the inner part were collected along transects traversing the bed. The four transects can be seen as four lines of data points, that cross the entire bed and run perpendicular to the borderline. The red arrows indicate the directions in which the transects are running.

The borderline for the areas with ≥ 20 % cover density will probably be located more towards the centre of the bed and should be determined by the second surveyor accordingly. However, in dense beds with a clear and distinct border, the course of the borderline for the area with ≥ 5 %- and ≥ 20 % cover density can be identical as it can be seen in the north-western part of the seagrass bed in fig. 1 where it is close to the island.

When the boundary between bare tidal flat sediment and - more or less - dense seagrass vegetation is abrupt, clear and distinct (photo 2), the determination of the outer border of a bed is easy. It is far more difficult at a generally low seagrass cover density or especially when seagrass gradually declines which makes the transition to bare tidal flats slow and smooth. This leads to fuzzy and diffuse boundaries. The boundary is then hard to determine and following the course of the borderline simply requires practicing and field experience.

In case that cover densities vary a lot over short distances and / or boundaries are fuzzy and diffuse, the surveyor might lose the course of the borderline. In such a case it is recommended to stop, to briefly leave the area, and to restart nearby. The seagrass bed should be approached anew perpendicular to its vegetation border until the cover reaches the wanted density and the according borderline can be found again so that the survey can be continued.

Seagrass patches

Seagrass that is spatial heterogeneously distributed and organised as patches is another difficulty that can occur during field work. In this case, seagrass is not equally distributed over the tidal flat area but forms dense patches like islands while the tidal flat sediment between the patches is unvegetated (photo 3). The determination of a borderline is less difficult here as the surveyor maps along the outside margin of the field of seagrass patches. The surveyor simply follows the outer edge from one single patch at the outskirts of the field to the next single patch and so on (see dashed line in fig. 2 A or 3 A).

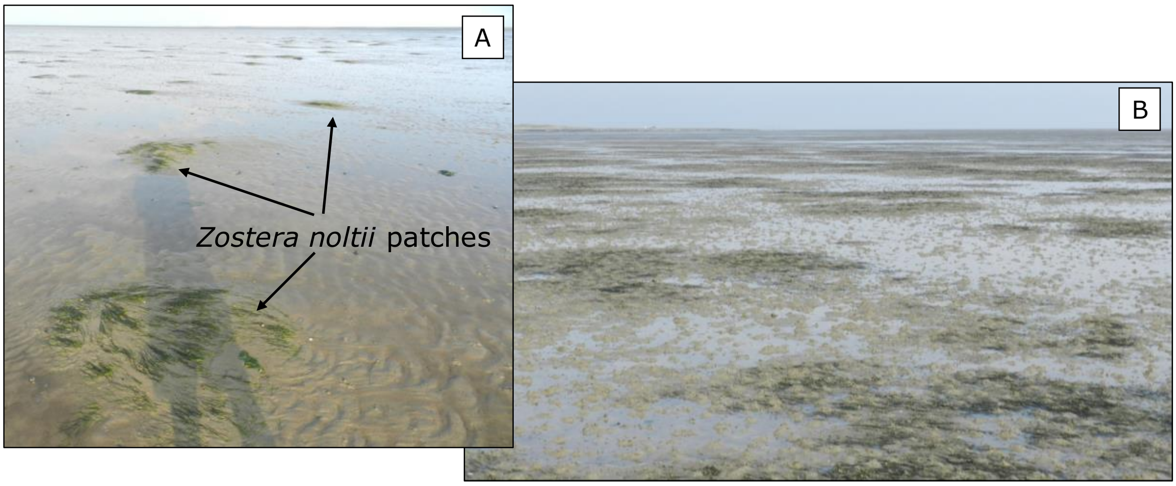


Photo 3: The mapping of seagrass which forms patches is a difficulty that surveyors have to deal with during field work. The dark spots in the two photos are patches of seagrass with unvegetated bare tidal flats between them.

It is more difficult to determine the average seagrass cover density, when seagrass is so spatial heterogeneously distributed. Some imagination by the surveyor is required here. According to the size and cover density of the seagrass patches and the distance between them, it has to be estimated how much seagrass would be needed to fill the unvegetated areas between the patches in order to achieve a homogenous and equal distribution. E.g. if the space between the seagrass patches is as big as the seagrass patches themselves, then imagine to double the patch area in order to fill the gaps. As the number of seagrass plants remains, this would go along with a reduction of the seagrass cover density by 50 % as half of the plants would be needed to fill the unvegetated parts (see fig. 2). If the unvegetated area between two seagrass patches is twice the size of a single patch, this would mean a reduction of the seagrass cover density by 66 % (see fig. 3) and so on. This interpolation has to be done in mind in order to roughly estimate the average seagrass cover density. The estimated average cover density is the value that has to be recorded (in other words the result seen in fig. 2 C or 3 C).

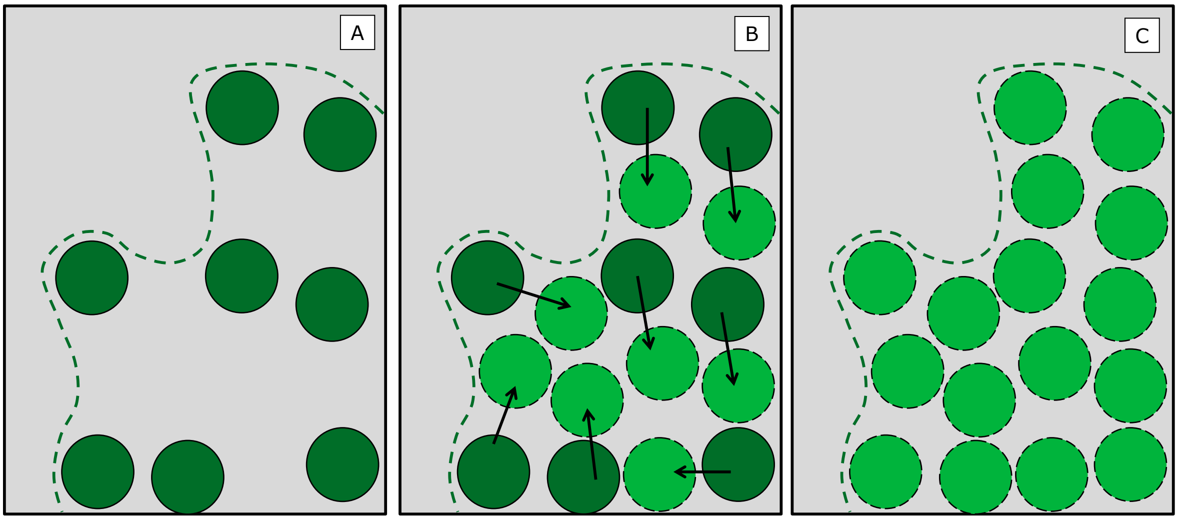


Fig. 2: The green points represent densely vegetated seagrass patches whereas the tidal flats (grey) between them are unvegetated (A). An interpolation in mind is done in order to estimate the average cover density of the entire seagrass patch field (area within the dashed line). In order to achieve a conceived equal distribution of seagrass within the entire field the seagrass patch area will be doubled in mind (B) which goes along with a reduction of the cover density of the patches by 50 % (C).

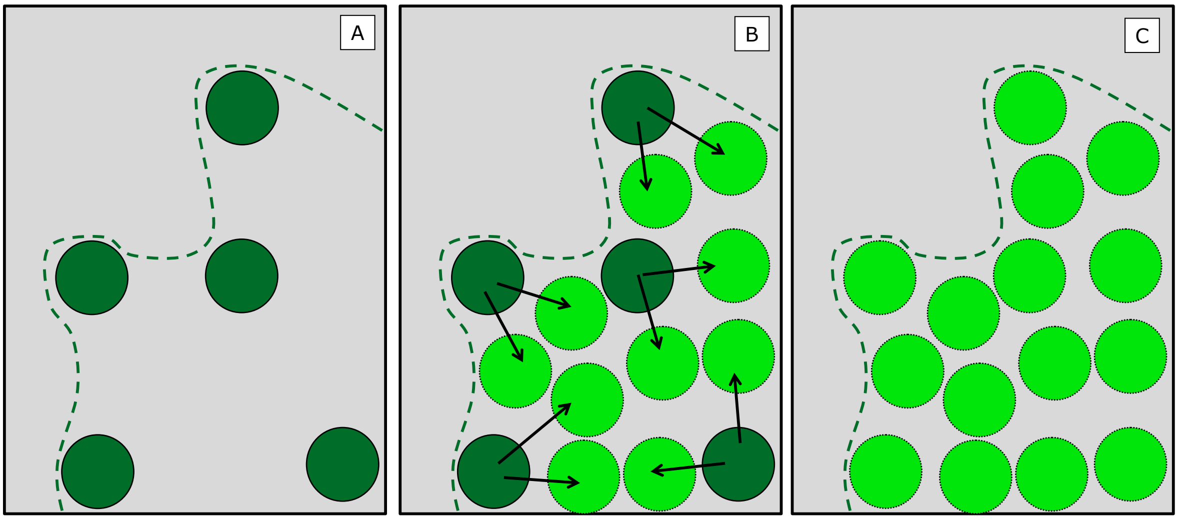


Fig. 3: The green points represent densely vegetated seagrass patches whereas the tidal flats (grey) between them are unvegetated (A). An interpolation of the spatial heterogeneously distributed seagrass is done in mind in order to estimate the average cover density of the entire seagrass field. In this case the seagrass patch area will be tripled in order to fill the unvegetated gaps between the patches (B) which results in a reduction of the cover density of the patches by 66 % (C).

Tidal channels

Tidal channels which cross a seagrass bed can also be a challenge during field work. Tidal channels are usually long and narrow and there is often more than one channel entering a seagrass bed. They enter a bed from outside and can intersect it deep to its centre. Due to the hydrodynamic conditions there is usually no seagrass growing in the tidal channel and there also an unvegetated buffer around the tidal channel banks (photo 4). As the seagrass border goes actually around the tidal channel, the surveyors would have to circulate the channel – strictly speaking. This would take too much time, especially regarding the fact that survey time is limited by the tides. Furthermore as tidal channels are usually narrow, the differences regarding the size of the seagrass bed whether a tidal channel is omitted or not is negligible.

Even though tidal channels should not be completely circulated, it has to be clearly indicated where they enter a seagrass bed and how wide the unvegetated zone around them is. This is done by following the seagrass borderline which will run parallel to the channel for some distance and then the channel should be crossed over. The notch in the course of the seagrass borderline and the straight line where the channel was crossed, indicate sufficiently where it enters the bed and the width of the unvegetated area (fig. 4). The distance how long the surveyor should walk along the tidal channel depends on the size and depth of the channel. However, it should be done at least for 50 to 100 m and the channel should only be crossed when seagrass can be clearly observed at the other side of the channel to make sure that the bed continues there.

Photo 4: A tidal channel intersecting a seagrass bed.

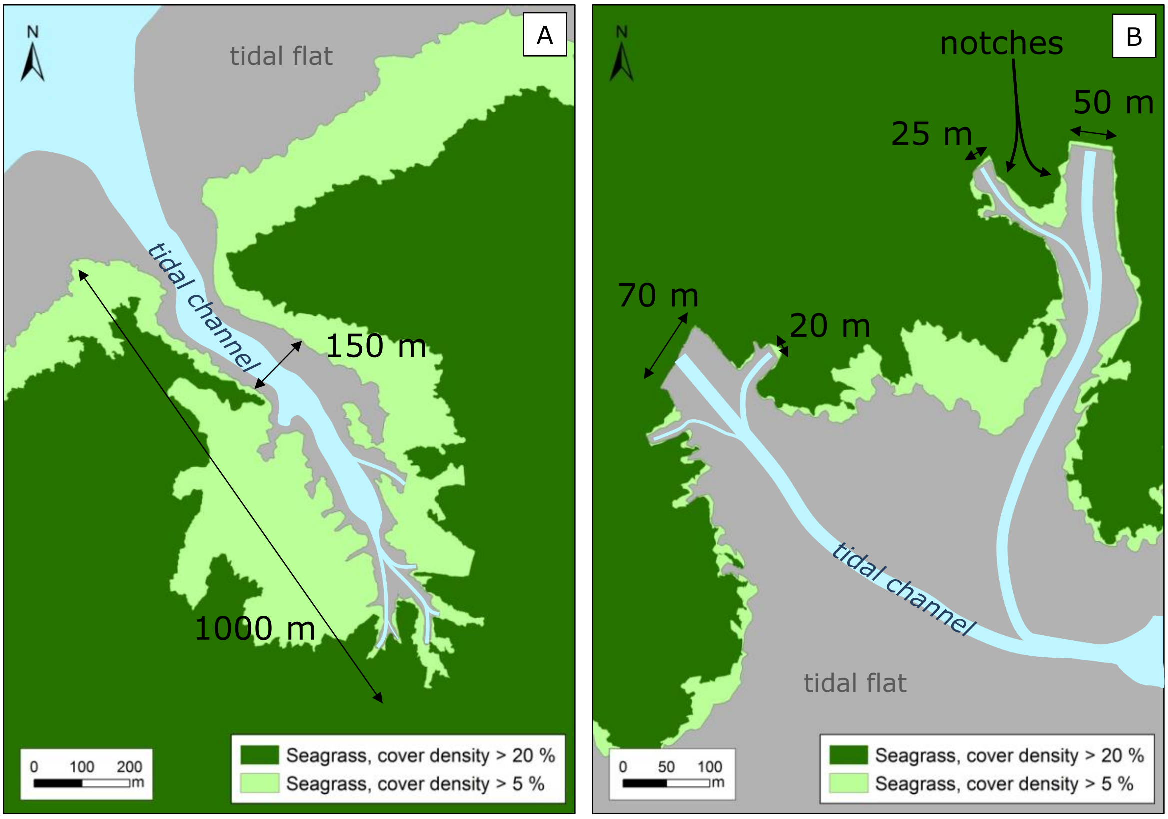


Fig. 4: Examples of tidal channels of different sizes entering a seagrass bed. The area around a tidal channel is usually unvegetated due to the strong hydrodynamics. A) This large and deep tidal channel had to be followed for about 1000 m to the area where it branches out before it was possible to cross it. The unvegetated area around the channel is in average about 150 m. B) The unvegetated area around this smaller tidal channel ranges from 20 to 70 m. The notches in the course of the seagrass borderline and the straight line where the channel was crossed over, indicate where it enters the bed and the width of the unvegetated area.

Transects through a seagrass bed

In order to get information from inside the seagrass bed, data is taken along transects which run perpendicular to the border and traverse the bed completely. The data is highly important to get complete information of the ecological status of the bed. It is also needed to assess the average cover density. Seagrass beds can show great variance regarding their structure (cover density, epiphyte cover, species composition etc.) and the number of transects and their interval depend on the size and width of the bed as well as on its homogeneity and heterogeneity, respectively. If a seagrass bed is heterogeneous and its structure varies a lot, more transects are required in order obtain significant data. For a homogeneous seagrass bed, less transects are needed. How diverse a seagrass bed is can be estimated by the structure of its margins. Therefore attributes from the beds margins are also important (fig. 1). If possible there should be a transect every 800 - 1000 m for heterogeneous beds and every 1200 – 1500 m for homogeneous beds. However, there should be at least one transect per seagrass bed, which should run through the centre. If the seagrass bed is very small and homogeneous, a single data point can also be sufficient.

A transect should start outside the 5 %-borderline, run perpendicular to the course of this border, and traverse the bed completely (fig. 1). The surveyor walks along this transect and records positions as well as the according attributes for each location in order to determine the inner features of a seagrass bed. A list of attributes that has to be recorded at every survey point is listed below (seagrass attributes). Most attributes are class-divided. Every time one of these parameters shifts to another class, a new data point has to be recorded.

The first data point should be taken directly at the 5 %-borderline. The position is recorded with the GPS device and all data according to the attribute list have to be specified. Walking along the transect, the next data point has to be recorded when one or more parameters have changed so much that they correspond with another class (in other words when a seagrass bed had an initial cover density of 20 – 40 % and now exceeds 40 %, it falls into the next class of 40 - 60 %). In order to avoid too small-scale phenomena, the changed parameter has to apply for an area of at least 10 m radius. The next data point has to be recorded when one of the parameter changes according to the classification. Regarding the seagrass cover this is either the case when the density increases to 60 – 80 % or decreases back to 20 – 40 %. If the seagrass cover density remains but e.g. the epiphyte cover or the macro algae (green algae) composition changes, a new data point has also to be recorded. According to this method the entire seagrass bed has to be crossed and finally, it ends with a certain number of data points along a transect. The number of data points gets higher the more heterogeneous the seagrass bed is.

In order to determine the overall character of the seagrass bed the data points have to be calculated according to the weighted average. The distance between the single data points determines the weighting (fig. 5). As a new data point is only recorded when the situation changes according to the classification, the distance from one data point to the other represents the space where a certain situation prevails. The longer the distance, the bigger the weighting of the according attribute. The example in figure 5 shows a transect through a seagrass bed with varying cover densities. The transect runs from south to north. It is important to notice the survey time of the data points in order to know the direction in which the transect is running in order to get the correct weighting of the attributes. In this example, at one point the seagrass bed has a cover of 60 – 80 % over a length of 91 m, followed by a 56 m long section with a cover of ≥ 80 % and a 90 m section with 60 – 80 % cover.

The weighted average can be calculated not only for the cover density but for each parameter. E.g. the area in the north shows a consistent cover density of < 20 % but data points with new attributes were taken due to changed green algae cover.

Based on the number of transects and their distance to each other, the characteristics for the entire seagrass bed can be assessed.

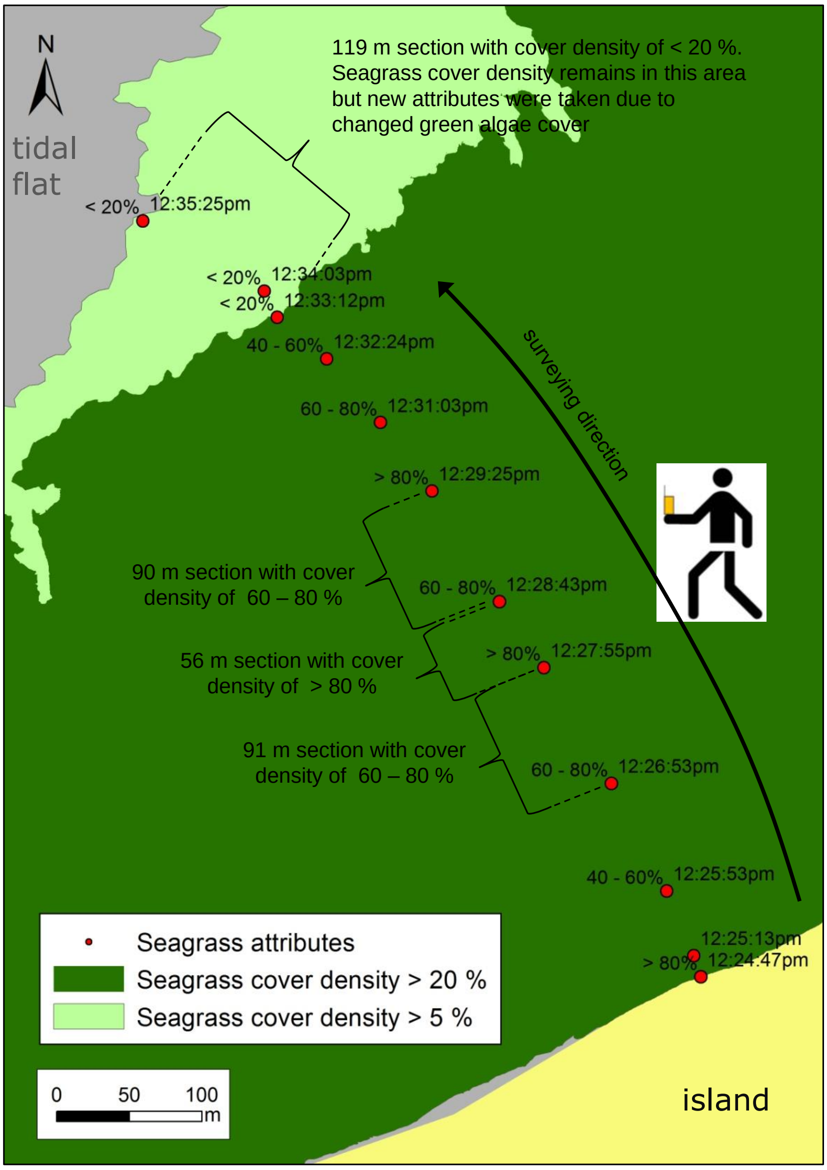


Fig. 5: The line of red data point represents a transect through a seagrass bed. This example focuses just on the varying seagrass cover densities. At each location (red point) the survey time and the classified seagrass cover density (40 – 60 %, 20 – 40 % etc.) is given. The survey time of the locations is important to see in which direction the transect was taken (from south to north). The distances between the red data points determine the weighting for the calculation of the weighted average.

Seagrass attributes at a data point

When a data point is taken, a set of parameters which are of ecological relevance for seagrass has to be recorded. A preselected list of attributes in defined classes is given. Every time a data point is taken each parameter has to be specified, even if just one of these attributes has changed since the previous data point.

In addition to the position, these are the relevant attributes and their defined classes that have to be recorded:

1) date
2) time
3) seagrass cover density (none, < 5%, 5 - 20 %, 20 – 40 %, 40 – 60 %, 60 – 80 %, ≥ 80 %)
4) seagrass species composition (none, *Zostera noltii*, *Zostera marina*, Mixed *Zostera*)
5) epiphyte cover density (none, < 25 %, 25 - 75 %, ≥ 75 %)
6) macro algae cover density (none, < 20 %, 20 – 40 %, 40 – 60 %, 60 – 80 %, ≥ 80 %)
7) the most dominant macro algae (none, *Gracilaria*, *Enteromorpha*, *Chaetomorpha*, *Ulva*)
8) the second most dominant macro algae (none, *Gracilaria*, *Enteromorpha*, *Chaetomorpha*, *Ulva*)
9) substrate (tidal flat, marsh / kley)
10) comment

The parameter 'seagrass cover density' is a scale for abundance. It has to be assessed how many per cent of the tidal flat sediments are covered with seagrass plants. The seagrass cover density has to be specified according to the classes listed above.

The 'seagrass species composition' presents biodiversity. In this case, the most dominant species at the position of the data point within a 10 m radius have / has to be specified. Once a seagrass species contributes with more than 25 % to the species community, this is regarded as ecological important and the species is significant at this location. If just one seagrass species is regarded to establish a seagrass bed at a certain point, this species has to contribute with more than 75 % to the seagrass species composition while accordingly the other seagrass species contributes with less than 25 %. If both seagrass species contribute with more than 25 % to the species composition, they are both regarded as significant and the area is classified as ‘Mixed Zostera’. The contribution to the species community is relative and irrespective of the cover density.

‘Epiphyte cover density’ indicates the growth of algae on the seagrass leaves. According to the classes listed above it has to be assessed to which degree the seagrass leaves are overgrown with epiphytes (photo 5).

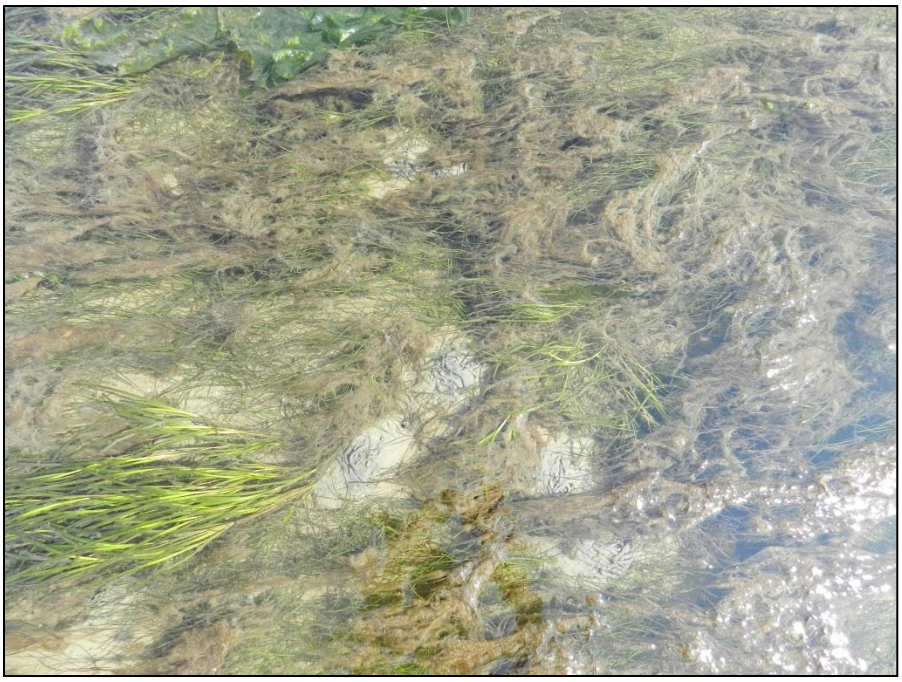


Photo 5: Seagrass overgrown with brown epiphytes.

The parameter ‘macro algae (green algae) cover density’ is a scale for the abundance of macro algae within a seagrass bed. All macro algae outside the bed are not to be considered. Macro algae usually accumulate on top of seagrass and the tidal flat sediments and it has to be assessed how many per cent of the area are covered with macro algae. The macro algae cover density has to be indicated according to the classes listed above.

If there is an occurrence of macro algae, the most dominant has to be specified (‘the most dominant macro algae’). As it is not possible in the field to identify the algae to species level, the distinction is made for the genera *Gracilaria*, *Enteromorpha*, *Chaetomorpha* or *Ulva*.

When macro algae are occurring, there is often more than one genera present. If applicable, name the second most dominant macro algae (*Gracilaria*, *Enteromorpha*, *Chaetomorpha* or *Ulva*). If just one genera is present, indicate ‘none’ here.

The sediment (‘substrate’) is only distinguished between tidal flat sediment and marsh / kley. This should be checked to a depth of 10 – 20 cm.

Remarkable features should be recorded under ‘comment’. This can be large sandy bedforms (megaripples) interfering with seagrass, peat near the surface, an unusually high presence of snails, thick mats of macro algae (green algae), anoxic sediment conditions, a high water level during the survey etc.

It is recommended to take pictures at each data point in order to document the seagrass situation, like e.g. species composition, epiphyte cover etc. Pictures can be taken of the general scenery but also vertically from about 1 m height. A folding role in the picture can help as a scale.

Types of data points

There are three different types of data points:

1. Transect data points
2. Marginal data points
3. Checking data point

Transect data points are collected along transects which run perpendicular to the border and traverse the bed completely in order to get information from its inner areas (see ‘Transects through a seagrass bed’).

Marginal data points are sampled when the surveyors run along the 5 %- und 20 %-borderline. Their detailed information (such as epiphyte cover and species composition) usually only refer to an area with a radius of 10 – 15 m at the margin of the seagrass bed while they can depict the general seagrass situation within a 50 m radius (such as cover density and spatial organisation i.e. patches). However, they give valuable information of the seagrass bed structure and composition and are also important as an indicator for its degree of heterogeneity. The number of marginal data points that is collected depends on the size and degree of heterogeneity of seagrass bed structure but t is also within the discretion of the surveyor. However, it is recommended to take every 1000 m a marginal data point. Marginal data points should not only be collected at regular intervals but also when there are significant and large-scale changes in the seagrass beds feature. This can be a remarkable shift in species composition, a high occurrence of epiphytes or macro algae (green algae), significant changes in the cover density but also the occurrence of large sandy bedforms (megaripple) within the bed or when the spatial structure changes from evenly, homogenously distributed seagrass to dense seagrass patches with unvegetated tidal flats between them. By definition, a seagrass bed exists and has to be mapped when seagrass occurrence has a cover density of $\geq$ 5 %. The areal extent of seagrass occurrence with a cover density below 5 % is not mapped (not as a polygon) but checking data point should be taken. Sparsely vegetated seagrass occurrences can be the initial population for a future seagrass bed. Checking data points should also be taken in areas that could be a potential habitat even though when there is no seagrass present. It is important to document that during the survey such tidal flat areas were checked and not accidentally forgotten. Checking data points can also be used to record an unusual high occurrence of macro algae even though when it is not interfering with seagrass.

All data points have in common that for every single one of them the list of attributes mentioned above has to be specified (see ‘Seagrass attributes at a data point’).

3 Data processing after field work

The borderlines for the seagrass areas with ≥ 5 % and – if applicable - ≥ 20 % cover density are taken directly during the field surveys. These data are supplemented by data points with seagrass attributes. Some of the required data to calculate an Ecological Quality Ratio (EQR) are not taken directly in the field but are obtained afterwards by analysing and processing of the collected field data. This is due to logistical reasons and the limited survey time as well as to try to limit the already extensive field work.

The analysis and editing of the field data should be done with a Geographic Information System (GIS). For the calculation of the EQR, the area of the very densely populated parts of the seagrass bed (≥ 60 % cover density) are required – if applicable – as well as the area covered by the different seagrass species.

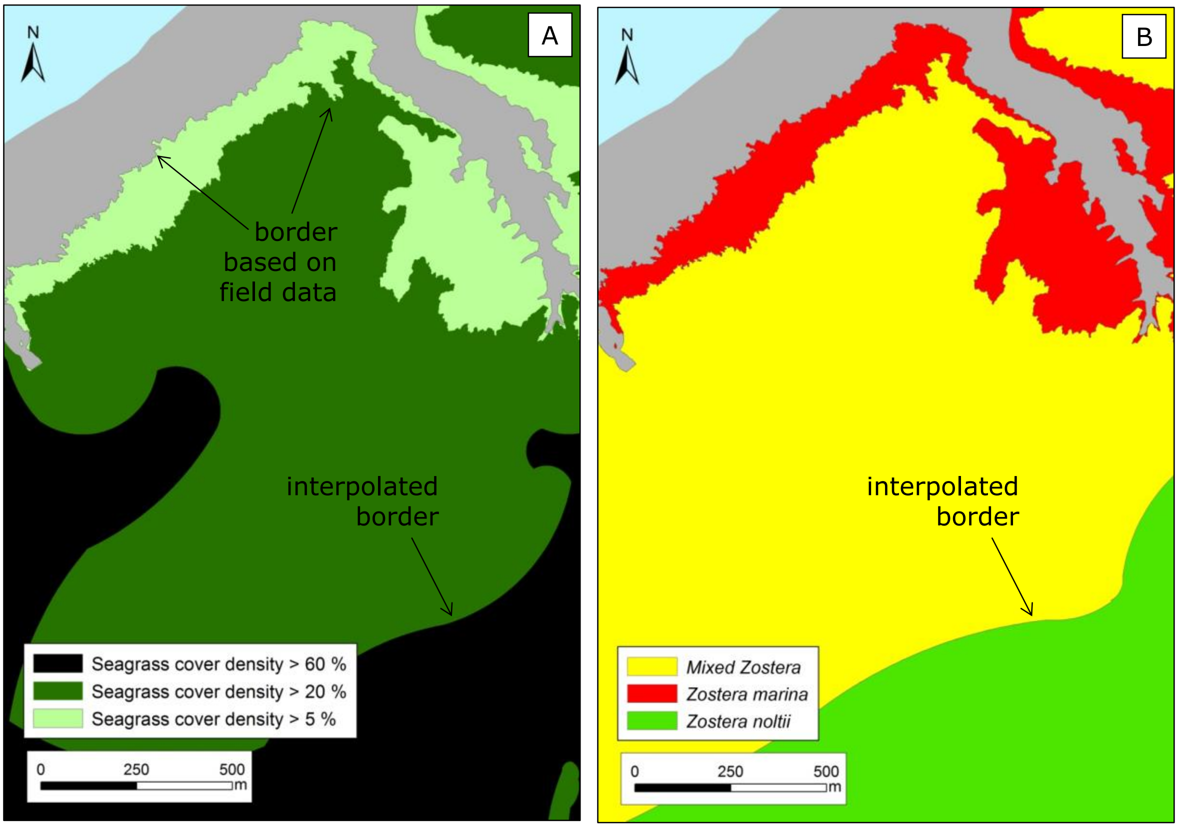


Fig. 6: A seagrass bed with detailed borders based on direct measures in the field and interpolated border shown as curved bends. The area with high cover density (≥ 60 %) (A) and the spatial distribution of the different species compositions (B) are interpolated. In this example *Zostera marina* dominates the area with a low seagrass cover density (≥ 5 %) why these areas are identical in A and B.

The data on the size, shape and position of area with ≥ 60 % cover density are obtained by a manual interpolation which is done in GIS. The interpolation is conducted by hand according to the seagrass attributes which were recorded along the transects and the margins. High-resolution aerial photographs as well as photos taken in the field and memories on the situation in the field should support the determination of the course of boundaries. It is recommended to do this interpolation shortly after the field survey before memories are receding. To clearly show at first glance that the boundaries for these areas are interpolated, the course of the boundaries is slightly rounded with curved bends which would not occur like this in nature. It should be avoided to pretend an accuracy that does not exist and it should be illustrated that the areas contain some uncertainty. The interpolated boundaries have to differ clearly from the detailed borders that are recorded directly during the field survey.

The designation of the seagrass species composition, namely areas dominated by *Zostera noltii*, *Zostera marina* or by both species (Mixed *Zostera*) is accordingly to the above mentioned interpolation method for the areas with ≥ 60 % cover density (see fig. 6 B and 7 B).

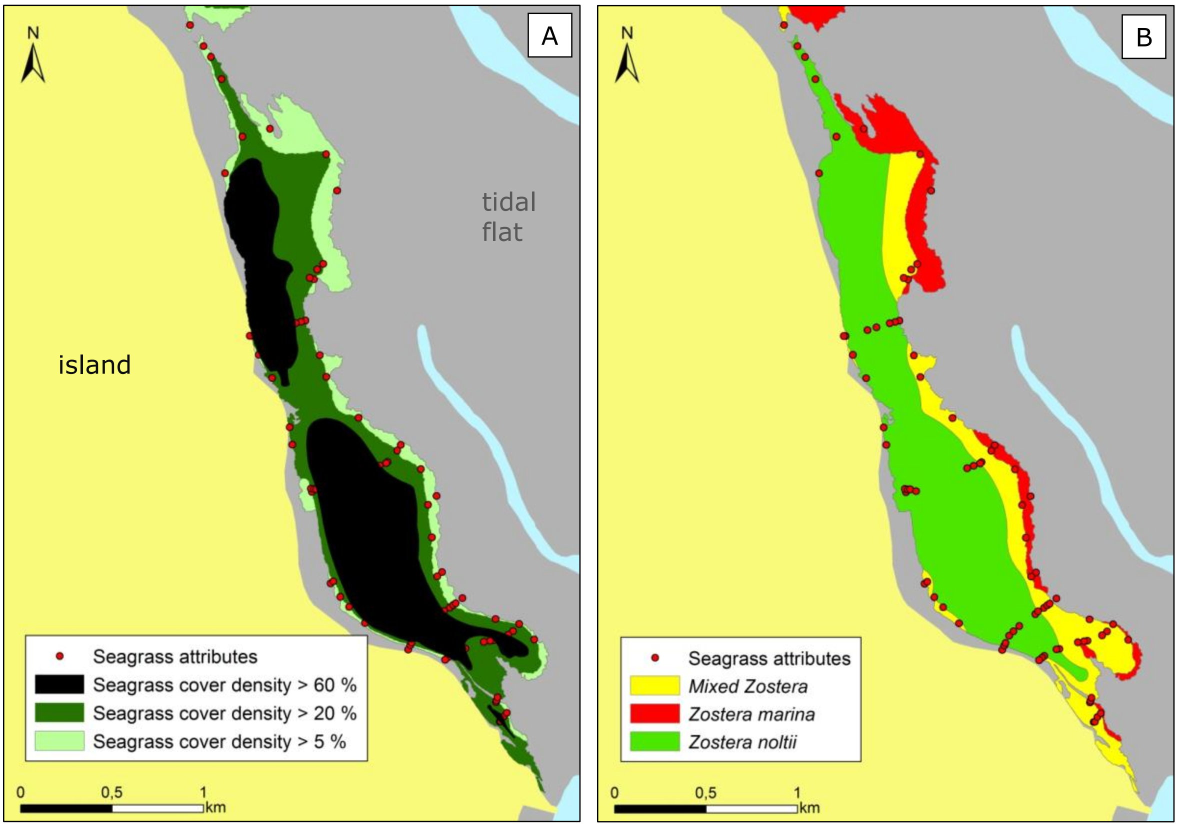


Fig. 7: A seagrass bed with the interpolated area of high cover density (≥ 60 %) (A) and the interpolated spatial distribution of the different species compositions (B).

4 SHWAP - Calculating Ecological Quality Ratios for the assessment of the Schleswig-Holstein Wadden Sea

An Ecological Quality Ratio (EQR) is a scale used for the EU Water Framework Directive to express an ecological status. The EQR for the coastal water body of the Schleswig-Holstein Wadden Sea is calculated on the base of seagrass and green algae data. Seagrass data are obtained by field surveys as green algae data are collected by an aerial monitoring (see introduction). This assessment system in the Schleswig-Holstein Wadden Sea is called SHWAP (Schleswig-Holstein Wadden Sea Assessment of Phytobenthos).

Seagrass, as an acknowledged indicator for ecosystem health, and green algae are responding to eutrophication: as seagrass declines at high eutrophication levels, green algae increases and vice versa at low eutrophication levels. Even though eutrophication levels are declining, it is still regarded to be a major ecological problem for the Wadden Sea. In short, the less green algal mats and the more seagrass beds there are, the better may be the environmental quality of the Wadden Sea. Based on this, a rating matrix to calculate an EQR was designed (fig. 8). In this rating matrix the 'biological quality element seagrass' contributes with three parameters ('coverage of tidal flat area', 'share of ≥ 60 % cover density' and 'occurrence of both species') while the 'biological quality element green algae' is represented by two parameters ('coverage of tidal flat area' and 'share of ≥ 60 % cover density'). These five parameters are needed to determine an EQR. They are weighted according their ecological significance and they all follow a geometric progression, except for 'occurrence of both species'.

The two major water bodies of the Schleswig-Holstein Wadden Sea, namely the Northfrisian Wadden Sea and the Dithmarscher Wadden Sea, have a different ecological potential for seagrass. Therefore two different rating matrixes with different reference values had to be designed for each water body and also two individual EQRs are assessed for each water body (see fig. 8 and 9). The differences of the two matrixes are for seagrass as for green algae the classification is the same. The references values for seagrass and green algae, on which the matrixes are based, were determined by the analysis of historic aerial photographs from 1926 to 1939 (Dolch et al. 2010), historic surveys and references (Nienburg 1927, Wohlenberg 1937, Raabe 1987) and field observations (Reise and Siebert 1994, Reise pers. comm.). For further details about the determination of reference values and the general concept of the rating matrix see Dolch et al. 2009 and Dolch et al. 2010.

	Ecological Quality Assessment of the Northfrisian Wadden Sea using a macrophytobenthos index						
	Ecological Quality classes	0	1	2	3	4	weighting %
		bad	poor	moderate	good	high	
	class boundaries	0 – 0.19	0.2 – 0.39	0.4 – 0.59	0.6 – 0.79	0.8 – 1.0	
biological quality element: seagrass [6]	coverage of tidal flat area (%) [1]	< 2	2 - 4.9	5 - 9.9	10 - 19.9	20 - 100	50
	share of ≥ 60 % cover density (%) [2]	< 6	6 - 11.9	12 - 24.9	25 - 49.9	50 - 100	10
	occurrence of both species (%) [3]	< 20	20 - 39.9	40 - 59.9	60 - 79.9	80 - 100	10
biological quality element: green algae [7]	coverage of tidal flat area (%) [4]	100 - 15	14.9 - 7	6.9 - 3	2.9 - 1	< 1	20
	share of ≥ 60 % cover density (%) [5]	100 - 50	49.9 - 25	24.9 - 12	11.9 - 6	< 6	10

1 seagrass beds with cover density of ≥ 20 %.

2 percentage of area with seagrass cover density of ≥ 60 % in relation to total seagrass bed area (cover density ≥ 20 %).

3 single occurrence are disregarded (seagrass species has to cover ≥ 5 % of the area of a bed with cover density of ≥ 5 %).

4 mats of green algae with cover density of ≥ 20 %.

5 percentage of area with green algae cover density of ≥ 60 % in relation to the total green algae area (cover density ≥ 20 %).

6 data refers to the maximum extent during the annual growth season (data recorded from mid July to mid September).

7 data refers to the observed maximum extent during the annual growth season (varies between June and September).

Fig. 8: The rating matrix to determine an EQR for the Northfrisian Wadden Sea.

	Ecological Quality Assessment of the Dithmarscher Wadden Sea using a macrophytobenthos index						
	Ecological Quality classes	0	1	2	3	4	weighting %
		bad	poor	moderate	good	high	
	class boundaries	0 – 0.19	0.2 – 0.39	0.4 – 0.59	0.6 – 0.79	0.8 – 1.0	
biological quality element: seagrass [6]	coverage of tidal flat area (%) [1]	< 0.3	0.3 - 0.69	0.7 - 1.49	1.5 - 2.9	3 - 100	50
	share of ≥ 60 % cover density (%) [2]	< 6	6 - 11.9	12 - 24.9	25 - 49.9	50 - 100	10
	occurrence of both species (%) [3]	< 20	20 - 39.9	40 - 59.9	60 - 79.9	80 - 100	10
biological quality element: green algae [7]	coverage of tidal flat area (%) [4]	100 - 15	14.9 - 7	6.9 - 3	2.9 - 1	< 1	20
	share of ≥ 60 % cover density (%) [5]	100 - 50	49.9 - 25	24.9 - 12	11.9 - 6	< 6	10

1 seagrass beds with cover density of ≥ 20 %.

2 percentage of area with seagrass cover density of ≥ 60 % in relation to total seagrass bed area (cover density ≥ 20 %).

3 single occurrence are disregarded (seagrass species has to cover ≥ 5 % of the area of a bed with cover density of ≥ 5 %).

4 mats of green algae with cover density of ≥ 20 %.

5 percentage of area with green algae cover density of ≥ 60 % in relation to the total green algae area (cover density ≥ 20 %).

6 data refers to the maximum extent during the annual growth season (data recorded from mid July to mid September).

7 data refers to the observed maximum extent during the annual growth season (varies between June and September).

Fig. 9: The rating matrix to determine an EQR for the Dithmarscher Wadden Sea.

As described in the previous chapter, quantitative (bed area) and qualitative data (attributes) of seagrass beds are collected in the field. The overall ecological situation of each seagrass bed is assessed primarily on the basis of the weighted data along each transect and then again on the number of transects (see 'Transects through a seagrass bed'). Further data is gained by the processing after the field work.

Some of these acquired data are needed to calculate an EQR which indicates the ecological status of the survey area. The three parameters of the biological quality element seagrass mean in detail:

- coverage of tidal flat area (%): the percentage value of the tidal flat area that is covered with seagrass with a cover density of ≥ 20 %.

  Besides the area of all seagrass beds that grow in the survey area and have a cover density of ≥ 20 %, the tidal flat area is also needed in order to calculate the percentage coverage in the survey area.

- share of ≥ 60 % cover density (%): referring to the seagrass area with a cover density of ≥ 20 %, the percentage value of the seagrass area with a cover density of ≥ 60 %.

- occurrence of both species (%):referring to the total area of all seagrass beds (≥ 5 % cover density) in a survey area, the percentage value of the area of seagrass beds that are overall classified as 'Mixed beds' (fig. 10).

  After the field work, the seagrass data is processed and areas dominated by *Zostera noltii*, *Zostera marina* or by both species are assigned within a bed (see chapter 3). When a seagrass species covers more than 5 % of the total area of a bed, referring to a cover density ≥ 5 %, this is regarded as an ecologically relevant contribution to the development of the seagrass bed. This contribution is relative and independent from the cover density of the area that contributes. As soon as the share of the area dominated by *Zostera noltii* and the share of the area dominated by *Zostera marina* exceeds 5 % of the total bed area or when the area 'Mixed *Zostera'* covers more than 10 %, a bed is to be classified overall as 'Mixed bed'. Here, it is important to refer to the area with ≥ 5 % cover density as otherwise *Zostera marina* would be underrepresented.

The two parameters of the biological quality element green algae mean in detail:

- coverage of tidal flat area (%): the percentage value of the tidal flat area that is covered with green algae with a cover density of ≥ 20 %.
- share of ≥ 60 % cover density (%): referring to the green algae area with a cover density of ≥ 20 %, the percentage value of the green algae area with a cover density of ≥ 60 %.

The occurrence of green algae on the tidal flats can be variable. When green algae are monitored several times a year, the annual maximum value should be taken in order to express the degree of eutrophication. The maximum values have to be taken for the Northfrisian Wadden Sea and the Dithmarscher Wadden Sea separately.

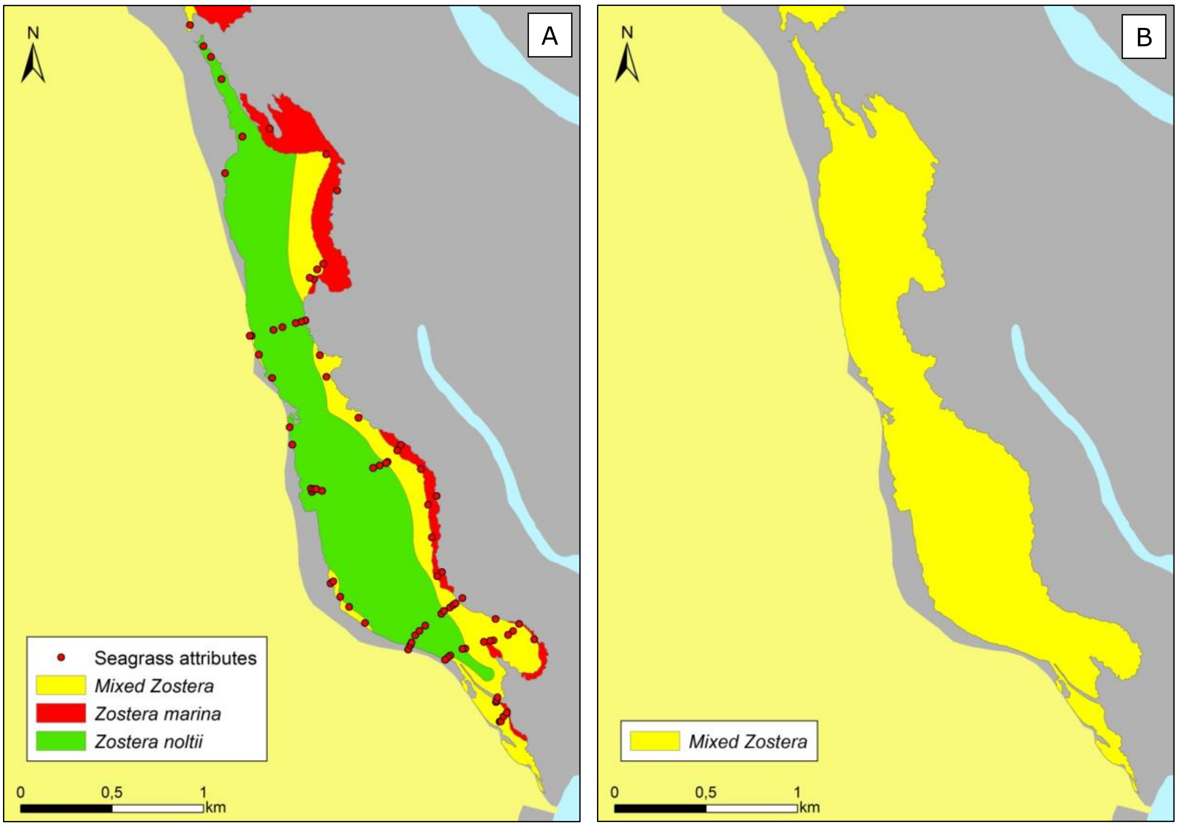


Fig. 10: Even though areas dominated by *Zostera noltii* (A) are prevailing (62 %) in this seagrass bed, it is overall classified as 'Mixed bed' (B) due to the sufficient share of areas dominated by *Zostera marina* (13 %) and by both species (Mixed *Zostera,* 25 %).

For each of these five parameters a norm EQR is determined (see fig. 8 and 9). The calculation method considers the entire range of an ecological quality class which ensures a precise and steplessly assessment. According to the value of the norm EQR it can be discerned if a parameter is closer to the upper or lower limit of the ecological quality class. The calculation formula is:

$$norm\ EQR = \frac{(\text{data} - \text{low\_lim\_data}) * (\text{up\_lim\_normEQR} - \text{low\_lim\_normEQR})}{(\text{up\_lim\_data} - \text{low\_lim\_data})} + \text{low\_lim\_normEQR}$$

This formula applies to both biological quality elements, seagrass and green algae. The difference is that referring to seagrass it is an ascending series (the higher the measured value the higher the EQR) while it is a descending series for green algae (the higher the measured value the lower the EQR). In other words: within an ecological quality class for seagrass, a measured high value is close to the upper limit of the class while a measured low value is close to the lower limit of the class. For green algae it is conversely: within an ecological quality class, a measured high green algae value is close to the lower limit of the class while a measured low value is close to the upper limit of the class.

A sample calculation for the norm EQR 'coverage of tidal flat area (%)' of the biological quality element seagrass illustrates the application of the formula:

The area of all seagrass beds in the Northfrisian Wadden Sea is measured in m^2. Referring this to the tidal flat area reveals that 17.73 % of the tidal flats in survey area are covered with seagrass. According to the rating matrix in fig. 8 a tidal flat coverage with seagrass between 10 and 19.9 % is regarded as 'good' and has a norm EQR between 0.6 and 0.79.

measured data (data), converted in percentage coverage	= 17.73
upper limit of class for measured data (up_lim_data)	= 19.9
lower limit of class for measured data (low_lim_data)	= 10
upper limit of class for norm EQR (up_lim_normEQR)	= 0.8
lower limit of class for norm EQR (low_lim_normEQR)	= 0.6

From this follows the calculation mentioned above:

$$norm\ EQR = \frac{(17.73 - 10) * (0.8 - 0.6)}{(19.9 - 10)} + 0.6$$

$$norm\ EQR = 0.75$$

The norm EQR of 0.75 is within the class ‘good’ and shows that the measured value is close to the upper limit of the ecological quality class. It has a tendency to the class ‘high’.

Supposed 2.78 % of the tidal flats in a survey area are covered with green algae (fig. 8: biological quality element green algae, ’coverage of tidal flat area (%)’). According to the rating matrix, a tidal flat coverage with green algae between 2.9 and 1.0 % is regarded as ‘good’ and has a norm EQR between 0.6 and 0.79. The calculation is as follows:

measured data (data), converted in percentage coverage	= 2.78
upper limit of class for measured data (up_lim_data)	= 1.0
lower limit of class for measured data (low_lim_data)	= 2.9
upper limit of class for norm EQR (up_lim_normEQR)	= 0.8
lower limit of class for norm EQR (low_lim_normEQR)	= 0.6

$$norm\ EQR = \frac{(2.78 - 2.9) * (0.8 - 0.6)}{(1.0 - 2.9)} + 0.6$$

$$norm\ EQR = 0.62$$

The norm EQR of 0.62 shows that the measured value is close to the lower limit of the ecological quality class and has a tendency to the class ‘moderate’.

After the five norm EQRs for the five parameters are calculated they are allocated according to their weighting given in the last column of the rating matrix. This results in one EQR for the Northfrisian Wadden Sea and one EQR for the Dithmarschen Wadden Sea. These are the values used for the EU Water Framework Directive.

5 Summary

Seagrasses are of high ecological importance for coastal ecosystems but sensitive towards a variety of environmental parameters, particularly to human induced eutrophication. As they are responding quickly to changed environmental conditions, this makes seagrass a suitable indicator for ecosystem health. It is used as such in the EU Water Framework Directive, which has the aim that water bodies should achieve a good status.

In the Schleswig-Holstein Wadden Sea the size, species composition and cover density of intertidal seagrass beds are taken as indicators for the ecological status of this coastal water body. Continuous monitoring programs are carried out to obtain these data for the EU Water Framework Directive. One major monitoring program implies field surveys with GPS devices that are carried out on foot when the intertidal seagrass beds have their seasonal maximum areal extent and density. This report is a kind of handbook for field surveys of intertidal seagrass beds and the given recommendations and suggestions are based on extensive field experience. The aim is to present a practical and safe but also accurate and precise way to monitor intertidal seagrass beds and to introduce a method how to assess the ecological status of coastal waters based on this data.

According to the Trilateral Monitoring and Assessment Programme (TMAP), the area of each seagrass bed with ≥ 5 % and – if applicable - ≥ 20 % cover density has to be mapped. The 5 %- and 20 %-borderlines have to be determined in the field in order to map the according areas. Seagrass that is spatially organised in form patches as well as tidal channels intersecting a seagrass bed are challenges during field work and approaches for solution are presented. Besides areal seagrass data, point data also need to be collected. A list of seagrass attributes that have to be specified at each survey point ensures the acquisition of important qualitative data. Point data are also needed for the data processing. Areas of a high seagrass cover density (≥ 60 %) and the spatial distribution of the species composition are identified after the field work. The measured or interpolated parameters are used to calculate an Ecological Quality Ratio (EQR) to express the current ecological status for the EU Water Framework Directive.

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6 References

Burkholder, J.M., Tomasko, D.A., Touchette, B.W. (2007). Seagrasses and eutrophication. Journal of Experimental Marine Biology and Ecology 350: 46-72.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., van den Belt, M. (1997). The value of the world's ecosystem services and natural capital. Nature 387: 253-260.

Cunha, A. H., Santos, R.P., Gaspar, A.P., Bairros, M.F. (2005). Seagrass landscape-scale changes in response to disturbance created by the dynamics of barrier islands: A case study from Ria Formosa (Southern Portugal). Estuarine, Coastal and Shelf Science 64: 636-644.

CWSS (Common Wadden Sea Secretariat, World Heritage Nomination Project Group) (2008). Nomination of the Dutch-German Wadden Sea as World Heritage Site. Wadden Sea Ecosystem No. 24. Common Wadden Sea Secretariat, Wilhelmshaven, Germany.

de Jonge, V.N., de Jong, D.J. (1992). Role of tide, light and fisheries in the decline of *Zostera Marina* L. in the Dutch Wadden Sea. Netherlands Institute for Sea Research Publication Series 20: 161-176.

den Hartog, C. (Ed.) (1970). The seagrasses of the world. North-Holland Publ Comp, Amsterdam, London.

den Hartog, C. (1987). Wasting disease and other dynamic phenomena in *Zostera* beds. Aquatic Botany 27: 3-14.

den Hartog, C., Phillips R.C. (2001). Common structures and properties of seagrass beds fringing the coasts of the world. In: Reise, K. (Ed.). Ecological Comparisons of Sedimentary Shores. Springer, Berlin, Heidelberg, New York: 195-212.

Dolch, T., Buschbaum, C., Reise, K. (2009). Seegras-Monitoring im Schleswig-Holsteinischen Wattenmeer 2008 – Forschungsbericht zur Bodenkartierung ausgewählter Seegrasbestände. LLUR, Flintbek.

Dolch, T., Buschbaum, C., Reise, K. (2010). Seegras-Monitoring im Schleswig-Holsteinischen Wattenmeer 2009 – Forschungsbericht zur Bodenkartierung von Seegrasbeständen in ausgewählten Gebieten. LLUR, Flintbek.

Duarte, C.M. (1995). Submerged aquatic vegetation in relation to different nutrient regimes. Ophelia 41: 87–112.

European Union (2000). Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. Official Journal L 327, 22/12/2000: 0001 – 0073.

Fonseca, M.S. (1996). The role of seagrasses in nearshore sedimentary processes: a review. Estuarine shores: evolution, environments, and human alterations. K. F. Nordstrom, Roman, C.T. (Eds.). Chichester, Wiley: 261-186.

Foden, J., Brazier, D.P. (2007). Angiosperms (seagrass) within the EU water framework directive: A UK perspective. Marine Pollution Bulletin 55: 181-195.

Giesen, W.B.J.T., van Kartwijk, M.M., den Hartog, C. (1990). Eelgrass condition and turbidity in the Dutch Wadden Sea. Aquatic Botany 37: 71-85.

Green, E.P., Short, T.F. (Ed.) (2003). World Atlas of Seagrasses. University of California Press.

Koch, E.W. (2001). Beyond Light: Physical, Geological, and Geochemical Parameters as Possible Submersed Aquatic Vegetation Habitat Requirements. Estuaries 24(1): 1-17.

Kolbe, K., Kaminski, E., Michaelis, H., Obert, B., Rahmel, J. (1995). Macroalgal mass development in the Wadden Sea: first experiences with monitoring system. Helgoland Marine Research 49: 519–528.

Krause-Jensen, D., Greve, T.M., Nielsen, K. (2005). Eelgrass as a bioindicator under the European Water Framework Directive. Water Resources Management 19: 63-75.

Lotze, H.K. (2005). Radical changes in the Wadden Sea fauna and flora over the last 2,000 years. Helgoland Marine Research 59: 71-83.

Marencic, H. Vlas, J. de (Eds) (2009). Quality Status Report 2009. Wadden Sea Ecosystem No. 25. Common Wadden Sea Secretariat, Trilateral Monitoring and Assessment Group, Wilhelmshaven, Germany.

Nacken, M., Reise, K. (2000). Effects of herbivore birds on intertidal seagrass beds in the northern Wadden Sea. Helgoland Marine Research 54: 87-94.

Nienburg, W. (1927). Zur Ökologie der Flora des Wattenmeeres. I. Der Königshafen bei List auf Sylt. Wiss Meeresunters (Abt Kiel) 20:146-196.

Orth, R.J., Carruthers, T.J.B., Dennison, W.C., Duarte, C.M., Fourqurean, J.W., Heck, K.L., Hughes, A.R., Kendrick, G.A., Kenworthy, W.J., Olyarnik, S., Short, F.T., Waycott, M., Williams, S.L. (2006). A global crisis for seagrass ecosystems. Bioscience 56: 987-996.

Philippart, C.J.M., Dijkema, K.S., van der Meer, J. (1992). Wadden Sea Seagrasses: Where and Why? Netherland Institute for Sea Research 20: 177-191.

Polte, P., Schanz, A., Asmus, H. (2005). The contribution of seagrass beds (*Zostera noltii*) to the function of tidal flats as a juvenile habitat for dominant, mobile epibenthos in the Wadden Sea. Marine Biology 147: 813-822.

Polte, P., Asmus, H. (2006). Intertidal seagrass beds (*Zostera noltii*) as spawning grounds for transient fishes in the Wadden Sea. Marine Ecology Progress Series 312: 235-243.

Raabe, E.W., Dierßen, K., Mierwald, U. (1987). Atlas der Flora Schleswig-Holsteins und Hamburgs. Wachholtz-Verlag, Neumünster.

Reise, K., Siebert, I. (1994). Mass occcurrence of green algae in the German Wadden Sea. Dt. Hydrogr. Z. Suppl. 1: 171-180.

Reise, K., Jager, Z., de Jong, D.J., van Katwijk, M., Schanz, A. (2005). Seagrass. In: Essink, K., Dettmann, C., Farke, H., Laursen, K., Lüerßen, G., Marencic, H., Wiersinga, W. (Eds.). Wadden Sea Quality Status Report 2004. Common Wadden Sea Secretariat, Wilhelmshaven, Germany: 155-160.

Reise, K., Kohlus, J. (2008). Seagrass recovery in the Northern Wadden Sea? Helgoland Marine Research 62: 77-84.

Reise, K., Buschbaum, C., Dolch, T., Herre, E. (2013). Vorkommen von Grünalgen und Seegras im Nationalpark Schleswig-Holsteinisches Wattenmeer 2012. Forschungsbericht im Auftrag des Landesamtes für Küsten- und Naturschutz, Tönning.

Romero, J., Martinez-Crego, B., Alcoverro, T., Perez, M. (2007). A multivariate index based on the seagrass *Posidonia oceanica* (POMI) to assess ecological status of coastal waters under the water framework directive (WFD). Marine Pollution Bulletin 55: 196-204.

Schanz, A., Asmus, H. (2003). Impact of hydrodynamics on development and the morphology of intertidal seagrasses in the Wadden Sea. Marine Ecology Progress Series 261: 123-134.

Schanz, A., Reise, K. (2006). Referenz und Klassifizierungsansatz für die Makrophytenvegetation des Nordfriesischen Wattenmeeres gemäß der Vorgaben der EG-Wasserrahmenrichtlinie (EGWRRL). Bericht an das Landesamt für Natur- und Umwelt des Landes Schleswig-Holstein, Flintbek.

Short, F.T., Burdick, D.M., Kaldy J.E. (1995). Mesocosm experiments quantify the effects of eutrophication on eelgrass, *Zostera marina*. Limnology and Oceanography 40 (4): 740–749.

Short, F.T.B., Polidoro, B., Livingstone, S.R., Carpenter, K.E., Bandeira, S., Bujang, J.S., Calumpong, H.P., Carruthers, T.J.B., Coles, R.G., Dennison, W.C., Erftemeijer, P.L.A., Fortes, M.D., Freeman, A.S., Jagtap, T.G., Kamal, A.M., Kendrick, G.A., Kenworthy, W.J., La Nafie, Y.A., Nasution, I.M., Orth, R.J., Prathep, A., Sanciangco, J.C., van Tussenbroek, B., Vergara, S.G., Waycott, M., Zieman, J.C. (2011). Extinction risk assessment of the world's seagrass species. Biological Conservation 144(7): 1961-1971.

van Beusekom, J.E.E. (2005). A historic perspective on Wadden Sea eutrophication. Helgoland Marine Research 59: 45-54

van der Graaf, S., Jonker, I., Herlyn, M., Kohlus, J., Fogh Vinther, H., Reise, K., de Jong, D.J., Dolch, T., Bruntse, G., de Vlas, J. (2009). Seagrass. Quality Status Report 2009 - Wadden Sea Ecosystem No. 25 - Thematic Report No. 12. In: Marencic, H., de Vlas, J. (Eds.), Common Wadden Sea Secretariat, Wilhelmshaven, Germany, Trilateral Monitoring and Assessment Group.

van Katwijk, M. M., Vergeer, L.H.T., Schmitz, G.H.W., Roelofs, J.G.M. (1997). Ammonium toxicity in Zostera marina. Marine Ecology Progress Series 157: 159-173.

van Katwijk, M.M., Schmitz, G.H.W., Hanssen, L.S.A.M., den Hartog, C. (1998). Suitability of Zostera marina populations for transplantation to the Wadden Sea as determined by a mesocosm shading experiment. Aquatic Botany 60: 382-305.

van Katwijk, M. M., Schmitz, G.H.W., Gasselink, A.P., van Avesaath, P.H. (1999). Effects of salinity and nutrient load and their interaction on Zostera marina. Marine Ecology Progress Series 190: 155-165.

van Katwijk, M.M., Bos, A.R., Kennis, P., de Vries, R. (2010). Vulnerability to eutrophication of a semi-annual life history: A lesson learnt from an extinct eelgrass (*Zostera marina*) population. Biological Conservation 143: 248-254.

Vermaat, J.E., Verhagen, F.C.A. (1996). Seasonal variation in the intertidal seagrass *Zostera noltii* Hornem, Coupling demographic and physiological patterns. Aquatic Botany 52: 259-281.

Wohlenberg, E. (1937). Die Wattenmeer-Lebensgemeinschaften im Königshafen von Sylt. Helgoländer wissenschaftliche Meeresuntersuchungen 1: 1-92.

Zipperle, A.M., Coyer, J.A., Reise, K., Stam, W.T., Olsen, J.L. (2009). Evidence for persistent seed banks in dwarf eelgrass *Zostera noltii* in the German Wadden Sea. Marine Ecology Progress Series 380: 73-80.