Winter survival of mussel beds in the intertidal part of the Dutch Wadden Sea

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Every winter, mussel beds in the tidal area of the Dutch Wadden Sea disappear due to storm and predation. The Dutch government only allows fishing of juvenile mussels on newly formed mussel beds if these have a low chance of surviving the following winter. However, at presence the mussel bed area that disappears during winter is unknown. Here, we present the distribution of mussel beds in the Dutch Wadden Sea from 1994 to 2003. We determined the spatial contour of present mussel beds in autumn and spring using GPS. For the first time, we can quantify winter losses and average winter survival. We show that almost 40% of all mussel bed area disappears every winter. Of all newly formed beds, 50% did not survive their first winter. The best areas for development of mature mussel beds are positioned south of Ameland and Schiermonnikoog and at Wierumer Wad along the Frisian coast. Furthermore, we compare average winter survival with a habitat suitability map.

Key words: mussel beds, Mytilus edulis, population dynamics, population stability, Wadden Sea, winter survival

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Introduction

Intertidal beds of the blue mussel *(Mytilus edulis)* are important biogenic structures in the Wadden Sea ecosystem. The beds serve as habitat and as an important food source for a number of species (de Vlas et al. 2005). For example, many birds eat the mussels or rely on the organisms that occur in and around the mussel bed (Dankers et al, 2003).

The larvae or spat of the blue mussel settle in May/June (Van de Koppel et al. 2005). After the settlement of larvae, which is also known as spat fall, a new mussel bed can be formed consisting of a monolayer of mussels. Between August and November a new bed rises 30-40 cm above the surrounding sand flat, due to sedimentation of considerable amounts of fine silt (Hilgerloh et al. 2003). After winter, sand and shells wash in and settle between the mussels. As beds mature, they can develop into a physically solid structure because the accumulated silt consolidates and forms a clay layer. For a detailed review on the development of mussel bed see e.g. Dankers et al. (2001).

The area of mussel beds in the Wadden Sea demonstrates large fluctuations in time due to the erratic amount of spat fall and due to environmental disturbances such as ice cover and storms (Beukema et al. 1993, Nehls & Thiel 1993, Nehls et al. 1997). Especially new mussel beds are vulnerable to these disturbances, because they are easily washed away. Only in sheltered areas, where the impact of storms and ice is less severe, mussel beds can develop into mature beds (Nehls et al. 1997, Nehls & Thiel 1993). When a mussel bed is clearly recognizable over many years, it is considered as a so-called stable bed (Brinkman et al. 2003, de Vlas et al. 2005).

In the early nineties, intertidal mussel beds in the Dutch Wadden Sea almost disappeared due to ongoing fisheries and a low amount of spat fall (Dankers et al. 1999). In 1993, the Dutch government took action to protect important habitats, such as mussel beds and closed permanently 25% of the intertidal area for shellfish fisheries (Ens et al. 2004, Dankers et al. 2001). In 1999, additional 10% of the intertidal area that was believed to be suitable for the development of mussel beds was closed for mussel fisheries (Dankers et al. 2001).

At present, the aim for Dutch Government management plan is a target area of 2000 ha of mussel beds that survived at least one winter in the entire Dutch Wadden Sea. Fisheries on newly formed mussel beds outside the above-mentioned closed areas are only allowed if the total mussel bed area is larger than the target. Even if this condition is met, fishing of juvenile mussels on a specific mussel bed is only allowed if this mussel bed has a low chance of surviving the following winter.

In order to be able to implement this policy, we need to 1) know the area of mussel beds on a yearly basis and 2) have a better understanding on the survival chance of mussel beds. Brinkman et al. (2002) present a habitat suitability map of the intertidal areas of the Dutch Wadden Sea based on the presence of mussel beds in the period 1960-1970 and several environmental characteristics. This map proposes classes of suitability for the natural establishment and survival of mussel beds (see also Brinkman & Bult 2002). Here, we monitored the distribution of mussel beds in the Dutch Wadden Sea from 1994 to 2003. We determined the spatial contour of present mussel beds in autumn and spring using GPS. For the first time, we can quantify winter losses and average winter survival. Now we can also compare average winter survival with the habitat suitability map.

Material and methods

Mussel bed localisation

We located mussel beds in autumn and spring from autumn 1994 to spring 2004. To roughly locate new mussel beds, we performed aerial inspection flights in both spring and autumn and used information from fishermen and fishery inspectors. To measure the precise geographical location, size and shape of each mussel beds, we walked around each mussel bed with a GPS device during low tide. As such, we obtained the spatial contours of all beds.

A mussel bed consists of a collection of smaller patches. Therefore, the boundaries between a mussel bed and the surrounding tidal flat are not always clear (De Vlas et al. 2005). To define the boundaries of a single mussel bed, we used the following criterion conform De Vlas et al. (2005); a group of mussel patches less than 25 meters apart is considered as a bed, but only if at least 5% of the tidal flat is covered by these patches.

Contour reconstruction of unvisited beds

We could not visit every mussel bed during all surveys. Therefore, we needed to reconstruct the spatial contour of the unvisited beds in the missing point of the time-series. Here, we present a summary of the used method of reconstruction. For a detailed description in Dutch see Steenbergen et al. (2003).

We assume that: 1) mussel bed do not change shape during summer, 2) newly formed beds appear in autumn and 3) mussel beds can partially disappear in winter.

If a mussel bed could not be visited in spring, we used the contour of the mussel bed present in autumn of that same year instead. If a mussel bed could not be visited in autumn, we used the contour of the mussel bed present in spring of that same year instead. If a newly formed mussel bed could not be visited in autumn, or an older mussel bed could not be visited in both spring and autumn of the same year, we used the contour of the mussel bed present in spring of the following year instead. In the latter case, there can be a systematic underestimation of the area of mussel beds, because substantial parts of a mussel bed can disappear during winter season. To reduce this underestimation during the surveys, we prioritised the newly formed beds in autumn and those beds that had not been visited in autumn, in spring.

Reconstruction of unvisited beds was therefore possible until spring 2003. In spring, we visited 65% of the total mussel bed area and therefore reconstructed 35%. In autumn, we visited 42% of the total mussel bed area and reconstructed 58%.

Data analysis

We used Arcview version 3.2 (ESRI) to analyse the geographical data. If mussels at a specific location were present in autumn and the subsequent spring, they survived winter. The average winter survival of mussels was calculated by dividing the number of winters that the mussels survived by the number of times mussels settled at the same location. For example, we consider a particular location in the investigated time series where mussels successfully settled in the first year, survived two winters and did not settle again. This location would be classified with an average winter survival of two (two divided by one). If in the fifth year mussels would settle again on this location that survive for three winters, the average winter survival equals 2.5 (five winters divided by two settlements). Because mussel beds almost never disappeared completely, mussel beds were divided into several parts with different average survival.

To calculate the percentage of the lumped area that survived either zero or one winter(s) this area was divided to the total mussel bed area that had been present up to and including autumn 2002. To calculate the percentage of the area that survived (more than) two winters this area was divided to the total mussel bed area that had been present up to autumn 2002. To calculate the percentage of the area that survived three winters this area was divided to the total mussel bed area that had been present up to autumn 2001. And so on. All data are presented as mean±SD.

Winter losses

We assume that the mussel beds are lost only due to natural effects, but we are aware of two fishing activities (De Vlas et al. 2005). Firstly, in the autumn of 1994, some fishery was allowed on newly formed beds of the 1994 spat fall. However, most of the newly formed beds - both fished and un-fished - disappeared completely due to severe storms before the survey in spring 1995 (De Vlas et al. 2005, Ens et al. 2004). Secondly, restricted experimental fisheries were carried out in 2001 on beds that were considered unstable to test the hypotheses that moderate fishery could restore the stability of young beds. Also in this case both fished and unfished beds were destroyed by autumn and winter storms (De Vlas et al. 2005; Smaal et al. 2003). We assume that the above-mentioned two fishing activities have a negligible on the monitored mussel bed area.

Results

From autumn 1994 until spring 2003, 9500 ha of the intertidal area were covered with mussel beds for at least one season. The total mussel bed area ranged from 451 ha in the spring of 1998 to almost 5000 ha in the autumn of 2001 (Fig. 1).

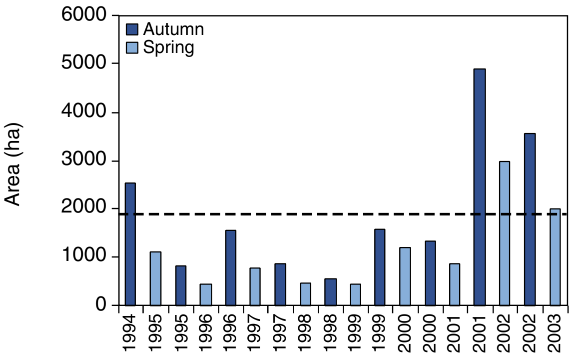

Figure 1. Development of mussel beds in the intertidal part of the Dutch Wadden Sea from autumn (au) 1994 until spring (sp) 2003. Dotted line indicates target area of 2000 ha.

The total mussel bed area in the Dutch Wadden Sea was very low in the nineties; in general there was less than 1000 ha present. In the nineties, the recovery of the mussel bed area started with good spat fall in 1994, but the winter losses were high and only 1000 ha remained. Until 2001 the total mussel bed area was below 2000 ha. The spat fall in autumn 2001 resulted in more than 2000 ha for the first time in seven years.

Almost 5000 ha of mussel beds were recorded of which 60% survived the winter period. The area of winter losses was 39.3 ± 12.6% (n = 9) and varied from 16.5% in the winter of 1998/1999 to 56.6% during the winter of 1994/1995 (Fig. 2). On 17% of the locations, mussels settled more then once.

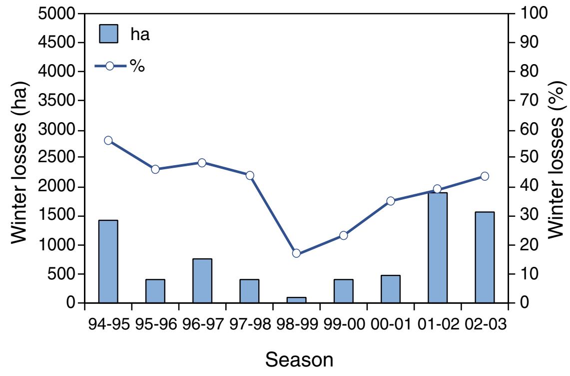

Figure 2. Yearly winter losses of mussel bed area in the intertidal part of the Dutch Wadden Sea since 1994, in hectares (left scale) and percentages (right scale).

The majority of mussel beds are located in the eastern part of the Dutch Wadden Sea (Fig. 3). More than half of the total mussel bed area did not survive the first winter (Fig. 4).

In the subsequent winters, the area roughly decreased by a two-fold: 27.8% survived one winter and 15.8% survived two winters. Of all the mussel bed area that was formed before autumn 2002, 22% survived two or more (2-9) winters. Only 1.3% of the area was formed before autumn 1994 and still present in spring 2003. These 32 ha of mussel beds therefore survived at least 9 winters. The mussel beds with large parts surviving more then four winters were situated at Wierummer Wad along the Frisian coast, or south of the islands Ameland (inset Fig. 3) and Schiermonnikoog.

Discussion

Our surveys show that 39.3 ± 12.6% (n = 9) of the mussel bed area in autumn disappeared during the winter season in the period 1994-2003. In many cases, mussel beds did not disappear completely; parts of beds could survive up to 4 years or more. Especially large parts of newly formed beds disappeared; 51.5% of the mussel bed area did not survive the first winter (Fig. 4). Parts of mussel beds that survived their first winter, still have a large change to disappear during following winters.

Winter losses are probably mainly caused by storms. Zwarts & Ens (1999) suggest that predation of birds can have a substantial effect, especially when only a few mussel beds are present. However, our data do not indicate higher winter loss percentages of mussel bed area in poor years. For example, in 1998-1999 the lowest winter loss (16.5%) co-occurred with the lowest area in autumn (540.5 ha).

We compared the average winter survival with the habitat suitability map of Brinkman et al. (2002).

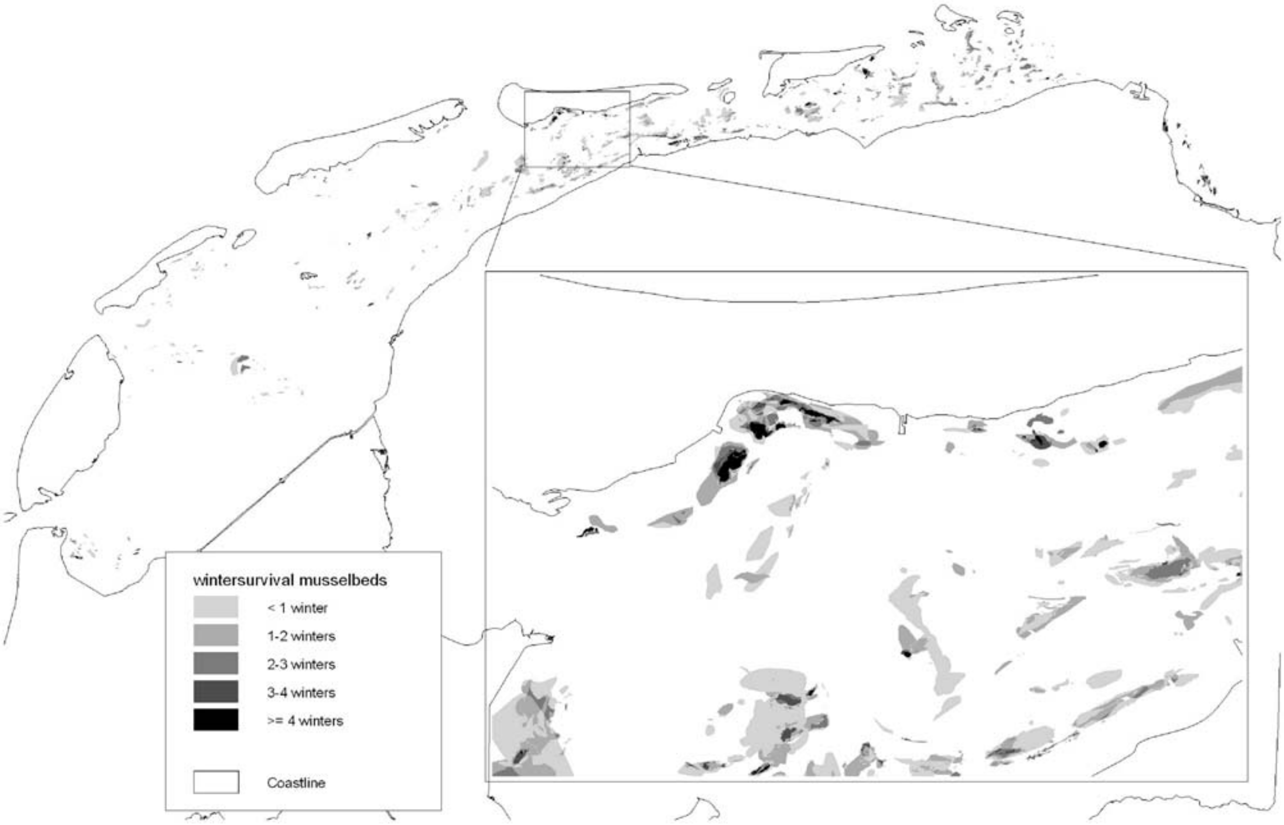

Figure 3. Average winter survival of (parts of) mussel beds in the intertidal of the Dutch Wadden Sea. The islands Ameland (A), Schiermonnikoog (B) and the Wierummer Wad along the Frisian coast (C) are indicated.

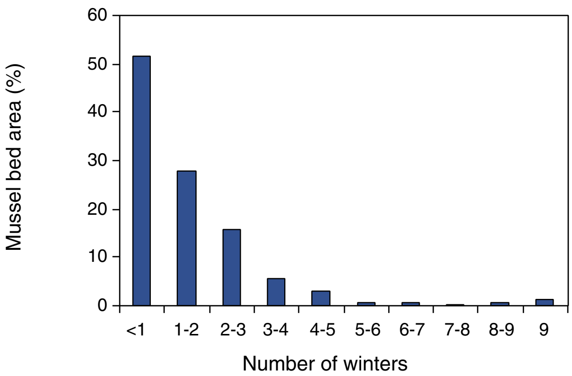

Figure 4. Average winter survival of the total mussel bed area that has been present in the intertidal of the Dutch Wadden Sea between autumn 1994 and spring 2003.

Average winter survival was 2 and 1.5 winters for class 1 and 2, respectively. These first two classes comprise the most suitable areas for the development of mussel beds and cover only 2% of the Wadden Sea. In the remaining part of the Wadden Sea, however, no major fluctuations in average winter survival were found (around 1 winter; Steenbergen et al. 2005). According to our data, the best areas for development of mature mussel beds are the areas south of the eastern islands, and at Wierummer Wad along the Frisian coast. These areas correspond with the 2% best areas suggested by the habitat suitability map.

Nehls et al. (1997) distinguished two types of mussel beds in the Wadden Sea of Schleswig-Holstein, Germany: dynamic or unstable beds and stable beds. Unstable beds were only present for some consecutive years and found in locations that were exposed to storms and ice. Stable beds were present for many years and found only at sheltered locations where the impact of storms and ice was less severe. We can conclude that mussel beds in the Dutch part of the Wadden Sea, which sustained over longer periods of time, all appear to be situated in sheltered areas. This seems consistent with the situation in the Niedersachsen (Germany) part of the Wadden Sea (Herlyn et al, 1999).

Although locations of stable mussel beds have been constant over decades, the total mussel bed area was highly variable in time (Dankers & Koelemaij 1989, Nehls & Thiel 1993). The unstable beds are of interest to mussel fisheries. In the investigated period from 1994 to 2003, a large area (83% of 9500 ha) of the intertidal area was covered with mussels only once due to erratic spat fall. With such a high spatial variability, it is not yet possible to predict future locations of unstable beds based only on observed winter survival.

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