Mussel culture and subtidal mussel stock management in the western Wadden Sea: are exploitation and conservation compatible?

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Abstract

Mussel culture in the western Wadden Sea is based on the collection of mussel seed from natural beds, culture of the stocks on bottom culture lots and harvesting consumption-sized mussels. Data from annual assessments of wild and cultured stocks over the period 2004-2008 are combined with collection, harvest and transplantation data to construct annual budgets. An average net gain is estimated to be 3.4 and 19.3 million kg of wild and cultured stocks respectively due to growth and survival which compensate for fishery and harvest. The average total subtidal Wadden Sea mussel stock of about 50 million kg is an important food source for Eider ducks in the area which show a long term maintenance of the winter numbers in contrast to other Dutch coastal waters where a significant decrease occurs. Given mussel stock management by the farmers and the Eider duck numbers it is concluded that Eiderduck conservation and mussel exploitation are compatible in the western Wadden Sea.

1. Introduction

Traditional mussel culture in the western Wadden Sea is an extensive sea-bed culture. Juvenile mussels are transplanted from wild stocks or other resources to culture, or nursery, lots located in subtidal areas in the western Wadden Sea (Figure 1). These are leased by the government to the mussel farmers and at present there are 510 lots in the Wadden Sea with a total surface of 7,700 ha, of which 4,000 ha is in use by the farmers. Not all the culture area is used for growing mussels as the total stock size varies over time and the suitability of lots for growing mussels differs from place to place. As the Wadden Sea is a designated nature conservation area the question arises to what extent the present mussel culture can be combined with the nature management goals of the Wadden Sea: are exploitation and conservation compatible? One of the issues in the debate addresses the role of mussel culture and management of the total mussel stock in view of the availability of prey for protected bird populations such as the Eider duck (Ens *et al.*, 2004, 2006). Therefore in this paper we provide quantitative data on mussel stock dynamics in the Wadden Sea, including the impact of mussel farming.

The mussel stock size on the culture plots is a function of the (i) supply of mussel seed, (ii) growth and survival on the plots, (iii) transplantation to other areas and harvesting for market delivery.

Mussel seed supply is predominantly based on the collection of juvenile and half-grown mussels from subtidal wild stocks in spring and autumn. Annual surveys show that the wild stocks occur in the western Wadden Sea (Marsdiep basin) (Figure 2). Density and distribution of the stocks is quite variable in time and space. Temporal variation is mainly due to annual recruitment success which depends largely on match or mismatch with preda-

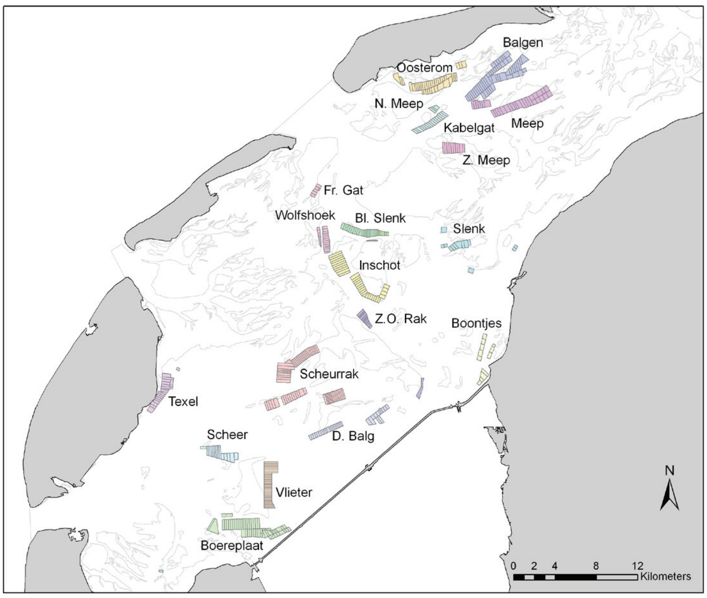

Figure 1: Map of mussel culture plots in the western Wadden Sea.

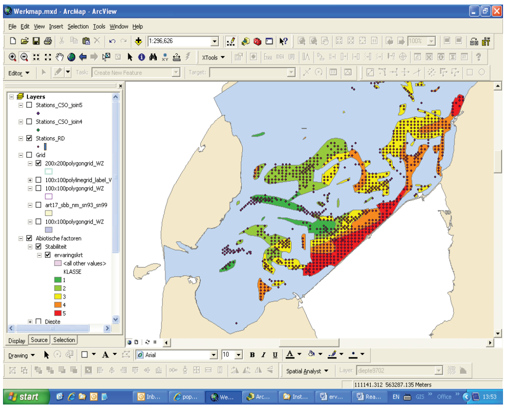

Figure 2:
Map of wild mussel stock areas with sampling stations in 2007 and 5 classes of relative stability based on expert judgement: dark(1) and light (2) green = low relative stability; yellow (3) = intermediate; orange (4) and red (5) = relatively high stability.

tors, and with winter temperatures (Beukema & Dekker, 2005). Spatial variation in the survival of wild mussel stocks depends on the vulnerability of areas to factors such as winter storms and predation by starfish. Based on expert judgement and the results of the annual surveys since 1992, wild stock areas are classified in terms of relative stability (Figure 2). It should be noted that, at the moment, intertidal wild mussel stocks are not exploited for mussel seed collection as a result of protection measures.

Growth and survival of mussels in an extensive culture predominantly depends on natural processes. Food availability is a function of primary production, supply by water currents, local mussel densities and occurrence of other filter feeder stocks. Survival depends on the vulnerability of the culture sites to storm damage, and on the occurrence of predators. The farmers manage their stocks by a series of measures which include transplantation of mussels from one site to another, depending on the season and the risk of predation, removal of predators, mixing several stocks and adapting seeding densities to local conditions.

Transplantation of mussels to other areas usually occurs in autumn when a mussel farmer decides to remove part of the Wadden Sea stock to the more sheltered culture lots in the Oosterschelde (SW Netherlands). This includes transplantation of half-grown mussels from Wadden Sea lots in order to provide space for new seed to be brought in, but also a part of the seed might be transplanted directly after collection to the Oosterschelde. It is noticed that natural seed supply is based mainly on collection from the Wadden Sea due to low recruitment success elsewhere. As the Wadden Sea has better growth rates but higher risk of storm damage, it is obvious that transplantation decisions by mussel farmers is part of their stock management strategy to spread risks between the two areas. Existing regulations so far prohibit transplantation of mussels from the Oosterschelde to the Wadden Sea, although this is now subject to revision (Regiegroep mosselconvenant, 2009). The harvesting season is from July till March, and mussels are taken from the plots and transported to the auction in Yerseke (SW Netherlands) as and when the farmer decides (see also Smaal and Lucas, 2000; Smaal, 2002).

In this paper the net effect of mussel culture on the stock dynamics is analyzed on the basis of annual data on seed supply, harvest size and annual assessment data of both wild and cultured stocks. The question of to what extent management by mussel farmer results in a mussel stock in the western Wadden Sea that is not only profitable for economic goals but also for nature management objectives and especially in relation Eider duck numbers is addressed.

2. Materials and methods

2.1 Wild stock surveys

Wild mussel surveys have been carried out in the western Wadden Sea since 1992. Based on experience, surveys are carried out in areas where wild mussel stocks happen to occur. In spring there is a quantitative survey following a grid design with distances of north-south transects of 0.5 or 2 nautical minutes, depending on the expected mussel densities, with distances between the stations of 0.25 nautical minutes. The number of stations varies between 450 and 600 per year. Sampling is carried out with a hydraulic dredge that samples over a distance of 150 m. The dredge has a sampling opening of 20 cm and a mesh size of 5 mm.

Mussels are sorted in three classes on the basis of shell length: seed ≤ 15 mm, seed/half-grown mussels ≤ 45 mm and mussels > 45 mm. Per size class wet weight is determined. In addition, fouling with barnacles and the number of crabs and starfish per station are registered. Data per station are accumulated on the basis of number and weight per sampled surface area, leading to average values per m^2 and total wet weight for all stations.

In August/September the survey is primarily focussed on the detection of new mussel seed. This survey is carried out with a traditional mussel dredge of 1.9 m wide with a mesh size of 8 cm and is considered as a semi-quantitative survey. The survey is done in the western Wadden Sea and sometimes in other areas of the Wadden Sea if there are indications of successful spatfall. About 200 - 300 m is dredged per station and in total 500

– 600 stations are sampled., covering an area of 3,500 – 5,000 ha. Per sample the amount of mussels is estimated and divided into the previously mentioned 3 size classes. Also predator occurrence (crab, starfish) is registered. Gross data are converted to net data by a correction factor which is for seed 0.6 and for larger size classes 0.75.

2.2 Fishery data

Data on the amount of fished mussels is derived from the Dutch Fisheries Board which is responsible for registration of the quantities taken in order to control the fish quota per mussel farmer. Catches are estimated in the field directly after collection. Fishing is based on a fishing plan, for which the survey data are used. The spring survey is 2 months prior to fishery during which period the growth of mussels is considerable. In drawing up the fishing plan, the survey data are therefore corrected for this growth. Gross–net correction is applied as previously mentioned. In this paper only net data are presented.

Fishery data are used for the budget of natural stocks but also as input into the culture stock budget. In addition to fishery, mussel seed is derived from the newly applied mussel seed collectors (MZI). Data on MZI seed input are based on evaluation reports (Kamermans and Smaal, 2009).

2.3 Culture stock surveys

Since 2004 annual surveys have been conducted in autumn on mussel culture lots in the Wadden Sea to quantify the standing stock. On the basis of a pre-assessment by fishery inspectors the survey is focused on the culture lots that are in use at the time by the farmers. On these lots samples are taken following a grid-based sampling design. Sampling stations are located on east-west and north-south transects with a distance of 0.2 geographical minutes, being 223 m and 370 m, respectively. In the four main culture areas, a finer grid was used with a 0.1 minute distance. Depending on the number of culture plots in use a total 400 – 500 stations was sampled. On each sampling station, five Van Veen grab samples are taken and pooled into one sample (total surface 0.276 m^2).

Samples are sieved over 2 mm and mussels are sorted in three classes on the basis of shell length: seed $\leq$ 15 mm, seed/half-grown mussels $\leq$ 45 mm and mussels > 45 mm. Per size class, the mussels are counted and wet weight is determined. In addition, fouling with barnacles and the number of crabs and starfish per station are registered. Data per station are accumulated on the basis of number and weight per sampled surface, leading to average values per m^2 and total wet weight of all stations. By means of a permutation test a power analysis is conducted which shows that given the number of sampled stations the 95 % confidence limits of the average biomass per station deviate less than 16 % from the average values.

2.4 Harvest and transplantation data

The harvested mussels all are traded through the auction in Yerseke that works under the Dutch Fisheries Board. At the auction the total harvest, size, meat content and quality of each mussel is registered and stored in a database. The mussel harvest data are derived from this database. In this paper total harvest data are presented, covering the whole season from July to March.

Transplantation of mussels from growing lots in the Wadden Sea to the Oosterschelde culture plots is not well documented prior to 2007. Therefore, we made the assumption that the harvest from the Oosterschelde is based on half-grown mussels that were transplanted in the year before harvest. We applied a correction factor as the Oosterschelde harvest comes not only from half-grown Wadden Sea mussels but also from the seed fishery in the Delta area, the import of seed from elsewhere (UK, Ireland) and some net biomass increase may also happen. The correction factor was arbitrarily set at 0.75.

3. Results

3.1 Wild stocks

Results from the wild mussel seed survey (Table 1) show a stock size in March that varies from 9 to 36 million kg in 2005 and 2007 respectively. The survey takes place before the seed fishery in the spring season. As shown, the yield varies from 7.5 to 25 million kg, except for 2005 and 2008 when there was no fishing in spring. Table 2 shows the results of the September survey and the subsequent autumn fisheries. Total stocks vary from 5 to 36 million kg, and fishery yield varied from 1.8 to 10.5 million kg.

3.2 Budget of wild stocks

A comparison of total stocks in March and the new spatfall in September minus the amount fished per year gives the net balance between input and output. When this is compared with the actual stock after the autumn season it shows (Table 3) that on average over 5 years there is a net annual gain of 3.4 million kg, which is about 20 % of the annual averaged wild stock size.

Table 1:
Biomass of wild blue mussel stocks from March surveys prior to the spring season fishery, and fishery yields

Wild stock March survey million kg fresh weight					Spring fishery
	≤15mm	15-45mm	>45mm	total stock	million kg
2004	14.7	2.0	6.5	23.3	24.3
2005	0.3	2.3	6.5	9.1	0.0
2006	9.2	1.5	5.5	16.1	7.5
2007	2.8	26.6	6.9	36.2	11.3
2008	3.9	1.5	5.5	10.8	0.0

Table 2:
Biomass of wild blue mussels from September surveys prior to the autumn season fishery, and fishery yields.

Wild stock September survey million kg fresh				Autumn fishery
	≤15mm	>15mm	total stock	million kg
2004	0.9	4.5	5.4	1.8
2005	9.9	12.0	21.9	9.6
2006	0.9	25.1	26.0	3.5
2007	12.0	24.4	36.4	10.5
2008	15.0	3.8	18.8	4.1

3.3 Culture stocks

The culture stock surveys show that total biomass in autumn (end November to December) varied between 15 million kg in 2005 to almost 50 million kg in 2004 (Table 3). This is the stock after the main harvest period, from July to November. Total harvest is also shown in Table 3 and varied from 11 to 30 million kg in 2006 and 2004 respectively. The relatively low harvest in 2006 corresponds with the low stock size in 2005.

3.4 Budget of culture stocks

The balance between input of seed from fisheries and seed collectors versus harvest and transplantation to the Oosterschelde (Table 4 and 5) shows that growth and survival results on average in a net annual gain of almost 20 million kg and this is 60 % of the average annual stock size.

4. Discussion

The budget approach as presented in this paper is a simplification of the processes that play a role in mussel stock dynamics (Bult *et al.*, 2004). Natural stocks are dependent on recruitment, growth and survival i.e. predation, and they are also subject to fishing. It is not clear what contribution different processes make in the dynamics of wild stocks. It can be hypothesized that fishing is detrimental to the development of wild stocks by the removal of part of the stock. However, it is also possible that fishing has positive impacts as thinning out of mussel beds and removal of predators might improve the long term survival of mussel beds and stimulate growth of the remaining mussels. It is likely that fishery impacts are different in areas of different stability (Figure 2). These questions are addressed in a research project where a pair wise comparison is made of areas closed and open to collection (Smaal, 2007). In addition, since spring 2009 a mussel bed of 140 ha in the relatively stable area is closed to harvest in order to allow undisturbed development. This decision is made in the framework of an agreement between the mussel farmers, the NGOs and the government to achieve sustainable mussel culture in combination with nature conservation. (Walker and Van

Table 3:
Budget of wild blue mussel stocks and net result in million kg per year and averaged over 5 year as a function of recruitment (in), growth, survival and fisheries (out).

Wild	Stock T_0 (March)	In	Out	Balance	Stock T_1 (Dec)	Net result
Based on	Spring survey	Autumn seed survey	Spring and autumn fishery	T_0+in-out	Autumn stock - autumn fishery	T_1-(T_0+in-out)
2004	23.3	0.9	26.1	-1.87	3.6	5.47
2005	9.1	9.9	9.6	9.42	12.3	2.92
2006	16.1	0.9	11.0	6.05	22.5	16.48
2007	36.2	12.0	21.8	26.44	25.9	-0.56
2008	10.8	15.0	5.1	20.73	13.7	-7.08
Average	**18.74**	**7.74**	**14.69**	**12.15**	**15.60**	**3.44**

Culture stock million kg fresh weight					Harvest	Transplantation to OS
Year	≤15mm	15-45mm	>45 mm	Total stock	Million kg	Million kg
2004	0.0	16.2	31.8	48.1	30.4	19.3
2005	0.8	8.9	5.2	14.9	26.4	12.5
2006	0.0	6.8	29.0	35.8	10.6	10.8
2007	17.5	3.2	14.5	35.2	26.3	11.3
2008	12.0	2.0	16.0	30.0	21.4	5.6

Table 4: Biomass of mussels on culture plots in Nov/Dec in the western Wadden Sea 2004 – 2008 in 3 size classes, total annual harvest and estimated transplantation to the Oosterschelde (OS).

Culture	Stock T_0	In	Out	Balance	Stock T_1	Net result of growth and survival
	January	From fishery +MZI	Harvest + transplantation	T_0+in-out	December	T_1 - (T_0+ in-out)
2004	30.0	26.1	49.7	6.4	48.1	41.7
2005	48.1	9.6	38.9	18.7	14.9	-3.8
2006	14.9	11.0	21.4	4.5	35.8	31.4
2007	35.8	23.5	37.5	21.8	35.2	13.4
2008	35.2	8.2	27.0	16.4	30.0	13.7
Average	32.8	15.6	34.9	13.5	32.8	19.3

Table 5: udget of mussel stocks on culture plots and net result in million kg per year and averaged over 5 years as a function of seeding (in), growth, survival and harvest/transplantation (out).

Leeuwe, this volume). No results are available for these new developments as yet. Therefore we address the question on the role of mussel culture in stock dynamics on the basis of data that are based on field surveys of culture plots since 2004. The data also allow a comparison with the model approach as presented in Bult *et al.* (2004).

With regard to the dynamics of cultured mussel stocks, the assumption was made that transplantation of half-grown mussels to the Oosterschelde can be based on the harvest in the following year, corrected with a factor of 0.75. Lack of data so far does not allow validation of these assumptions but it can be argued that the mussel harvest from the Oosterschelde is largely based on mussels in more or less similar quantities from the Wadden Sea as net growth and survival in the Oosterschelde result in a production efficiency (yield as a function of stock size) of 1 (Bult *et al.*, 2004) and both local and imported seed supplies are of limited importance. The other elements in the budget, however, are based on quantitative measurements.

The budget for wild stocks in most years shows a net annual increase of the stock per year over the period 2004 - 2008. The low budget value of 2008 is related to high predation by starfish in the autumn of 2007 as shown by the large difference between T_1 of 2007 and T_0 in 2008. Average yield was estimated at about 15 million kg annually which is compensated by spatfall, growth and survival, resulting in a net increase of 3.4 million kg. It is still an open question as to what natural stock size would develop in the absence of a fishery.

For cultured stocks the budget also shows a net annual increase. Total average harvest including transplantation was estimated as 35 million kg per year. Net growth and survival was almost 20 million kg per year. In 2005 there was a negative net result as the T_1 stock (from November/December survey: 14.9 million kg) was quite low. Indeed, the relatively low harvest in 2006 (Table 3) confirms the low stock estimate. However, the budget shows that mussel culture results in a large mussel stock on culture plots that is maintained throughout the years. Total size of wild and cultured stocks was on average almost 50 million kg over the period 2004-2008.

Net budgets of cultured stocks show a higher gain than the wild stocks. This confirms the hypothesis that growth and survival of mussels on culture lots is higher due to cultivation measures than on wild beds, as was the basis of the model of Bult *et al.* (2004). Based on the model it was calculated that mussel culture would result in a higher stock (on average 15 %) in comparison to wild stocks. Data so far indicate that this might be an underestimation.

This stock size represents an important food resource for Eider ducks. Annual bird counts show an overall decrease of the Eider duck population in Dutch coastal waters over the period 1993 – 2008 (Figure 3) (after Arts, 2008). Only the western Wadden Sea is an exception to this long term

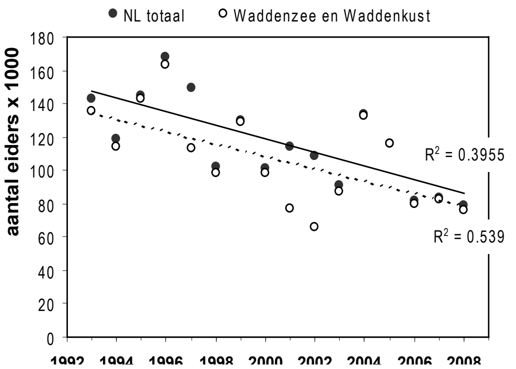

Figure 3: Eider duck numbers showing a significant decrease over time in Dutch coastal waters (Closed circles: total Dutch population, open circles: Wadden Sea population), after Arts (2008).

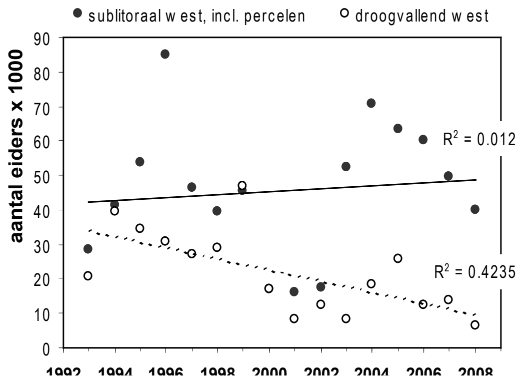

Figure 4: Eider duck numbers in the western Wadden Sea in littoral areas (open circles) showing a significant decrease, and in sublittoral areas including mussel culture plots (closed circles) with no decrease over the period 1993 – 2008, after Arts (2008).

trend. As shown in Figure 4, despite large fluctuations, the Eider duck population did not show a decrease in the sublittoral areas of the western Wadden Sea in contrast with intertidal areas. It is noted that Eider numbers show a decrease in recent years that does not correspond with mussel stock data. A more thorough statistical analysis including possible factors such as higher winter temperatures, overwintering in the Baltic, role of other food items (Ens *et al.*, 2006) would be required to explain these data. The trends in Figures 3 and 4 indicate the importance of the sublittoral Wadden Sea areas for Eiderduck populations which is probably due to the presence of extensive mussel stocks in the area (Kats, 2007).

It is concluded that mussel stocks in the western part of the Wadden Sea, influenced by mussel cultivation, are maintained at about 50 million kg. Harvest and transplantation to the Oosterschelde are compensated by recruitment, survival and growth including a net gain that is relatively high on culture lots. The available stocks play a role as food for Eiderducks of which numbers in this area have maintained. It is therefore concluded that the exploitation of mussel stocks by man and birds are compatible.

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