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Effect of seeding density on biomass production in mussel bottom culture

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ABSTRACT

Effects of seeding density on biomass production in mussel bottom culture are investigated by detailed monitoring of culture practice in the western Wadden Sea, The Netherlands. The seeds originate from different sources. The seeds differ in size and farmers apply seeding techniques dependent on the seed size resulting in different seed densities on the culture plots. We hypothesise growth to be density dependent and that biomass production is primarily determined by survival and is therefore a function of seed density which is related to the activities of the farmers. Data was collected from 42 different culture plots over a three year period (June 2009–June 2012). During this period, 66 sub-populations were followed from seeding until harvest. Seeding at the start of the culture resulted in an instantaneous drop in biomass production, caused by large losses in mussel number. These losses were on average 42% of the mussels seeded. This seeding loss decreased with mussel size and increased with seeding density. A subsequent density dependent loss of 1.8 mussels per day was found for smaller mussels (<30 mm), and a non-density dependent loss of 0.8 mussels per day for larger mussels (>30 mm) during grow out. Overall loss from seeding to harvest was high, from 92% for the smallest seeds collected from spat collectors, to 54% for half-grown mussels fished from natural beds in the spring. No indication was found that growth or mussel condition was affected by culture plot scale density. Growth was dependent on mussel size and age, and this largely determined the differences in biomass production between seed sources. The density dependent seeding loss associated with seeding activities largely determined survival, and hence overall biomass production.

1. Introduction

About 50% of the aquaculture production of *Mytilus edulis* L. in Europe is produced in bottom cultures (FAO, 2015; Smaal, 2002). In mussel bottom culture, juvenile mussels (seed) are collected from natural beds or by using suspended seed mussel collectors (SMCs, Kamermans et al., 2002). Mussels are seeded on subtidal or intertidal culture plots, where they grow for a period of 1 to 3 years until they reach market size (Gosling, 2003). Relative biomass production (RBP) is the ratio between mussel biomass (kg m^{-2}) at any given point in the culture cycle, and mussel biomass seeded (kg m^{-2}). RBP is thus the product of the relative growth and survival between these two points in time. RBP over the entire period from seeding to harvest is defined as the average physical product (APP), discussed in Ferreira et al. (2007).

Mussel bottom culture is an extensive culture as it depends on natural resources for feed, seed and space. Abiotic conditions vary between areas where culture plots are located, which causes differences in growth and survival (Brinkman et al., 2002). Cultivation techniques seem to have limited influence on the fate of the product during the culture cycle. Mussel farmers have to work within the static spatial boundaries of their culture plots and use these differences in environmental characteristics for strategic translocation of mussels between areas throughout the culture cycle. The RBP of extensive mussel culture from seeding to harvest is on average 1.5–2.5 kg harvested per kg seeded in the Wadden Sea, and is even often below 1 kg harvested per kg seeded in Ireland (Bult et al., 2004; Calderwood, 2015; Dijkema, 1997; Wijsman et al., 2014). However, at the scale of individual plots, RBP shows more variation and a maximum RBP of 6 kg harvested per kg seeded has been reported for the Wadden Sea (Dijkema, 1997) and for Strangford Loch (Northern Ireland), a maximum of 7 kg harvested per kg seeded has been modelled (Ferreira et al., 2007). The source of the large variability in RBP is often not clear.

Relative biomass production on a culture plot will only be larger than one as long as growth can compensate for losses in mussel number (Petraitis, 1995). Growth depends mainly on natural factors such as food supply at a given mussel density (Ferreira et al., 2007). Survival

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of individual mussels in extensive bottom culture is a result of natural factors such as predation, mussel dislodgement and competition. Yet, survival also depends on culture techniques, in particular seeding techniques (e.g. Munch-Petersen and Kristensen, 2001; Seed, 1976; Seed and Suchanek, 1992; Smaal, 2002). In a previous study, we showed that the spatial organisation of mussels on culture plots is affected by seeding such that high local densities result in a density-related seeding loss, with maximum values of 75% within four weeks (Capelle et al., 2014).

In the Netherlands, mussels are cultured on bottom plots in the Oosterschelde estuary (ca. 20 km^2) and in the western part of the Wadden Sea (where ca. 33 km^2 of culture area is used). The Wadden Sea is a shallow coastal sea, stretching from the Netherlands to Denmark, separated from the south-eastern North Sea by a range of barrier islands. Chlorophyll-a concentrations in the western part of the Wadden Sea are characterized by a dominant spring bloom, with chlorophyll-a levels around 35 mg m^{-3} and a sporadic autumn bloom, with Chlorophyll-a levels around 10 mg m^{-3}. Chlorophyll-a concentrations over the rest of the year stay generally below 10 mg m^{-3}, especially in winter (Philippart et al., 2010).

Fishing seed from natural seed beds is the traditional method used for the mussel culture cycle. Seed fishing in the Netherlands occurs mainly in autumn, but only in areas that are considered unstable for sustainable natural mussel beds. In spring, seed beds outside unstable areas can be fished (Smaal, 2002). Meanwhile, the amount of mussel seed obtained from an alternative resource, SMCs, is sharply increasing (from 8 million kg in 2009 to 15 million kg in 2012). This increase is the result of an agreement signed by the government between environmental NGOs, and the mussel producers trade organisation (Van Hoof, 2012). With the covenant, the mussel producers' trade organisation has agreed to cooperate in the protection of wild mussel seed beds by a gradual transition from seed fisheries on wild mussel beds, to SMCs for mussel seed as input resource for the culture cycle. SMCs are harvested from July until October, and are a reliable source of mussel spat. However, seed origin can affect survival as, for example, SMC seed has a thinner shell that makes it more vulnerable to predation (Kamermans et al., 2009). However, after transplantation, SMC seed tends to aggregate more than mussels from seedbeds, resulting in better survival (Christensen et al., 2015).

While cultivation techniques seem to have a limited effect on RBP, previous studies showed that cultivation techniques do affect survival of the mussel seed. In the culture cycle, the farmers make use of the different seed resources. Those resources differ in size and farmers apply seeding techniques dependent on seed size, which may result in different seed densities on the culture plots. We hypothesise growth to be density dependent, and that biomass production is primarily determined by survival and is therefore a function of seed density which is related to the activities of the farmers. We tested this by analysing the culture cycle for a number of years in an extensive number of culture plots to account for spatial and temporal variability.

2. Methodology

2.1. Sampling

A sampling procedure closely following routine culture methods was set-up to describe mussel growth and losses from subtidal culture plots in the western part of the Wadden Sea. Sampling of the mussels from culture plots was undertaken in collaboration with seven mussel-growing companies. The size of the company, by the number of culture plots a company leases in the Wadden Sea, may affect culture practices and since we want our data to be representative for the whole sector, we therefore pre-selected two small companies (<10 culture plots), three medium companies (between 10 and 20 culture plots) and three large companies (>20 culture plots). These companies reported after each fishery and SMC harvest within the period 2009–2011 on: (a) where mussels were seeded, which was pinpointed through GPS coordinates of the seeded area; (b) mussel size, measured by the typical mussel-farmer's method (N_{vol}, amount of fresh mussels fitting in a 880 ml tin can); (c) biomass seeded, with an estimation of the debris and associated flora/fauna percentage (tare); when this was not estimated we assumed a tare of 40% for seed from fishing, 15% for seed from SMCs, and 25% for mussels larger than 30 mm, following Wijsman et al. (2014); and (d) after mussels had been seeded: when translocation of the mussels and management measures took place. All areas on the culture plots in which mussels had been seeded by the selected companies, from spring 2009 until autumn 2011, were sampled four times per year, in February, June, September and at the end of November/beginning of December, resulting in four sampling periods. The measurements in June and November/December were carried out after the spring and autumn fishery, respectively.

In total, 42 unique culture plots were sampled from June 2009 until June 2012 (Fig. 1). From these plots, 66 series were obtained (a series being mussels seeded on a culture plot area and sampled repeatedly until harvest). Some plots were used for more than one series. These 66 series included 22 plots with SMC-seed, 11 plots with seed from the autumn fishery, 18 plots with seed from the spring fishery and 15 plots with seed relayed from other culture plots. In all, 190 measurements were obtained.

Each measurement consisted of 70 random samples taken with a Van Veen grab (0.0552 m^2) within the seeded area on a culture plot. Each individual sample was sieved using a 5 mm sieve, and the number of mussels was counted. From the 70 samples, the mean ($\overline{x}'$) and standard deviation (s) of the number of mussels per square metre was calculated.

The mussels from the 70 grab samples were pooled and homogenized. A volumetric subsample of 1 l was taken from the pooled sample. The subsample was weighed to the nearest mg and the mussels counted and cooked in order to measure cooked meat weight. In the lab, the individual lengths of the mussel shells were measured with a digital calliper (accurate to 0.1 mm). Dry weight of mussel meat per plot was obtained by drying at 70 °C in a prepASH (prepASH® 340 series, http://prepash.com) until the change in weight of each sample was less than 1% per 0.5 h. Ash weight was obtained by heating at 540 °C in a prepASH until the change in weight of each sample was less than 0.1% per 0.5 h. Ash free dry weight (*AFDW*) was calculated as the net difference between dry weight and ash weight. Average weight was calculated by dividing the total weight by the number of mussels in the sample.

2.2. Growth

Mussel weight was fitted to mussel age by the Von Bertalanffy growth equation, with a sinusoidal correction for seasonal growth fluctuations (Somers, 1988).

$$W_t = W_\infty\left[1-e^{-K(t-t_0)-\frac{CK}{2\pi}\sin 2\pi(t-t_s)}\right]^b \quad (1)$$

Parameters W_∞, K, t_0, C and t_s were estimated with a non-linear model using the generalized least squares method from the nlme library for R software (Pinheiro et al., 2014). The model was fitted based on the average weight per sampling station and per sampling moment. Mussel age was calculated using the known year class of mussels from the culture plots. The b parameter (2.89, with standard error: 0.0496, n = 190) was calculated from the relation between length and weight, assuming the allometric relationship: $W_t = a * L_t{}^b$, and $W_\infty = a * L_\infty{}^b$ ($a = 1.43 \times 10^{-4}$, with standard error: 2.79×10^{-5}), following von Bertalanffy (1938) and fitted with a non-linear model using generalised least squares method from the nlme library for R software (Pinheiro et al., 2014).