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Effect of shellfish filtration during two experiments: Spring and Summer 2019 (Deliverables D3.2 and D3.3)

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Wageningen University &
Research report C082/20

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Wageningen Marine Research
Yerseke, september 2020

Wageningen Marine Research report C082/20

WAGENINGEN
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Keywords: Renewable Energy, Mussels, Filtration, Turbidity.

Client: Waddenfonds
Provincie Fryslân
Rijksbijdrage Ambities Afsluitdijk (Astmafonds)

This report can be downloaded for free from https://doi.org/10.18174/531638
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KvK nr. 09098104,
WMR BTW nr. NL 8113.83.696.B16.
Code BIC/SWIFT address: RABONL2U
IBAN code: NL 73 RABO 0373599285

A_4_3_2 V30 (2020)

Contents

Summary

In a reverse electro dialysis (RED) installation, power is produced from the chemical potential difference between salt- and freshwater using ion-selective membranes. In order to make a RED plant commercially feasible, large amounts of salt- and freshwater are needed. At the Afsluitdijk, salt water can be extracted from the Wadden Sea and freshwater from Lake IJssel. The water from the Wadden Sea, however, contains high concentrations of suspended particles (on average ca 50 mg l^{-1}). These particles adversely affect the efficiency of the plant and need to be removed from the water before it enters the membrane stacks.

Shellfish are efficient filterfeeders that are capable to filter large amounts of suspended solids from the water. Therefore, it has been suggested that shellfish can be used to pre-filter the water from the Wadden Sea, before it enters the reverse electro dialysis power plant. In a previous model study, it has been shown that, depending on residence times and amount of shellfish, mussels are capable to remove 50% of the suspended particles from the water.

In this report, the results of a large-scale experimental study, that was executed to test if shellfish can be used as pre-filter for marine intake water, are presented. Two consecutive experiments (in spring and in summer) were run at the test facility at the Afsluitdijk using the blue mussel (*Mytilus edulis*). Filtration efficiency of marine intake water by shellfish was measured in a flow-through system containing mussels and compared to a control flow-through system without shellfish. The flow-through system was designed to create low flow velocities allowing the larger suspended particles (faeces and pseudofaeces) to sink and accumulate at the cone-shaped bottom of the tank. The accumulated deposits can be quantified and removed from the tank.

The results of the large-scale experiments showed that depending on the set-up, the mussels were able to remove 6-11% of the incoming sediment over a period of 2 to 3 months. Within this period, moments occurred where more than 50% of the suspended particles were removed by the mussels. During the experiment in spring, the deposition rate in the tank with mussels (average 95 kg fresh weight) was on average 2.9 kg day^{-1} while the deposition rate in the control tank, without mussels, was 1.2 kg day^{-1}. During the experiment in summer, the deposition rates in the mussel (average 35 kg fresh weight) and control tanks were 2.4 and 0.4 kg day^{-1}, respectively.

At a flow rate of 5 m^3 per hour 11% of the incoming suspended matter was filtered by on average 35 kg of mussels. A powerplant with a capacity of 10 MW needs 10 m^3 s^{-1} sea water (36 000 m^3 per hour). To pre-filter the water with an efficiency of 11%, a total of 252 000 kg of mussels are needed, producing a total of about 16 tons of biodeposits per day. For upscaling purposes the design of the shellfish filtration system should be optimised to increase filtration efficiency of the mussels, minimize resuspension of (pseudo)faeces and increase the efficiency to remove the produced (pseudo)faeces from the systems.

During the experiments, the mussels survived and even increased in weight. In the spring experiment the mussels grew on average 5 mm in length, increased their fresh weight (shell + tissue) by 62% and increased their flesh percentage on average from 12.7% to 20.6% over the course of the experiment executed between March and May. Approximately 57% of the mussels survived the experiment. Over the course of the experiment executed in summer (June – September), mussels grew on average 3 mm in length and increased their fresh weight (shell + tissue) by 15%. Percentage flesh decreased from 12.7% to 8.0% over the course of the experiment. The survival of the mussels during the second experiment was lower (38%) than in the first experiment. It is expected that modifications in the design of the set-up will increase the efficiency of the sediment removal from the water and the survival of the mussels.

1 Introduction

1.1 Project environmental effects Blue Energy

The term Blue Energy is used for energy harvested from the salinity difference between fresh water and salt water. The main and best investigated techniques are pressure-retarded osmosis (PRO) and reverse electro dialysis (RED) (Boon and Van Roij, 2011). In 2014, a test site for a 50 kW reverse electrodialysis plant was built on the Afsluitdijk in the Netherlands. This plant uses salt water from the Wadden Sea and an equal amount of fresh water from Lake IJssel. The resulting brackish water is discharged into the Wadden Sea. For commercial purposes, it is assumed that the plant should be scaled-up to about 100 MW, requiring large amounts of water from lake IJssel (ca 100 m^3 s^{-1}) and the Wadden Sea (ca 100 m^3 s^{-1}). During discussions with stakeholders, a number of potential environmental effects have been identified such as removal of pelagic organisms (algae, zooplankton, (jelly)fish), inorganic suspended particles, changes in current patterns in the Wadden Sea and a change in salinity gradients. In order to study the environmental effects of a Blue Energy plant in the Afsluitdijk, the project environmental effects of Blue Energy, was initiated in 2016. The project is funded by the Waddenfonds, the province of Friesland and Rijksbijdrage Ambities Afsluitdijk. The project is subdivided in 6 workpackages:

- WP1: Inventory study on the potential effects of a Blue Energy plant on the marine environment
- WP2: Monitoring of organisms
- WP3: Pre-filtration of the salt water by shellfish
- WP4: Effects of scaling-up
- WP5: Communication
- WP6: Coordination

This report is a product of task 3.2 and 3.3 (deliverables D3.2 and D3.3) within WP3 which focus on testing theory in practice at the test site. Initially, the effect of shellfish as pre-filter of marine intake water would be experimentally tested on a small scale within task 3.2 and tested on a larger scale within task 3.3. However, during a project meeting on 22 Augustus 2017, it was decided aim for testing the efficiency of shellfish as pre-filter during winter because the proposed upscaling of the plant with a renewed intake was not feasible. Concentration of suspended particles is expected to be highest in winter due to storms, whereas filtration activities of shellfish is lowest at low winter temperatures. Unfortunately, the experimental set-up was not available on time to measure during a winter period. Consequently, two consecutive experimental runs were executed in spring (March 15 till May 21) (Experiment 1) and summer (June 12 till September 11) (Experiment 2). Within WP1 an inventory was made of potential shellfish species (mussels and oysters) and design of conceptual filtration systems (flume and coupled tanks) (Wijsman and Smaal 2017). For the pre-filtration system a functional design was set up inspired by the in series coupled tanks (Walles et al. 2018). However, due to the high construction costs, only two tanks could be included in the experimental setup. Since one of the two tanks was used as a control. Therefore it was not possible to compare the effect of different species (e.g. mussels and oysters) within one trial. Although oysters have a higher individual filtration rate, mussels where chosen as test species out of practical and potential commercial considerations. Small mussels from seed mussel collection devices (MZIs) are usually harvested at the end of summer. Since the mussels from the MZIs are small, the filtration capacity per kg is high (Wijsman and Smaal, 2017). During wintertime, the mussels can be used in the filtration systems on land. Survival of the mussels might be higher than on the commercial culture plots since predation can be controlled on land. In the next summer mussels can be replaced by new mussels from the MZIs and the "old mussels" can be sold back to mussel farmers who can use them at their culture plots. If the shellfish in the system are well-managed in the tanks, they can grow while the losses are reduced, resulting in a higher yield. This can be profitable for the mussel farmers.

1.2 Problem definition

The reverse electrodialysis plant uses freshwater from Lake IJssel and an equal amount of saltwater from the Wadden Sea. The resulting brackish water is discharged into the Wadden Sea. The water pumped from the Wadden Sea is full of organic and inorganic particles. These particles affect the efficiency of the RED process by clogging the channels between the membranes. Currently a drum filter with a mesh size of 20 or 50 µm (two different mesh sizes have been uses subsequently on the drum filters) pre-filters the water. However, particles smaller than 20 µm (silt, bacteria, phytoplankton) still pass to the RED systems.

Shellfish can effectively filter particles down to a size of 2-5 µm from the water with their gills (Cranford et al. 2011). In this study we experimentally tested to what extent shellfish are capable of pre-filtering marine intake water. We also investigated if a combination of aquaculture and energy production can be economically feasible. The questions to be answered in the experimental study are:

1. Can shellfish be used to pre-filter the water?
2. How much suspended solids can be removed by the shellfish?
3. What is the survival rate of shellfish used in pre-filtering?
4. What is the growth rate of shellfish used in pre-filtering?

1.3 Approach

This report is the result of a large-scale experimental study which tested if shellfish can be used as pre-filter of marine intake water. Two consecutive experimental runs (Experiment 1 and 2) were carried out using the blue mussel *Mytilus edulis* as a natural filter. Filtration efficiency of marine intake water by shellfish was measured in a flow-through system containing mussels and compared to a control flow-through system without shellfish.

1.4 Acknowledgements

The authors would like to thank Peter Herman (Deltares) for his valuable comments on an earlier draft version this report. Rik Siebers (RedStack), Luca van Duren (Deltares) and Zwanette Jager (Zilwater Advies) are thanked for their input in the discussions during the project meetings. Erik Tippersma (RedStack), Pim van Dalen and Vincent Escaravage (WMR) assisted in the operation and the sampling. Jacco Schot (Neeltje Jans Mosselen) provided the mussels and the socks for the experiments. Finally, Aad Smaal (WUR) is thanked for initiating the idea of pre-filtration of water with shellfish.

2 Materials and Methods

2.1 Experimental setup

The water from the Wadden Sea contains relatively high concentrations of suspended particles (e.g. Brinkman, 2015). At the present configuration of the plant, a drum filter is used to filter suspended particles from the water before it enters the system. For the shellfish filtration experiment, part of the water from the Wadden Sea branched off to the filtration system (Figure 1) before it entered the drum filter. The filtration system consisted of two experimental flow-through tanks, a buffer tank, an aeration tank and a deposition tank. When the water supply from the Wadden Sea stopped due to maintenance, water was recirculated from the buffer tank, while the aeration tank prevented oxygen depletion in the water. The top 1m of the experimental flow-through tanks was divided into an inner (Ø 0.71 m) and outer (Ø 1.20 m) part by a ring. The lower part of the tank had a cone shape to collect the faeces and pseudo-faeces from the shellfish. The sediment from the experimental tanks can be discharged into the deposition tank. During the experiment, water entered the tank at the top in the inner part where, in the shellfish tank, the mussels were located. The inner part has a volume of 0.4 m^3. Assuming 50% - 60% of the volume occupied by mussels, the flow-through system can host ~100 kg of mussels (~66 000 individuals of 1.5 g total weight) when assuming 3.4 cm^3 space (1.5 x 1.5 x 1.5 cm) per mussel. A specially designed head was used to ensure that the inflowing water became evenly distributed over the surface of the inner part. Once the water, flowing down the inner part, reached the bottom of the inner ring it flowed up and left the tank at the top of the outer part. Since the outer part (1.2 m^3) had a larger volume than the inner part (0.4 m^3), the current velocities in the outer part (0.006 m s^{-1}, at a flow rate of 15 m^3 h^{-1}) were lower than in the inner part (0.01 m s^{-1}, at a flow rate of 15 m^3 h^{-1}). Due to the lower flow velocities in the outer part, the larger suspended particles in the form of faeces and pseudofaeces should be able to sink to the bottom of the tank, where they accumulated. When the cone-shaped bottom of the tank was filled with sediment, the collected deposits were discharged into the deposition tank by manually opening the valve at the bottom of the tanks.

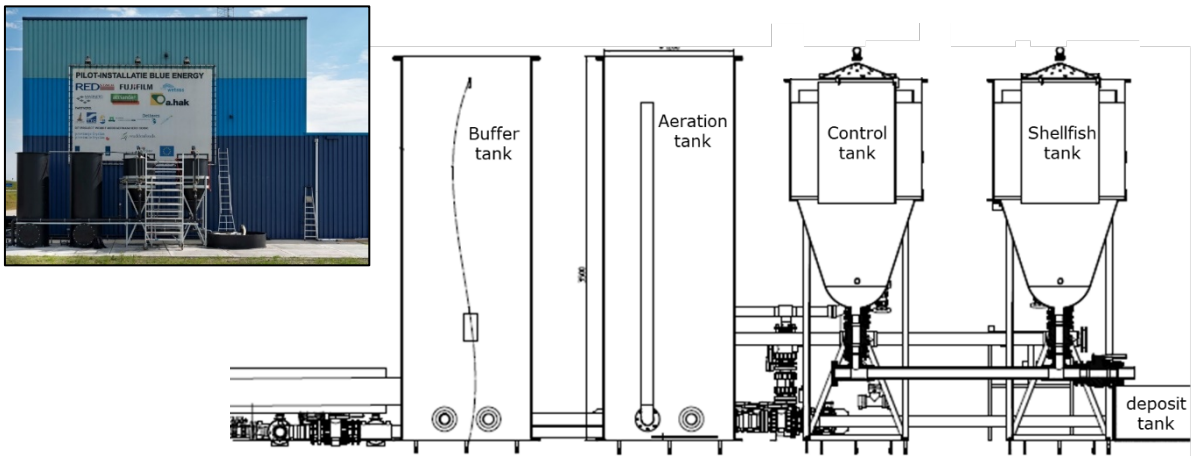


Figure 1. Experimental setup at test site the Afsluitdijk. From left to right: Buffer tank, aeration tank, flow-through system without (control) and flow-through system with shellfish in the inner ring. The buffer and aeration tanks were 3.30 m high and had a diameter of 1.2 m. The flow through systems had a volume of 1600L, were 2.15 m in length (3.3 m high in total, including steel frame) and were 1.2 m in diameter. The inner part had a diameter of 0.71 m and a length of 1 m. The cone-shaped bottom of the tank was 1.05 m in height. De deposit tank was 2.2 m in diameter and is used for both the shellfish and control tank.

2.2 Measurements

To measure the effect of filter feeding shellfish on the suspended particle concentration, several measurements were executed to obtain insight in the inflow and outflow concentrations and the deposition (Figure 2). The concentration of suspended particles at the inflow was recorded every 2 minutes with an optical backscatter sensor (OBS) during the course of the experiment. The concentration of suspended particles in the outflow was recorded in the top of the outer part of either the mussel or control tank with an OBS set at 2 minute intervals. The OBS in the outflow was transferred every 3.5 days between the mussel and control tank over the course of the experiment. To measure the amount deposited in the tank, height of the deposit was measured using a sounding rod and converted to volume using the dimensions of the tank. Height measurements of the deposit were also used to check if the tank was filled with deposit and needed to be discharged into the deposition tank. Additionally, water samples were weekly taken from the inflow and outflow of the mussel and control tanks during the course of the experiment to determine total particular matter (TPM) and particulate organic matter (POM). Water samples were filtered over pre-ashed and pre-weighted GFF-filters. TPM was determined by drying filters at 70°C for 4 days. Subsequently, POM was determined by ashing filters at 540°C for 4 hours.

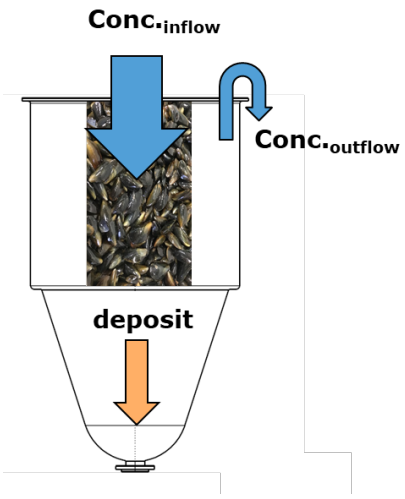


Figure 2. Schematic overview. Water with a high suspended particle concentration enters the tank. Due to filtration by shellfish and deposition a lower concentration leaves the tank.

Initial condition of the mussels was measured using 400 randomly selected individuals at the start of the experiments. Individual lengths were measured using an electronic calliper. Per group of 50 individuals, average fresh weight (tissue + shell) was determined. Mussels were subsequently dissected, separating the tissue from the shell, after which the flesh was dried at 70°C until weight constancy was achieved (4 d). Subsequently, they were incinerated at 540°C for 4 h to determine their ash-free dry weight (AFDW). Shells were dried at 70°C for two days to determine their weight. Average individual fresh weight and the total wet weight of mussels placed in the tank was used to estimate the number of individuals placed in the mussel tank at the start of the experimental runs. At the end of the experimental runs, the total weight of the mussels left in the tank was measured. Condition of the mussels was measured using 400 randomly selected mussels. Average individual fresh weight and total wet weight of all mussels in the tank was used to determine the number of individuals at the end of the experimental runs, to calculate the loss rate.

2.3 Experiment 1

Experiment 1 was run from the 15th of March till the 21th of May 2019. Flow rate during this experiment was set at 15 m^3 h^{-1} in both the shellfish tank and the control tank (total tank volume is 1.6 m^3, inclusive 0.4 m^3 of the inner part). This resulted in a flow velocity of 0.01 m s^{-1} in the inner part and a flow velocity of 0.006 m s^{-1} in the outer part of the experimental tank. At this flow rate water in the tank is refreshed every 6 minutes. Mussels were collected from seed mussel collection devices (MZIs) in the Oosterschelde. They were put in cotton socks of one meter length with a rope in

the middle (Figure 3). The mussels could attach to the rope, while the sock would deteriorate over time. At the start of the experiment 21 socks filled with mussels were placed in the tank, corresponding to a total weight of 101 kg of mussels (excluding 14 kg of ropes and sock netting). Mussels had an average length of 25.98 ± 4.55 mm (mean ± sd). Individual fresh weight was 1.51 ± 0.11 g. Individual dry weight, ash-free dry weight and shell weight were 0.036 ± 0.003 g, 0.031 ± 0.002 g and 0.49 ± 0.03 respectively. Mussels had a flesh percentage of 12.7 ± 1.7 %. Based on the total weight of mussels (101 kg) at the start of the experiment and their average individual fresh weight (1.51 g) it was estimated that 66 887 individuals were placed in the tanks at the start of the experiment.

Figure 3. Socks filled with mussels (left) submerged in the inner part of the mussel tank during experiment 1.

2.4 Experiment 2

Experiment 2 was run from the 12th of June till the 11th of September 2019. Flow rate during this experiment was set at 5 m^3 h^{-1}, which resulted in a downward flow velocity of 0.003 m s^{-1} in the inner part and an upward flow velocity of 0.002 m s^{-1} in the outer part. At this flow rate water in the tank was refreshed every 19 minutes. Initially new mussels, collected from a bottom culture plot in the Oosterschelde, were placed in the tank. However, due to the poor condition of the mussels, they were replaced by mussels that survived experiment 1 on June 25th. . Based on the experience of the first experiment, where the mussels massively migrated to the top of the tank and therefore blocked the water flow, the housing of the mussels was adapted in the second experiment. The mussels were put in ten rings and three cages (Figure 4). The rings were stacked on top of each other. Weight of mussels in each ring and cage was measured before placement into the tank to know the total weight of mussels at the start of the experimental run. A batch of mussels were brought to the lab to determine their initial condition.

At the start of the experiment a total weight of 45 kg of mussels were placed in the tank. Mussels had an average length of 28.29 ± 4.18 mm (mean ± sd). Individual fresh weight was 2.13 ± 0.23 g. Individual dry weight, ash-free dry weight and shell weight were 0.053 ± 0.004 g, 0.049 ± 0.004 g and 0.68 ± 0.06 respectively. Mussels had a flesh percentage of 12.7 ± 0.5 %. Based on the total weight of mussels (45 kg) at the start of the experiment and their average individual fresh weight (2.13 g) it was estimated that 21 126 individuals were placed in the tanks at the start of the experiment.

Figure 4. Cages and rings filled with mussels (left) submerged in the inner ring of the mussel tank during experiment 2.

2.5 Statistics

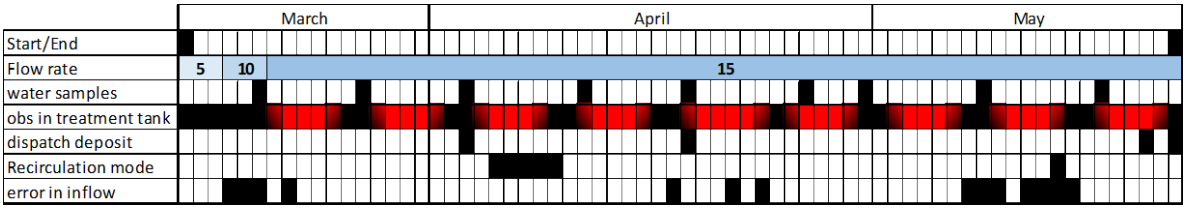
A t-tests was used to test if mussels significantly increased in shell length over the course of the experiment. All analyses were performed using "R" statistical software (R Development Core Team). Statistical significance was set at $p \leq 0.05$.

3 Results

3.1 Experiment 1

Experiment 1 started the 15th of March when the mussels were placed in the shellfish tank. Initial flow rate was set to 5 m^3 h^{-1} during the first 3 days to enable mussels to attach themselves to the rope and each other before increasing the flow rate to 10 m^3 h^{-1} and subsequently to 15 m^3 h^{-1} (see overview Table 1). At weekly intervals water samples were taken from the inflow, outflow control and outflow mussel tank to determine the concentration of total particulate matter (TPM) and particulate organic matter (POM). The thickness of the deposit accumulated in the mussel and control tank was measured with the sounding rod on March 29, April 3, 11 and 18 and May 5 and 21. The deposit that accumulated in the mussel tank was discharged two times during the experiment and at the end. The control tank was only emptied at the end of the experiment, since there was no need to do it sooner based on the amount of material that was accumulated. Turbidity of the inflowing water was measured throughout the experimental run, whereas the outflowing water was measured each 3.5 day in either the mussel or control tank (Table 1). When the OBS was not in the treatment tanks, it measured in the control tank.

Table 1. Overview of the measurements during experiment 1. Indicating when the flow rate of the incoming water changed; water samples were taken; the OBS sensor measured in the mussel (black) or control (red) tank; sediment deposit was dispatches; tanks were in recirculation mode and when errors in the inflow occurred.



Biodeposition

At the end of the experiment more suspended matter was deposited at the bottom of the shellfish tank (0.33 m^3) compared to the control tank (0.13 m^3) (Figure 5). Biodeposition in the flow-through tanks is a mixture of consolidated and recently settled silt. Bulk density of recently settled and consolidated silt is in the order of 400 to 800 kg per m^3 (Ysebaert et al. 2020). Therefore, we assume that 1 m^3 of deposit has a weight of 600 kg in this study. As such deposition was in the order of 1.2 and 2.9 kg d^{-1} at the control and shellfish tank, respectively. As such, mussels were able to remove on average 1.7 kg d^{-1} suspended matter. Deposition was not constant but varied over time (Figure 5). During the first two weeks for example 19 times more suspended matter was captured in the shellfish tank (0.022 m^3) compared to the control tank (0.001 m^3). During this period mussels actively removed on average 0.8 kg d^{-1}.

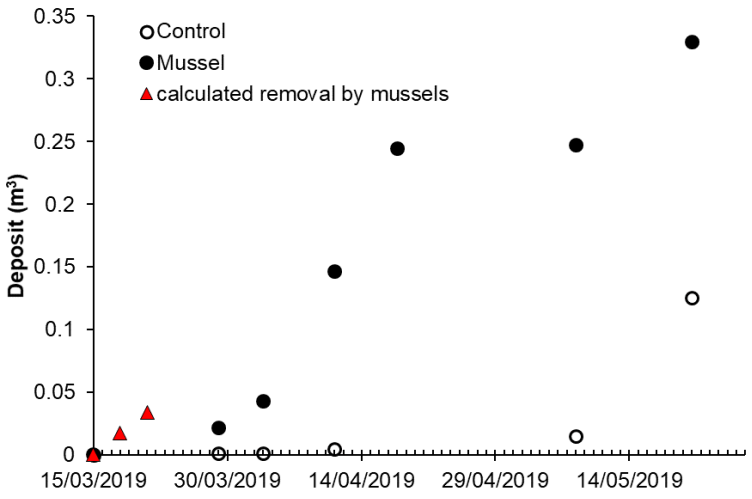


Figure 5. Cumulative volume of deposit measured at the bottom of the mussel (solid circles) and control (open circles) tank during experiment 1. Red triangles indicate the expected amount deposited in the mussel tank based on OBS measurements during the first six days.

Concentration of suspended matter

Concentration of suspended matter was recorded at 2 min intervals, using the two OBS sensors, after which it was averaged per hour. The OBS in the outflow stopped recording 3th of May due to an empty battery. The suspended matter concentration showed large variation over time (Figure 6). Recorded concentrations of suspended matter in the inflow showed from time to time peaks which were not observed in the outflow of the treatment tanks. Recorded concentrations by the OBS sensor were in the same order as weekly concentration measurements by filtering water samples (red triangles, Figure 6).

Alternately, concentration of suspended matter flowing out of the mussel or control tank was measured (Figure 6). Recorded concentrations by the OBS sensor were most of the time in the same order as weekly concentration measurements by filtering water samples (green circles and blue diamonds, Figure 6). In the outflow of the control tank an increase in suspended matter was observed after 18th of April. This was not observed at the inlet but also not when the OBS was positioned in the mussel tank. A lot of foam from proteins was produced at the inner part of the control tank which spilled into the outer part (Figure 7). As this process was even worse at the mussel tank, this could not be the cause of the observed increase.

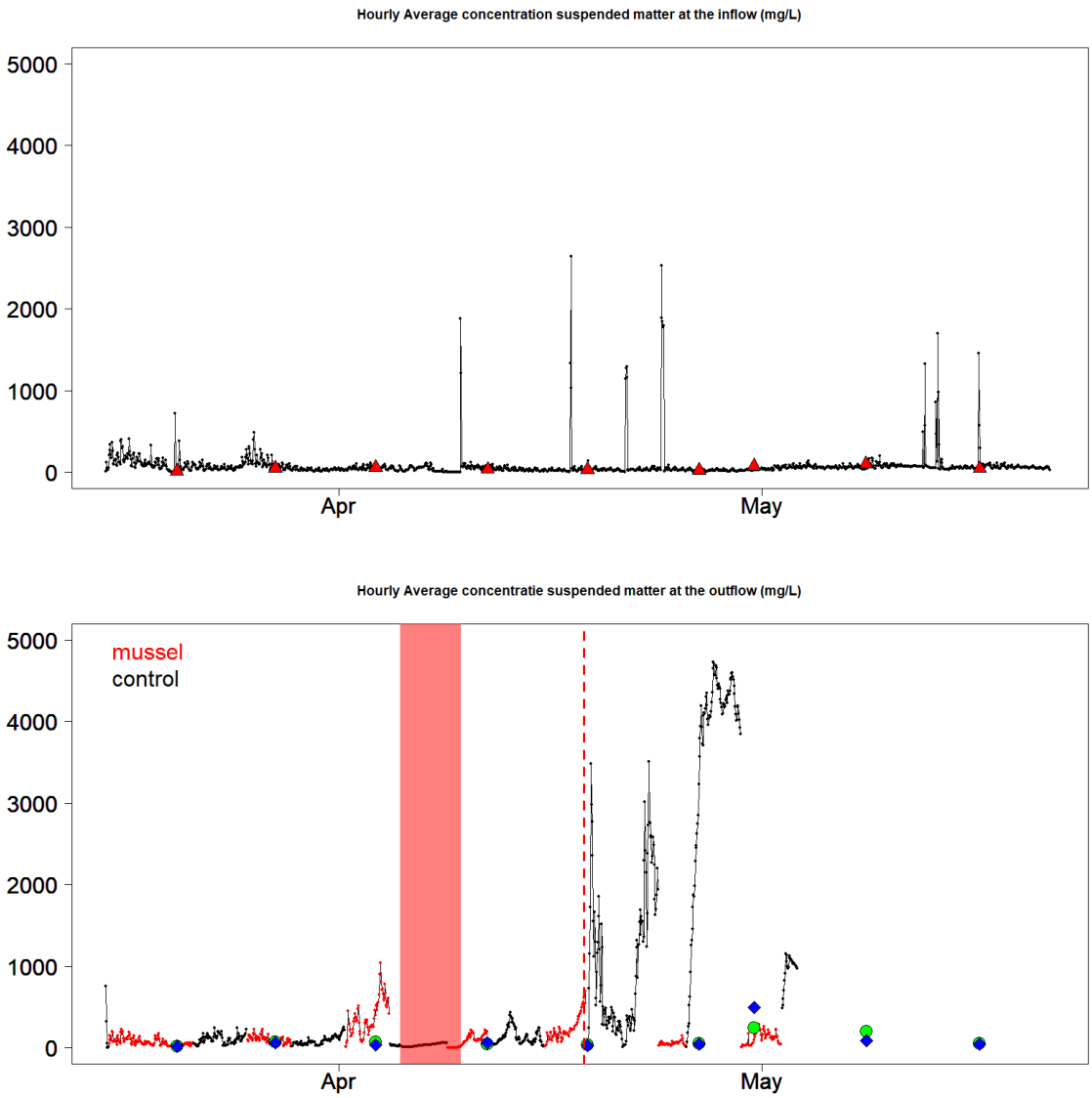


Figure 6. Hourly averaged concentration of suspended matter (mg L^{-1}) at the inflow (top) and outflow (bottom), measured with two optical backscatter sensors (OBS) during experiment 1. The red area indicates the period in which the treatment tanks were in recirculation mode. Vertical dotted red line indicates the moment foam produced at the top of the mussel and control tanks flowed into the outer part of the tank (18th of April 2019). Concentrations measured by filtering water samples are indicated by the red triangles (inlet), green circles (control) and blue diamonds (mussel). Note that these are snapshots whereas the OBS data are hourly averaged concentrations.

Figure 7. Foam in the inner part of the control (left) and mussel (right) treatment tank flowing to the outer part (18th of April 2019).

Calculated biodeposition

During the first six days of the experiment, flow rate increased from 5 to 15 m^3 h^{-1}. Below we calculated per flow regime the amount of sediment that potentially could have accumulated in the tanks. During the first three days (flow rate 5 m^3 h^{-1}) average concentration of suspended particles measured with the OBS in the inflow was 168.8 mg L^{-1} which corresponds with a total of 20 kg suspended matter entering each tank per day. During this period the OBS measuring the outflow was positioned in the mussel tank and recorded an average concentration of 95.8 mg L^{-1}, corresponding to 11 kg suspended matter per day. The mussel tank captured 45% (9 kg d^{-1}) of the incoming suspended matter (Table 2). During the period with a flow rate of 10 m^3 h^{-1} average concentration at the inflow was 84.9 mg L^{-1} (20 kg d^{-1} per treatment tank). With an average concentration of 51.1 mg L^{-1} (12 kg d^{-1}) at the outflow of the mussel tanks mussels captured 40% (8 kg d^{-1}) of the incoming suspended matter. Calculated removal of suspended matter by mussels during the first six days is in the order of the removal measured by measuring the deposition layer in the tank (Figure 5). When the flow rate was set at 15 m^3 h^{-1} the OBS was moved to the outflow of the control tank for three days. During this period the amount of suspended matter entering the system (66.5 mg L^{-1} corresponding with 24 kg d^{-1} per tank) was lower than the outflow of the control tank (108.1 mg L^{-1} corresponding with 39 kg d^{-1}). At the three subsequent days only a small percentage (12%) of the entering suspended matter was removed by the mussels (Table 2). During subsequent periods suspended matter concentrations at the outflow was from time to time higher than the inflow, suggesting a production of suspended matter in the tank.

Mussels

At the end of the experiment mussels had significantly ($t_{777.6}$=-14.5, $p<0.0001$) grown to an average length of 30.29 ± 0.19 mm (mean ± se) (Figure 8 and Table 3). Individual (fresh) wet weight increased 62% over the course of the experiment to 2.43 ± 0.06 g. Individual dry weight and ash-free dry weight increased to 0.103 ± 0.003 g and 0.094 ± 0.003 g respectively. Flesh percentage increased with 62% from 12.7 ± 0.6 % to 20.6 ± 1.0 %. Individual shell weight was on average 0.76 ± 0.02 g. At the end of the experiment a total weight of 92 kg of mussels (excluding 13 kg of ropes, sock netting had degraded) was harvested. It was estimated that this corresponded with 37 860 individuals indicating a loss of rate of 43% over the course of the experiment.

Table 2. Average suspended matter concentration (in mg/L) recorded by the OBS at the inlet and outflow. Based on flow rate and time suspended matter (in kg per day) passing the inlet and the outflow of the mussel or control tank was calculated. Difference between the inlet and outflow is indicated in percentage of suspended matter deposit in either the mussel or control treatment. Negative percentages indicate a net outflow of material instead of deposition.

period	treatment tank	hours	flow rate (L/h)	average concentration (mg/L)		suspended matter (kg/d)		% removed
			outflow	*inflow*	*outflow*	*inflow*	*outflow*	
15-03-2019 (15:00) - 18-03-2019 (13:00)	mussel	70	5000	168.8	95.8	20	11	43%
18-03-2019 (14:00) - 21-3-2019 (15:00)	mussel	73	10000	84.9	51.1	20	12	40%
21-03-2019 (16:00) - 25-03-2019 (09:00)	control	89	15000	66.5	108.1	24	39	-63%
25-03-2019 (11:00) - 28-03-2019 (13:00)	mussel	74	15000	114.5	100.3	41	36	12%
28-03-2019 (15:00) - 01-04-2019 (09:00)	control	90	15000	33.9	88.0	12	32	-159%
01-04-2019 (11:00) - 04-04-2019 (13:00)	mussel	74	15000	55.3	371.6	20	134	-571%
04-04-2019 (15:00) - 08-04-2019 (15:00)	control *	96	15000	41.6	33.7	15	12	19%
08-04-2019 (17:00) - 11-04-2019 (12:00)	mussel *	67	15000	89.4	83.5	32	30	7%
11-04-2019 (14:00) - 15-04-2019 (13:00)	control	95	15000	37.7	126.2	14	45	-235%
15-04-2019 (15:00) - 18-04-2019 (12:00)	mussel	69	15000	98.0	237.6	35	86	-142%
18-04-2019 (14:00) - 23-04-2019 (15:00)	control	121	15000	72.1	1024.2	26	369	-1321%
23-04-2019 (17:00) - 25-04-2019 (14:00)	mussel	45	15000	247.6	57.4	89	21	77%
25-04-2019 (16:00) - 29-04-2019 (12:00)	control	92	15000	25.5	3592.7	9	1293	-13994%
29-04-2019 (14:00) - 02-05-2019 (09:00)	mussel	67	15000	36.7	123.0	13	44	-235%
02-05-2019 (11:00) - 03-05-2019 (13:00)	control	26	15000	69.7	964.9	25	347	-1285%

* recirculation mode

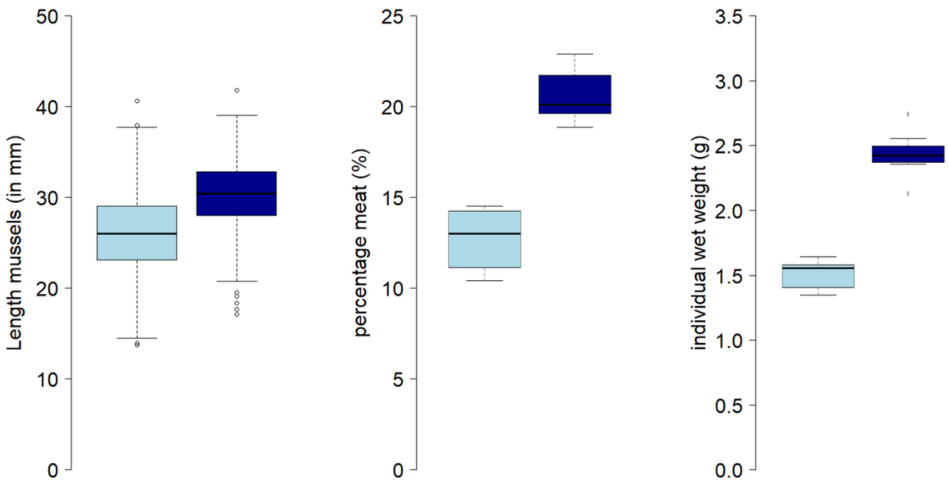


Figure 8. Boxplot of lengths (in mm), individual (flesh) wet weight (g) and percentage meat of 400 mussels at the start (light blue) and end (dark blue) of experiment 1.

Table 3. Statistics (mean ± se) of the mussels at the start and end of experiment 1.

	start			end		
length (mm)	25.98	±	0.23	30.29	±	0.19
fresh weight (g)	1.51	±	0.04	2.43	±	0.06
dry weight (g)	0.036	±	0.001	0.103	±	0.003
ash-free dry weight (g)	0.031	±	0.001	0.094	±	0.003
shell weight (g)	0.49	±	0.01	0.76	±	0.02
flesh percentage	12.7	±	0.6	20.6	±	1.0

Filtration

Filtration rate was calculated over a short period from 15th of March to 21th of May. This period was selected as it represents a continues period in which the outflow of the mussel tank was measured before the OBS was switched to the control tank. In this period, the difference in biodeposition between the control and mussel tanks was on average 1.8 kg per day. At the inlet an average concentration of 78.5 mg per litre was measured. This corresponds with on average amount of 28.3 kg sediment per day entering the flow-through systems. As such, based on the deposition in the tanks, 6% of the sediment entering the shellfish tank is filtered out by the mussels. The amount of 1.8 kg sediment filtered per day corresponds to a filtration rate of 22.9 m^3 per day at an average concentration of 78.5 mg per litre. Considering an average number of 52 374 individuals, on average, each mussel filtered 0.018 litre per hour. This is less than expected based on results from other studies (see cross point dotted lines Figure 9). It is important to note that re-filtration of the water is minimized, often by using only one animal, in experiments to estimate clearance rates as presented in Figure 9. In the present experiment filtration rate is calculated from a large group of mussels, and therefore re-filtration of the water will occur. Clearance rate of individual mussels is expected to be more than 0.018 litre per hour as refiltration takes place in the flow-through system.

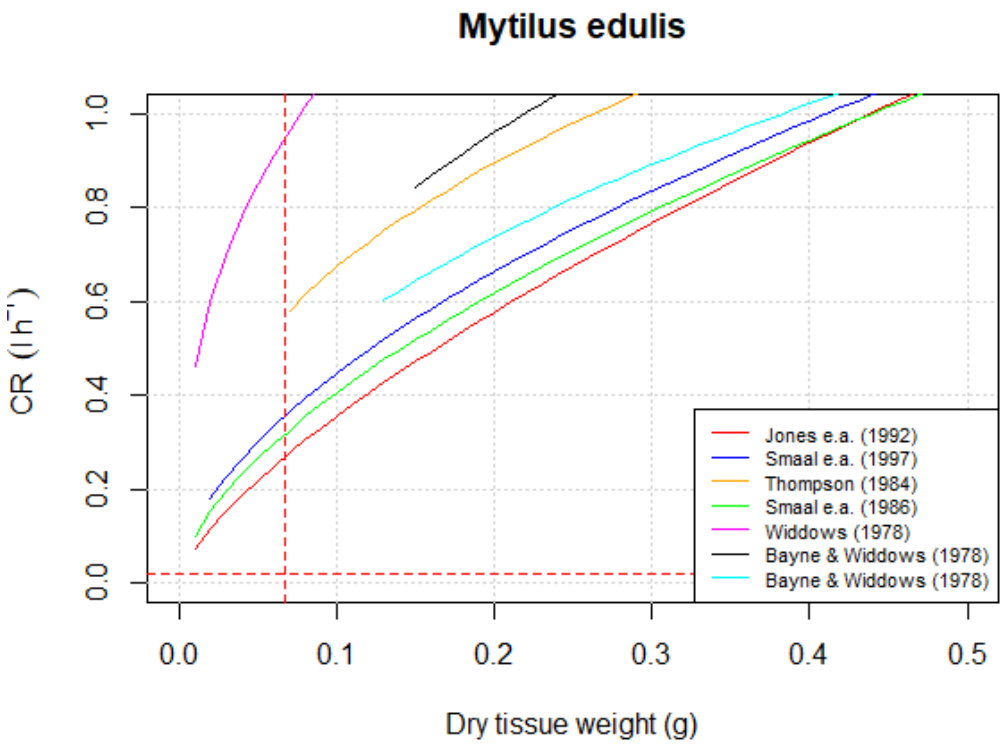


Figure 9. Clearance rate versus tissue dry weight for *Mytilus edulis*, adapted from Wijsman et al. 2017. Red dotted lines indicate dry tissue weight and calculated filtration rate of the mussels in experiment 1 between 15th of March and 21th of May.

Temperature

The OBS sensors measured temperature at the inflow and outflow. Daily fluctuation in temperature were observed at the in- and outflow (
Figure 10), followed trends in air temperature measured at a nearby KNMI station. Variance in the inflow was substantially larger than in the outflow. The OBS at the inflow was placed in and enclosed upstanding dead-end black pipe filled with water. The water in this pipe was hardly replaced. The sensor in the outflow was placed in the tank, where the water was replaced continuously. This could have caused the differences in temperature variation between the inflow and the outflow. As a consequence, the temperature recordings at the outflow are a better indicator for the water temperature for the mussels than the temperature recordings at the inflow. During the period the system was in recirculation mode (period indicated by a red band) temperature increased.

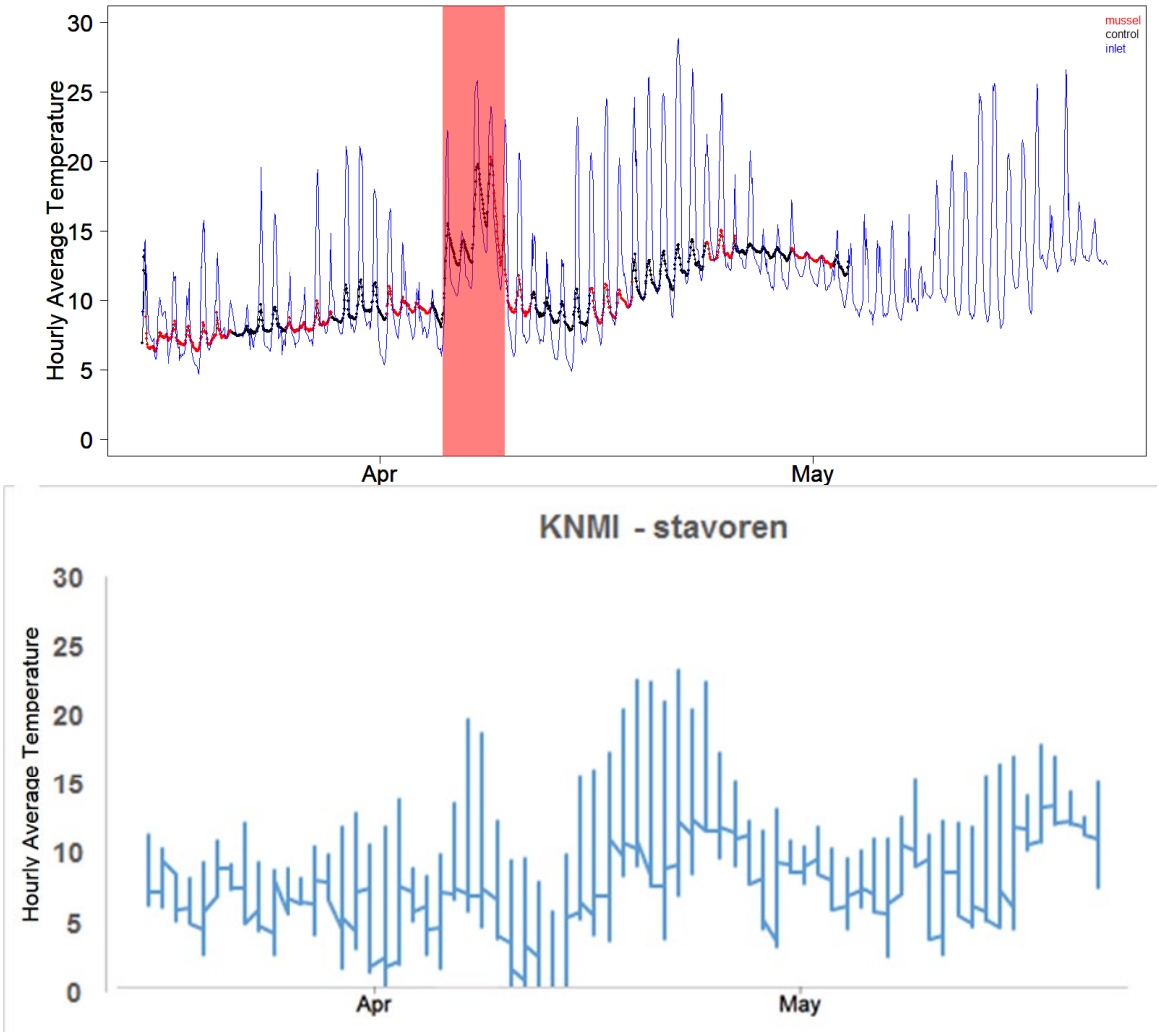


Figure 10. Hourly averaged temperature at the inflow (blue line) and outflow (red and black line), measured with two optical backscatter sensors (OBS) during experiment 1 (above). The red area indicates the period in which the treatment tanks were in recirculation mode. The OBS in the outflow (mussel and control) stopped early may due to an empty battery. Hourly temperature at KNMI station Stavoren (below).

3.2 Experiment 2

Experiment 2 started the 12th of June when the mussels were placed in the flow-through tank. Due to the poor condition of the mussels, new mussels were placed in the treatment tank 25th of June. Flow rate was set at 5 m^3 h^{-1} over the course of the experiment (see overview Table 4). At eight moments water samples were taken from the inflow, outflow control and mussel tank to determine total particulate matter (TPM) and particulate organic matter (POM). The thickness of the deposit accumulated in the mussel and control tank was measured with the sounding rod on July 17 and August 2 and 22. Accumulated deposit in the mussel tank was discharged one time during the experiment (4th of August) and at the end for both tanks (Mussel tank: 2th of September; Control tank: 12th of September). The deposit was not removed when new mussels where placed in the tank on the 25th of June. Concentration of suspended matter of the inflowing water was measured throughout the experimental run at the inlet, whereas the outflowing water was measured each 3.5 day in either the mussel or control tank (Table 4). When the OBS was not in the treatment tanks, it measured in the control tank.

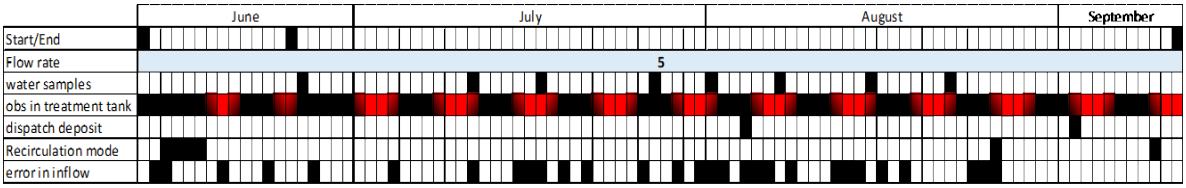


Table 4. Overview of the measurements during experiment 2. Indicating when the flow rate of the incoming water changed; water samples were taken; the OBS sensor measured in the mussel (black) or control (red) tank; sediment deposit was dispatches; tanks were in recirculation mode and when errors in the inflow occurred. The first mussel batch was replaced on the 25th of June.

Biodeposition

At the end of the experiment significantly more suspended matter deposited at the bottom of the shellfish tank (0.29 m^3) compared to the control tank (0.04 m^3) (Figure 11). Deposition was in the order of 0.4 and 2.4 kg d^{-1} at the control and shellfish tank, respectively. As such, mussels were able to remove on average 2.0 kg suspended matter per day. Deposition was not constant but varied over time (Figure 11). A month after the start of the experiment (17th of June) for example, 4 times more suspended matter was captured in the shellfish tank (0.022 m^3) compared to the control tank (0.005 m^3). During this period mussels actively removed on average 0.3 kg d^{-1}.

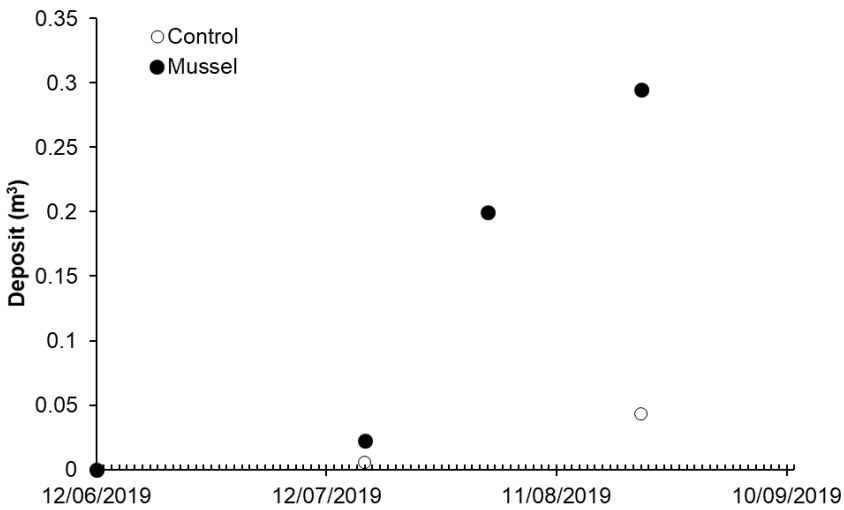


Figure 11. Volume of deposit measured at the bottom of the mussel (solid circles) and control (open circles) tank during experiment 2.

Concentration of suspended matter

Concentration of suspended matter was recorded at 2 min intervals, using the two OBS sensors, after which it was averaged per hour. The concentration showed large variation over time (Figure 12), especially in June at the inlet, this was, however, not observed at the outflow of the treatment tanks. Three different periods can be distinguished in the concentrations at the inlet. A period with large variations and high concentrations (June), a period with low concentrations and small variance (July – mid August), and a period with slightly higher concentrations but larger variance (end of August and September). Despite the high concentrations at the inlet in June, concentrations at the outflow were relatively low. At the end of June when the OBS was positioned in the mussel tank, an increase in concentration was observed. As an increase was not observed at the inlet, another mechanism could have caused this increase over time. Except for June, recorded concentrations by the OBS sensor at the inlet were in the same order as concentrations obtained by filtering water samples (red triangles, Figure 12). Concentrations at the outflow of the control and mussel tank recorded by the OBS were an order of magnitude lower compared to the concentrations measured by taking water samples.

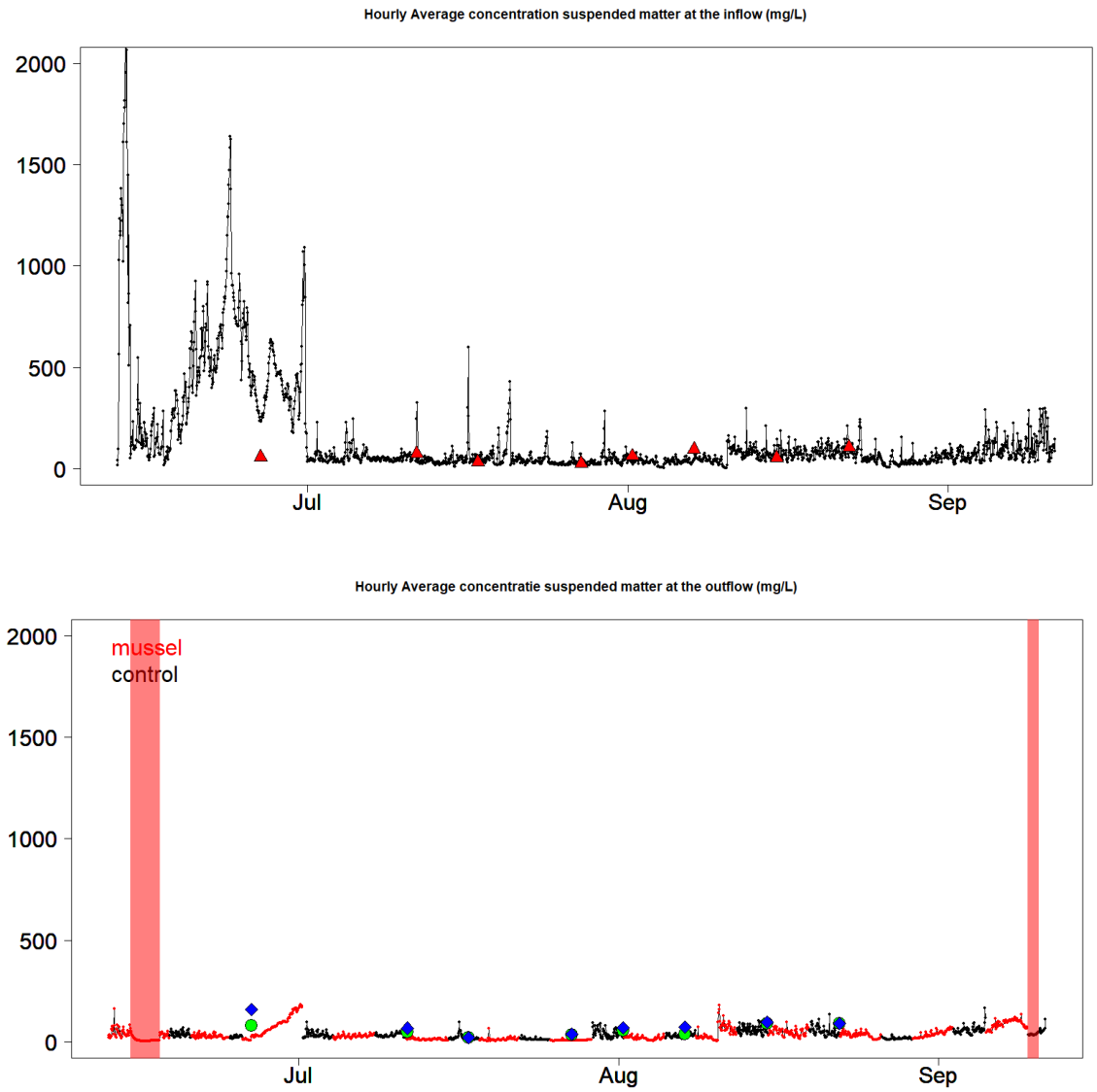


Figure 12. Hourly averaged concentration of suspended matter at the inflow (top) and outflow (bottom), measured with two optical backscatter sensors (OBS) during experiment 2. The red area indicates the period in which the treatment tanks were in recirculation mode. Concentrations measured by filtering water samples are indicated by the red triangles (inlet), green circles (control) and blue diamonds (mussel). Note that these are snapshost whereas the OBS data are hourly averaged concentrations.

Calculated biodeposition

Table 5 shows, per period the OBS was positioned in either the control of mussel tank, the concentrations measured at the inflow and outflow. During the first three days (flow rate 5 m^3 h^{-1}) average concentration of suspended particles measured with the OBS at the inflow was 381.1 mg L^{-1} which corresponds with a total of 46 kg suspended matter entering each tank per day. During this period the OBS measuring the outflow was positioned in the mussel tank and recorded an average concentration of 28.2 mg L^{-1}, corresponding to 3 kg suspended matter per day. The mussel tank captured 93% (43 kg d^{-1}) of the incoming suspended matter (Table 5). In the three subsequent days, the control tank also captured a high percentage (90%) of the incoming suspended matter. This suggests inactivity of the mussels. New mussels were placed in the treatment tank on the 25th of June. The subsequent days, these mussels were able to remove 80% (38 kg d^{-1}) of the incoming suspended matter, while the control tank captured only 33% (Table 5). Note that this was in the month June when concentrations at the inlet were quite high. Between July and mid-August mussels removed on average 65% (~ 4 kg d^{-1}) of the suspended matter whereas 42% (~ 3 kg d^{-1}) deposited in the control

tank. During the subsequent period, with slightly higher concentrations at the inlet and a higher variation, less suspended matter deposited in the mussel treatment (30%, ~2 kg d^{-1}) compared to the control treatment (43%, ~5 kg d^{-1}).

Table 5. Average suspended matter concentration (in mg/L) recorded by the OBS at the inlet and outflow. Based on flow rate and time suspended matter (in kg) passing the inlet and the outflow of the mussel or control tank was calculated. Difference between the inlet and outflow is indicated in percentage of suspended matter deposit in either the mussel or control treatment.

period	treatment tank	hours	flow rate (L/h)	average concentration (mg/L)		suspended matter (kg/d)		% removed
			outflow	*inflow*	*outflow*	*inflow*	*outflow*	
12-06-2019 (14:00) - 18-06-2019 (11:00)	mussel	141	5000	381.1	28.2	46	3	93%
18-06-2019 (13:00) - 20-06-2019 (13:00)	control	48	5000	421.0	40.5	51	5	90%
20-06-2019 (15:00) - 24-06-2019 (07:00)	mussel	88	5000	753.9	28.1	90	3	96%
24-06-2019 (09:00) - 25-06-2019 (12:00)	control	29	5000	653.5	25.9	78	3	96%
25-06-2019 (14:00) - 01-07-2019 (08:00)	mussel	138	5000	393.7	77.0	47	9	80%
01-07-2019 (10:00) - 04-07-2019 (07:00)	control	69	5000	53.5	36.1	6	4	33%
04-07-2019 (09:00) - 08-07-2019 (09:00)	mussel	96	5000	67.8	28.8	8	3	58%
08-07-2019 (11:00) - 11-07-2019 (09:00)	control	70	5000	53.6	34.1	6	4	36%
11-07-2019 (11:00) - 15-07-2019 (12:00)	mussel	97	5000	43.2	13.9	5	2	68%
15-07-2019 (14:00) - 18-07-2019 (10:00)	control	68	5000	64.8	21.7	8	3	66%
18-07-2019 (12:00) - 22-07-2019 (09:00)	mussel	93	5000	72.0	13.1	9	2	82%
22-07-2019 (11:00) - 25-07-2019 (08:00)	control	69	5000	46.1	13.9	6	2	70%
25-07-2019 (10:00) - 29-07-2019 (09:00)	mussel	95	5000	31.2	8.9	4	1	71%
29-07-2019 (11:00) - 01-08-2019 (12:00)	control	73	5000	54.8	42.4	7	5	23%
01-08-2019 (14:00) - 05-08-2019 (12:00)	mussel	94	5000	34.9	19.2	4	2	45%
05-08-2019 (14:00) - 08-08-2019 (10:00)	control	68	5000	42.7	32.4	5	4	24%
08-08-2019 (12:00) - 12-08-2019 (10:00)	mussel	94	5000	61.8	45.8	7	5	26%
12-08-2019 (12:00) - 15-08-2019 (10:00)	control	70	5000	76.7	59.7	9	7	22%
15-08-2019 (12:00) - 19-08-2019 (10:00)	mussel	94	5000	75.7	48.4	9	6	36%
19-08-2019 (12:00) - 22-08-2019 (09:00)	control	69	5000	90.5	52.3	11	6	42%
22-08-2019 (11:00) - 26-08-2019 (10:00)	mussel	95	5000	61.7	32.9	7	4	47%
26-08-2019 (12:00) - 29-08-2019 (11:00)	control	71	5000	35.9	17.2	4	2	52%
29-08-2019 (13:00) - 02-09-2019 (09:00)	mussel	92	5000	57.4	39.1	7	5	32%
02-09-2019 (11:00) - 05-09-2019 (13:00)	control	74	5000	80.4	58.8	10	7	27%
05-09-2019 (15:00) - 09-09-2019 (14:00)	mussel	95	5000	99.0	88.9	12	11	10%
09-09-2019 (16:00) - 11-09-2019 (08:00)	control	40	5000	149.9	46.3	18	6	69%

Mussels

At the end of the experiment mussels significantly ($t_{781.4}$=-9.9, $p<0.001$) grew to an average length of 31.47 ± 0.24 mm (mean ± se) (Figure 13). Individual (fresh) wet weight slightly increased over the course of the experiment to 2.46 ± 0.17 g. Individual dry weight, ash-free dry weight and percentage flesh decreased (Table 6). Individual shell weight increased over the course of the experiment. At the end of the experiment a total weight of 29 kg of mussels was harvested. It was estimated that this corresponded with 11 890 individuals indicating a loss of rate of 62% over the course of the experiment.

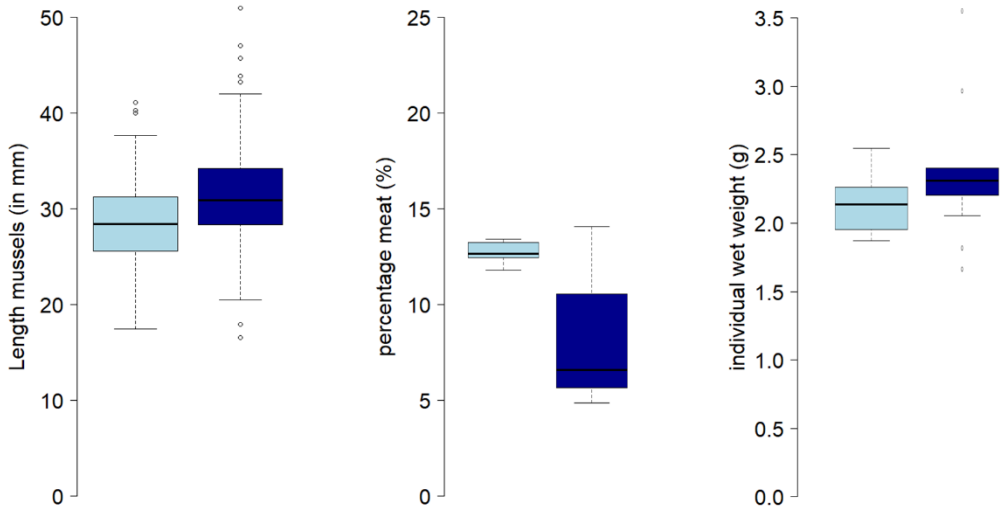


Figure 13. Boxplot of lengths (in mm), individual (flesh) wet weight (g) and percentage meat of 400 mussels at the start and end of experiment 2.

Table 6. Statistics of the mussels (mean ± se) at the start and end of experiment 1.

	start			end		
length (mm)	28.29	±	0.21	31.47	±	0.24
fresh weight (g)	2.13	±	0.08	2.46	±	0.17
dry weight (g)	0.053	±	0.002	0.029	±	0.006
ash-free dry weight (g)	0.049	±	0.001	0.025	±	0.005
shell weight (g)	0.68	±	0.02	0.81	±	0.07
flesh percentage	12.7	±	0.2	8.0	±	0.9

As some of the mussels in experiment 2 were located in rings stacked on top of each other differences in performance could also be studied over a depth profile. Whereas no big differences were observed in individual performance, large differences in survival were observed. Each ring started with 3 kg of mussels. Highest losses of mussels occurred in the top rings and loss decreased with increasing depth (Figure 14). This is most likely due to accumulation of suspended matter within the bottom rings (Figure 14).

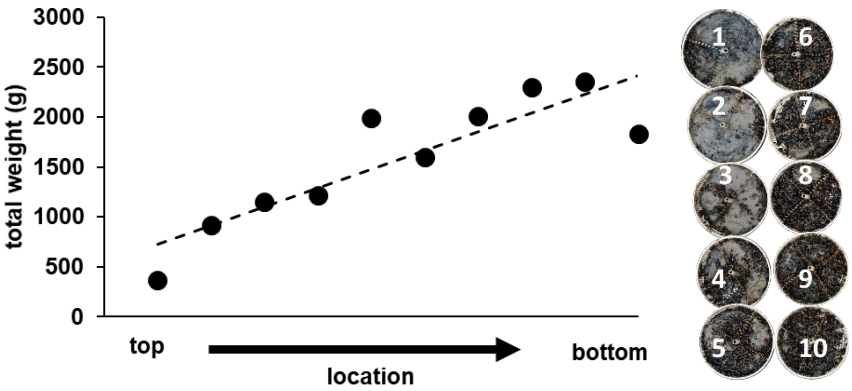


Figure 14. Total weight of mussels per ring and a top-view photo of each ring at the end of experiment 2. The photos show a decrease in accumulated amount of mud with depth, with ring 1 being located at the top and 10 at the bottom.

Filtration

Filtration rate was calculated over a short period. Between 16th of June and 22th of August difference in biodeposition between the control and mussel tanks was on average 2.2 kg per day. At the inlet an

average concentration of 169 mg per litre was recorded. This corresponds with on average 20.3 kg sediment per day entering the flow-through systems. As such 11% of this sediment is filtered out by the mussel stock. Based on the concentration at the inlet and the deposition rate, 13 m^3 water per day is expected to be filtered by the mussel stock. Considering an average number of 16 508 individuals, on average, each mussel filtered 0.032 litre per hour. This less than expected from other studies (see cross point dotted lines, Figure 15) but more than what was calculated for experiment 1. Also here refiltration of the water impacts the amount each individual mussel can filter per time unit. Further factors like temperature, periods in which they don't filter, etc could influence the filtration rate.

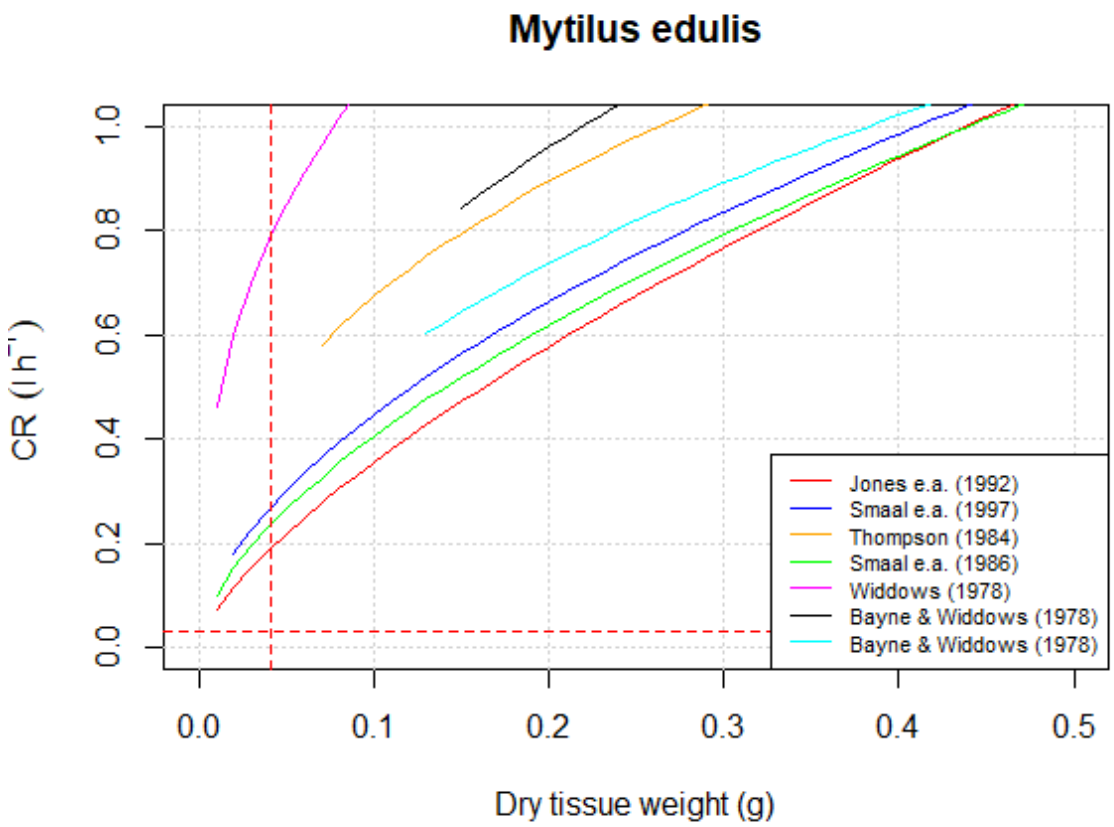


Figure 15. Clearance rate versus tissue dry weight for *Mytilus* edulis, adapted from Wijsman et al. 2017. Red dotted lines indicate dry tissue weight and calculated filtration rate of the mussels in experiment 1 between 16th of June and 22th of August.

Temperature

The OBS sensors measured temperature at the inflow and outflow. Daily fluctuation in temperature were observed at the in- and outflow (Figure 16), followed trends in air temperature measured at a nearby KNMI station. Variance in the inflow was lower than in the outflow. During the period the system was in recirculation mode no clear increase in temperature was observed.

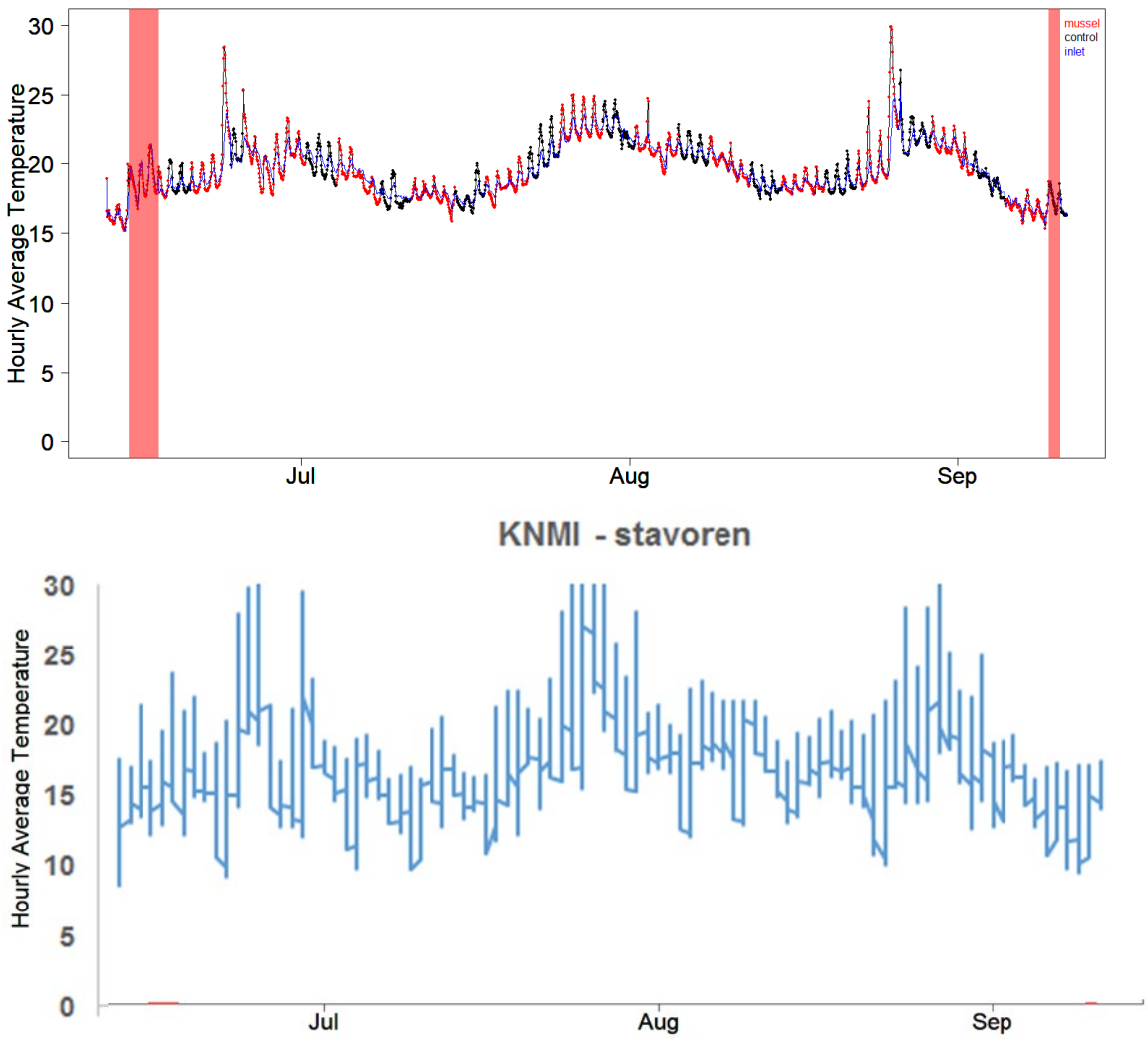


Figure 16. Hourly averaged temperature at the inflow (blue line) and outflow (red and black line), measured with two optical backscatter sensors (OBS) during experiment 2 (above). The red area indicates the period in which the treatment tanks were in recirculation mode. Hourly temperature at KNMI station Stavoren (below).

4 Discussion and conclusion

Shellfish are efficient filterfeeders that are capable to filter large amounts of suspended solids from the water. A single mussel, for example, can filter more than 1 liter of water per hour (Cranford et al. 2011). Therefore, shellfish can be used to pre-filter the water from the Wadden Sea, before it enters the reverse electro dialysis power plant. In a previous study, Wijsman and Smaal (2017) have shown based on model calculations that, depending on residence times and amount of shellfish, mussels are capable to remove 50% of the suspended particles from the water. The large-scale experiments showed that depending on the set-up, the mussels were able to remove 6-11% of the incoming sediment over a period of 2 to 3 months. Within this period, moments occurred where more than 50% of the suspended particles were removed by the mussels. During the experiments, the mussels survived and even increased in weight. The mortality, however, was 43% and 62% in experiment 1 and 2 respectively. It is expected that modifications in the design of the set-up will increase the efficiency of the sediment removal from the water and the survival of the mussels.

Deposition

Deposition of suspended matter at the bottom of the shellfish tank was more than the amount deposited in the control tank, indicating that mussels had an added value. During experiment 1, the deposition rate in the tank with mussels was on average 2.9 kg day^{-1} while the deposition rate in the control tank was 1.2 kg day^{-1}. During experiment 2 the deposition rates in the mussel and control tanks were 2.4 and 0.4 kg day^{-1}, respectively. Inflow and outflow concentrations measured with the OBS sensors indicate that the removal is not constant over time. With a high inflow concentration of suspended matter (June, experiment 2), high deposition occurred in both the control and shellfish tanks, whereas with low inflow concentrations (July- mid-August) mussels removed a higher fraction of the suspended matter. During periods of high concentrations of suspended matter filtering capacity can decreases (>125 mg l^{-1}) or even stop (>250 mg l^{-1}) (Bayne et al 1993 and Widdows et al. 1979), which could explain the lack of a clear difference in June, when the suspended solid concentrations measured at the inflow were very high, between the shellfish and control tanks.

Concentration changes

At the end of April during experiment 1, an increase in suspended solid concentrations measured by the OBS sensor in the outflow occurred. The control tank differed from the mussel tank by the amount of macro-algae growing inside the tank. Initially it was thought that accumulation in the head of the OBS sensor could explain the sudden recorded increase each time the sensor entered the control tank. However, an increase in concentration was also measured end of June and beginning of September in both the shellfish and control tank. Another explanation could be the build-up of suspended particles with the same sinking speed as the upwelling speed of the water, resulting in an accumulation of suspended solids over time. As it is unknown at present why the OBS measured such increases additional research is needed to understand what the OBS measured in those moments. This could be tested in the lab by filling the head of the OBS with sediment and see if this causes an increase. Or by increasing the suspended concentration over time and keeping it in resuspension. Another mechanism could be algal growth, which could be investigated by placing the OBS sensor in an algal culture. It should be noted that mussels also only filter a fraction of the sediment (see LISST results in Walraven et al. 2020) whereas a sand filter can remove sediment across the whole size spectrum.

Mussels

During the first experiment, mussels were placed in socks within the inner part of the flow-through tank. The idea was that mussels would attach themselves to the internal rope before the sock itself would decade. Mussels, however, migrated upwards and completely filled the inner part of the tank and were attached to each other instead of the ropes. They also crawled on top of each other blocking the water flow through the inner part of the tank. As a results of this behaviour, a large part of the water entering the shellfish tank immediately entered the outer part without passing the mussels first (Figure 17). Adjustment were made for the second experiment. Mussels were placed in rings and cages to ensure that they would stay in place. Problem with this set-up was the amount of sediment

deposited within the rings (Figure 14) and cages (Figure 18). This affected the survival rate of the mussels. Survival during experiment 2 (38%) was lower than during experiment 1 (57%). The low survival during experiment 2 can be linked to sediment accumulation in the cages (Figure 14). Furthermore, high summer temperatures could have influenced survival. Despite the mussels crawling on top of each other during experiment 1, growth, survival and overall conditions where high. Probably mussels did get enough food even when completely packed on top of each other (Figure 17). For future experiments it is important to find a proper housing for the mussels which will keep them in one place but at the same time does not accumulate too much sediments. Perhaps the tanks need to be flushed from time to time to remove the accumulated sediments.

Flow rate
The results of the flow rate experiment were inconclusive due to the lack of information on the incoming concentration.

Upscaling
At a flow rate of 5 m^3 per hour 11% of the incoming suspended matter was filtered by on average 35 kg of mussels (see experiment 2). It is expected that with a better design, the efficiency could be doubled or even tripled with the same amount of mussels. A powerplant with a capacity of 10 MW needs 10 m^3 s^{-1} sea water (36 000 m^3 per hour). To pre-filter the water with an efficiency of 11%, a total of 252 000 kg of mussels are needed, producing a total of about 16 tons of biodeposits per day.

Recommendations
Deposition measures gave a good indication for the difference between the control and mussel tank. This measure should be taken at regular intervals during a next experiment.

Only two OBS sensors were available for this experiment. As a consequence, the inflow and outflow of the mussel and control tank could not be monitored simultaneously. This makes direct comparison between the mussel and control tank impossible as the concentration of suspended matter at the inflow is constantly changing. Furthermore, deposition could only be calculated for the first days when the OBS was positioned in the mussel tank. For a new experiment extra OBS sensors (minimal 4 in total) are needed to have a continuous monitoring in all tanks. The concentrations measured with the OBS were in most cases in the order measured by filtering water, giving confidence in using this sensor for the experiment. Moreover, both OBS sensors were calibrated simultaneously at the start of the experiment with water from the intake (TPM concentration 91 mg l^{-1}).

The way mussels were placed in the shellfish tank is not optimal yet. A new way of placing mussels in the tank should be found to keep them in place and decrease the chance that they become suffocated by accumulation.
For upscaling purposes the design of the shellfish filtration system should be optimised to (1) increase filtration efficiency of the mussels, (2) minimize resuspension of (pseudo)faeces and (3) increase the efficiency to remove the produced (pseudo)faeces from the systems. Optimization 1 could be reached by changes in the housing for the mussels in such a way that they have optimal access to the incoming water. Optimization 2 (and 3) could be reached by placing the mussels on top of a 2D wireframe. (Pseudo)faeces produced by the mussels could fall through the wireframe from where it can collected mechanically (or by events of flushing with water).

Figure 17 Mussels growing on top of each other (top) blocking the waterflow (bottom right) resulting in a spill of water directly into the outer part of the tank (bottom left). Pictures were taken at the end of experiment 1.

Figure 18 Sediment accumulation in the cages. Picture was taken at end of experiment 2.

5 Quality Assurance

Wageningen Marine Research utilises an ISO 9001:2015 certified quality management system. This certificate is valid until 15 December 2021. The organisation has been certified since 27 February 2001. The certification was issued by DNV GL.

References

Bayne, B. L., J. I. P. Iglesias, A. J. S. Hawkins, E. Navarro, M. Heral and J. M. Deslouspaoli (1993) Feeding-behavior of the Mussel, *Mytilus edulis* - responses to variations in quantity and organic content of the seston. Journal of the Marine Biological Association of the United Kingdom 73: 813-829.

Boon, N. and R. Van Roij (2011). Blue energy' from ion adsorption and electrode charging in sea and river water. Molecular Physics 109: 1229-1241.

Cranford, P. J., J. E. Ward and S. E. Shumway (2011) Bivalve filter feeding: variability and limits of the aquaculture biofilter, Pages 81-124 in S. E. Shumway, ed. Shellfish Aquaculture and the Environment, Wiley-Blackwell.

Brinkman, A. G. (2015) Ecosysteemeffecten van lokaal veranderde slibgehaltes in de westelijke Waddenzee. IMARES, Rapport nummer: C157/15, 121 pagina's.

Walles, B., J.W.M. Wijsman and A.C. Smaal (2018). Onderzoek omgevingseffecten Blue Energy. WP3 schelpdierfiltratie: Functioneel ontwerp schelpdierfitratie unit. Wageningen Marine Research memo? .

Van Walraven, L., D. Mosk, E. Van Weerlee en H. W. Van der Veer (2020) OOBE WP2.5: Sediment composition in the Blue Energy Pilot installation Breezanddijk 2016-2019. NIOZ, Rapport, 47 pagina's.

Widdows, J., P. Fieth and C. M. Worrall (1979) Relationships between seston, available food and feeding-activity in the common mussel *Mytilus edulis*. Marine Biology 50: 195-207.

Wijsman, J.W.M and A.C. Smaal (2017). The use of shellfish for pre-filtration of marine intake water in a reverse electro dialysis energy plant. Wageningen Marine Research report. C078/17.

Ysebaert, Tom; Walles, Brenda; van der Werf, Jebbe; Van Kessel, Thijs; de Vet, Lodewijk, Hansen, Jill; van Duren, Luca; Bouma, Tjeerd; Stronkhorst, Joost. 2019. Natuur Impuls Oosterschelde: toepassingsmogelijkheden van slibrijk sediment voor natuurbouw. Wageningen Marine Research, Rapport C038/20.

Justification

Report C082/20
Project Number: 4313100040

The scientific quality of this report has been peer reviewed by a colleague scientist and a member of the Management Team of Wageningen Marine Research

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