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Ecosystem services by blue mussels in a coastal area

A study with commercial fish farming and blue mussels in the Faroe Islands

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Fiskaaling rit 2022-05

20-12-2022

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Report

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Ecosystem services by blue mussels in a coastal area: A study with commercial fish farming and blue mussels in the Faroe Islands

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Status: Open	Report no.: 2022-05	Project: AquaVitae/SureAqua
Date: 20-12-2022	Number of pages: 9	Responsibility: Sandra Ljósá Østerø
Approved: Gunnvør á Norði		DOI: 10.5281/zenodo.7515449

Summary:

As aquaculture production continues to increase, there has followed increasing concerns on the environmental impact from aquaculture. Blue mussels grown in a co-culture with fish aquaculture has been recommended to extract particulate waste from fish production. It is however, debated if significant mitigation can be obtained by direct waste assimilation, as studies have shown minimal mitigation by this method. Mussels can instead be used on a regional ecosystem scale, by controlling phytoplankton biomass, to avoid nutrient over-enrichment of the waters and eutrophication. The aim of this study was to evaluate how many nutrients can be harvested in blue mussel biomass in Faroese conditions, compared to what is emitted from a commercial Atlantic salmon farm. The aim is to fix nutrients into mussel biomass, and when the biomass is harvested, the nutrients are removed from the environment. A mussel growth experiment in Sørvágsfjørður, Faroe Islands and production data from a commercial salmon farm were used for this. The study showed that the salmon farm released 40 ton of dissolved inorganic nitrogen during summer, which could possibly increase phytoplankton biomass. Harvesting mussels containing 40 ton of nitrogen would require a biomass harvest of 2920 ton of mussel. The area needed to grow this biomass depends highly on the blue mussel density on the lines and the blue mussel farming strategy. Mussel spat settlement, density and growth varies greatly in different countries and regions, which is important for the nutrient harvest potential of an area.

Search words:

Blue mussels, Atlantic salmon, IMTA, nutrient mitigation, biomitigation, nitrogen recycling

1 Introduction

As aquaculture production continues to increase (FAO, 2022), there has followed increasing concerns on the environmental impact from aquaculture. Aquaculture production releases nutrients to the aquatic environment, and these different nutrient components can influence different parts of the marine ecosystem (Wang et al., 2012). Increased nutrient concentrations can for example cause eutrophication, which is defined as nutrient over-enrichment of water, causing excessive growth of algae and oxygen depletion. The main cause of eutrophication in coastal waters has been identified to be human activities, such as aquaculture (Skogen et al., 2009). Integrated Multi-trophic Aquaculture (IMTA) could be a means to mitigate some of these environmental impacts. IMTA is using low trophic species to feed on waste from higher trophic species, as a method to diminish the environmental impact from aquaculture. á Norði et al. (submitted) found, that in a commercial Atlantic salmon (*Salmo salar*) farm, approximately 52% of the nitrogen, and 55% of the phosphorous, that was fed to the fish, was lost to the environment (figure 1).

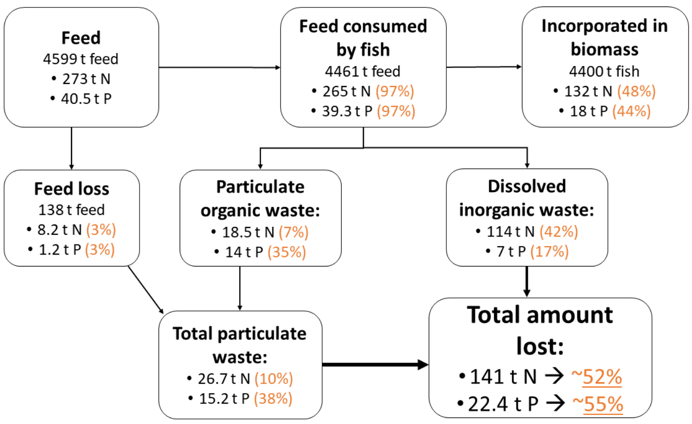

Figure 1: Fate of feed nutrients in Atlantic salmon aquaculture. Based on á Norði et al. (submitted)

1.1 Blue mussels

Blue mussels (*Mytilus edulis*) grown in a co-culture with fish aquaculture have been recommended in IMTA systems to extract particulate waste (feed and faeces particles) from fish production (Handå et al., 2012). However, it is debated if significant mitigation can be obtained by direct assimilation of fish farm waste (Sanz-Lazaro and Sanchez-Jerez, 2017). á Norði et al. (submitted) found the direct uptake by blue mussels of particulate fish farm waste to be minimal at a commercial salmon farm. Instead of having a direct link between the nutrient source and the mussels, mussel farming has been proposed as a mitigation tool for removing excess nutrients from coastal marine waters by filtering the water for phytoplankton, removing them from the water, while incorporating them into mussel tissue (Timmermann et al., 2019). Dissolved nutrients are transformed into phytoplankton, which then can be filtered from the water by mussels and turned into mussel biomass (Holbach et al., 2020). The mitigation could therefore instead be on a regional ecosystem scale, focusing on controlling phytoplankton biomass, to avoid nutrient over-enrichment of the waters and eutrophication.

This indirect approach is based on relatively simple mass balance principles. Inorganic nutrients that are released to the environment from fish aquaculture are assimilated by phytoplankton, which is then filtered from the water by mussels and incorporated into mussel biomass (Taylor et al., 2019). The aim is therefore to fix as many nutrients as possible into mussel biomass, and when harvesting the mussels, the nutrients are removed from the environment. Therefore, mussel growth and biomass harvest are of crucial importance for the extent and success of the nutrient mitigation. Mussel growth depends on several factors, such as larvae density, settlement success, phytoplankton concentration, salinity, temperature, predation etc., and thus varies greatly between countries and regions.

1.2 Aim of study

The aim of this study was to evaluate how many nutrients can be harvested in blue mussel biomass in Faroese conditions, compared to what is emitted from a commercial Atlantic salmon farm.

2 Method

Mussel size, growth and density data is from a mussel settlement and growth trial in Sørvágsfjørður from 2018-2020 (Danielsen and á Norði, 2021). Danielsen and á Norði (2021) deployed mussel lines in Sørvágsfjørður in 2018 and 2019, and sampling was done in 2018, 2019 and 2020. The lines were self-thinning, meaning new mussel spat was allowed to settle on the lines continuously and no restocking or thinning occurred. This is a method used in mitigation mussel farming, since it minimizes labor and cost (Petersen et al., 2014). The mussels in the study by Danielsen and á Norði (2021) where grown directly on spat collectors at 0-15 m depth. The mussel data from Sørvágsfjørður is used to find the growth rate of the mussels. As the lines had passive spat collection and new spat was allowed to settle continuously, the data from the lines deployed in 2018 was filtered to see the actual growth rates of the mussels, so the new spat settlement in the following summers was excluded. In the study by Danielsen and á Norði (2021) three different substrates were used for the mussels to settle and grow on: Fuzzy rope, Trawl and "Svendsker band". The the size and growth of the mussels used in this study, are only data from the Trawl substrate.

According to Taylor et al. (2019), 1 ton of harvested mitigation mussels (including shells, tissue, byssus) will in general yield 13.7 kg of nitrogen (N). Since wet weight was not measured for the mussels in Sørvágsfjørður, a study in Hvalfjörður, Iceland (Thorarinsdóttir, 1996) was used to calculate the expected wet weight of the mussels in Sørvágsfjørður. The growth of the mussels in Sørvágsfjørður was similar to the growth rates found in Hvalfjörður, Iceland by Thorarinsdóttir (1996) (figure 2, left). The environmental conditions (temperature, salinity, chlorophyll a) were also similar. Thorarinsdóttir (1996) measured length and wet weight every month for 15 months. Based on this data, a relationship between shell length and wet weight was found (figure 2, right). This was used to calculate the wet weight of the blue mussels from Sørvágsfjørður.

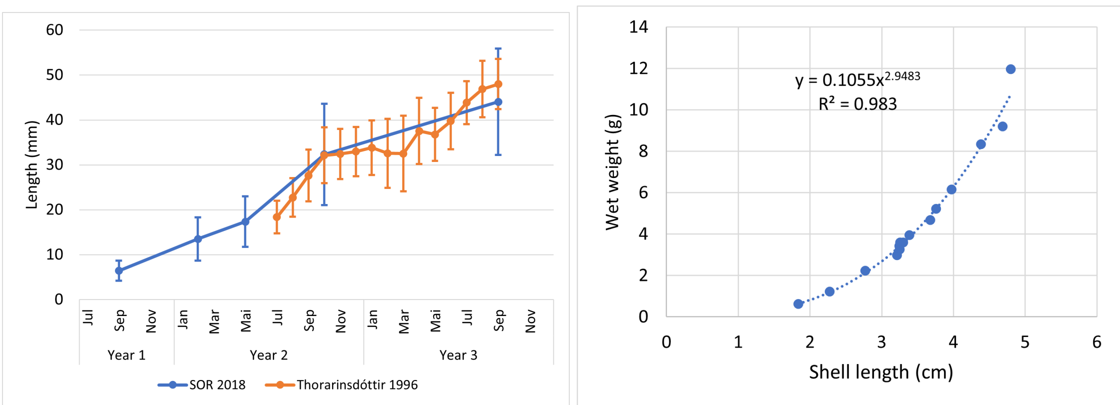

Figure 2: Left: Mussel growth (shell length ± SD) in Sørvágsfjørður 2018 (SOR) and Hvalfjörður, Iceland (Thorarinsdóttir, 1996). Spat that settled on the lines in Sørvágsfjørður during summer 2019 and 2020 is excluded from the data. Right: Shell length to wet weight relation based on growth of mussels in Hvalfjörður, Iceland (Thorarinsdóttir, 1996).

To calculate how much biomass can be achieved in a certain area, a hypothetical mussel farm was set up: The spacing between the longlines was 1 meter, the spacing between the droppers was 0.5 meter and the length of the droppers was 10 meters, corresponding to 200,000 meter of mussel line per hectare (figure 3).

The expected mussel density (# individuals/meter line) varies with different environments and different sites. Gaard (1986) investigated possibilities for blue mussel cultivation in Trongisvágs-

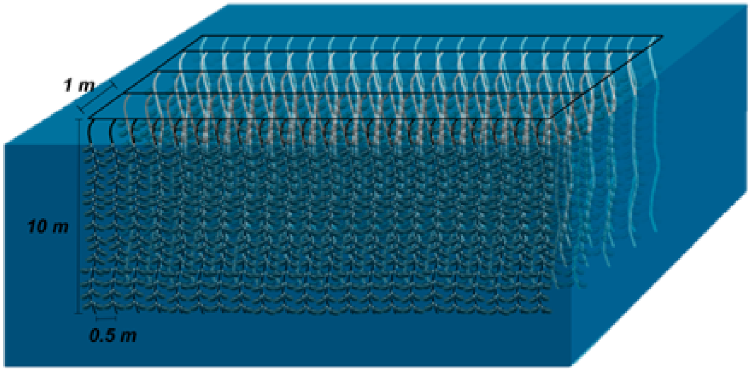

Figure 3: Setup of hypothetical mussel farm. 1 meter between longlines, 0.5 meters between droppers and the length of the droppers is 10 meters.

fjørður, Faroe Islands in 1984-1985, and found a peak density of 5100 ind/m after settlement. Jensen and Patursson (2011) did a similar study at 4 different sites in the Faroe Islands in 2011, and found a peak density of 4500 ind/m after settlement. Jensen and Patursson (2011) deployed mussel lines in four different areas in the Faroe Islands (Kaldbaksfjørður, Skálafjørður, Sundalagið Ey. and Sundalagið Str.). The density on the blue mussel lines after settling varied greatly between the four areas, with the highest settlement in Skálafjørður, and almost no settlement in Sundalagið Ey. The density after settling can be expected to stabilize at a lower number later due to competition etc. Danielsen and á Norði (2021) found the density after settling to only reach 243 ind/m in 2019 and 83 ind/m in 2018. The density decreased on the lines during the first year in 2019. The settlement in Sørvágsfjørður in both 2018 and 2019 can thus be considered very low. Figure 4 shows the average density on the mussel lines in Sørvágsfjørður over the three years they were deployed.

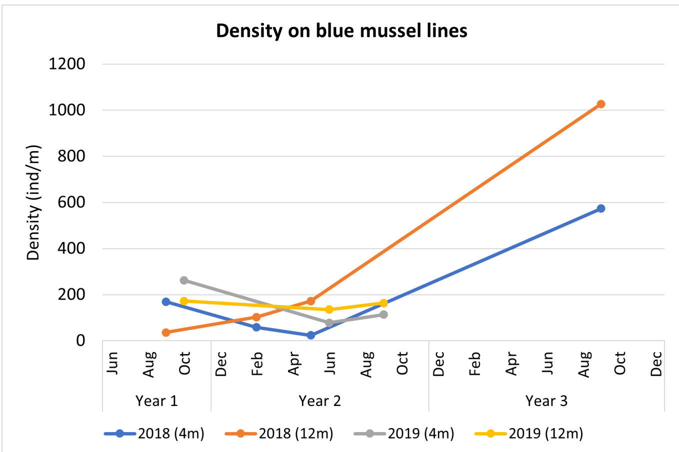

Figure 4: Density (individuals/m line) on mussel lines deployed in Sørvágsfjørður in 2018 and 2019. Data from Danielsen and á Norði (2021).

To have an upper limit for potential mussel density, a relation by Holbach et al. (2020) that was found in inner Danish waters with very high settlement was used. Holbach et al. (2020) found a weight density relation to be described by the power function

$$Density = 1269 \cdot DW^{-2/3} \tag{1}$$

This relation was found at mussel farms for mitigation purposes, which are not restocked, thus self-thinning as they grow.

To calculate this density from Holbach et al. (2020), the dry weight (DW) is needed. From the mussel growth trial in Sørvágsfjørður, a shell length (L) to dry weight of soft parts (DW) relation was found (figure 5):

$$DW(g) = 0.0066 \cdot L(cm)^{2.99} \tag{2}$$

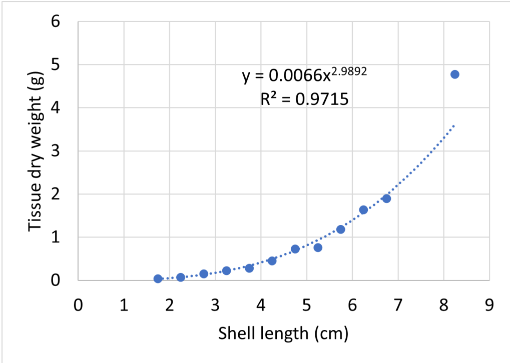

Figure 5: Shell length to tissue dry weight relation (equation 2). Dots are observations from mussel growth trial in Sørvágsfjørður (Danielsen and á Norði, 2021).

3 Results

Figure 6 shows results from the mussel growth trial in Sørvágsfjørður. The blue line is mussels from lines deployed in 2018, representing optimally-thinned lines (data filtered as described in method section). The orange is from lines deployed in 2019, and are self-thinning lines (data not filtered). After two summers at sea, the blue mussels on the optimally-thinned lines reach an average length of 32.34 mm and the blue mussels on the self-thinning lines an average length of 20.47 mm.

The growth pattern of the mussels is similar to previous findings by Gaard (1986) and Jensen and Patursson (2011) (figure 6, right). The results show a limited growth during the first summer after settling, which is probably related to late settling, short summers and low temperatures in the Faroe Islands. The highest growth was observed the second summer.

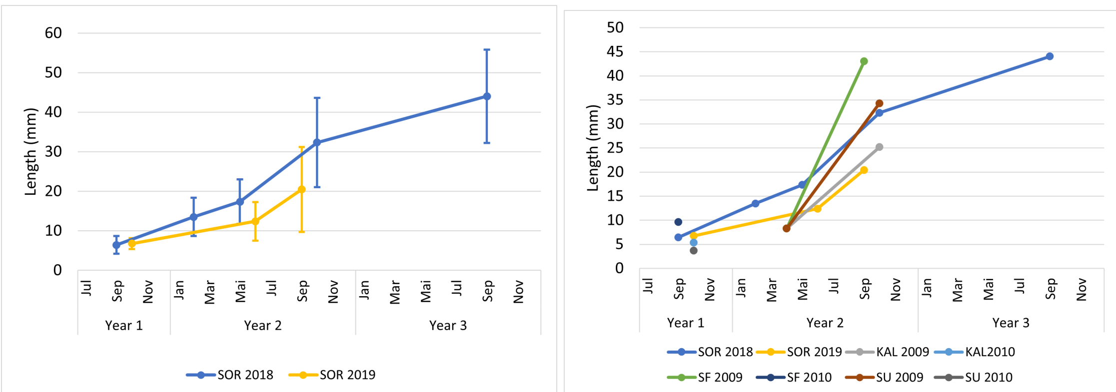

Figure 6: Left: Average shell length (± SD) of blue mussels deployed in Sørvágsfjørður in 2018 (blue line) and 2019 (orange line). The blue line represents the shell length of optimally thinned mussel lines, while the yellow line represents mussels on self-thinning lines. Right: data from the left figure compared to average shell lengths found in other studies in the Faroe Islands. Sørvágsfjørður (SOR), Kaldbaksfjørður (KAL), Skálafjørður (SK) and Sundalagið (SU). Data from KAL, SK and SU are from Jensen and Patursson (2011).

From the relation by Holbach et al. (2020), an upper density limit of 9875 ind/m for the self-thinning lines after 2 years (20.47 mm shell length) and 3499 ind/m for the optimally-thinned lines after 2 years (32.34 mm shell length) was found.
Table 1 shows the nitrogen mitigation potential per hectare with varying mussel densities on ropes and the two different farming strategies (self-thinning or optimally-thinned lines). The upper limits are from the relation by Holbach et al. (2020), and the lower limit is the lowest density after settling found in the study by Danielsen and á Norði (2021). The calculations are based on the mussel farm

setup shown in figure 3 and the N content of mitigation mussels (13.7 kg N/ton mussel) from Taylor et al. (2019).

Table 1: Nitrogen mitigation potential with setup shown in figure 3, varying densities on lines, and the N content of mitigation mussels from (Taylor et al., 2019). Example with two sizes of mussels; Optimally-thinned lines that reached a mean length of 32.34 mm after two years and self-thinning lines that reached a mean length of 20.47 mm after two years.

	N/hectare (t)	
ind/m	**32.34 mm**	**20.47 mm**
9875		23.6
9000		21.5
8000		19.1
7000		16.7
6000		14.3
5000		11.9
4000		9.6
3499	32.2	8.4
3000	27.6	7.2
2500	23.0	6.0
2000	18.4	4.8
1200	11.0	2.9
1000	9.2	2.4
800	7.4	1.9
600	5.5	1.4
500	4.6	1.2
400	3.7	1.0
300	2.8	0.7
200	1.8	0.5
100	0.9	0.2
80	0.7	0.2

3.1 Dissolved nitrogen from Atlantic salmon farm

Figure 7 (left) shows the dissolved inorganic nitrogen release from a commercial Atlantic salmon farm in Sørvágsfjørður over a full production cycle (from á Norði et al. (submitted)). The total dissolved inorganic nitrogen release was 114 ton. Figure 7 (right) shows an example of the chlorophyll a concentration in a Faroese fjord over a year (from Østerø et al. (2022)). Chlorophyll a concentrations are high during summer, and absent during winter. This same growth pattern was seen in Sørvágsfjørður. As the aim with the mussels is to control phytoplankton biomass and avoid eutrophication, the nutrients that are released during winter, and will not increase phytoplankton concentration, are discarded. The total amount of dissolved inorganic nitrogen released during summer in this farming cycle was 40 ton.

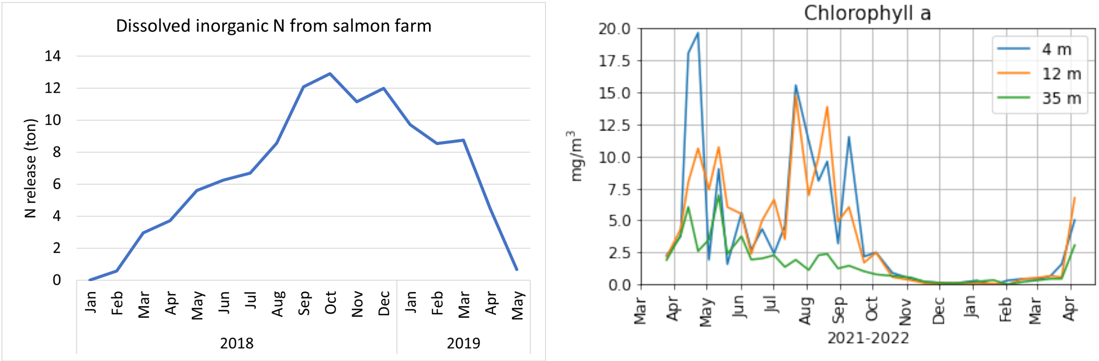

Figure 7: Left: Dissolved inorganic nitrogen (N) release from Atlantic salmon farm in Sørvágsfjørður over a full production cycle. Data from á Norði et al. (submitted). Right: Example of chlorophyll a concentrations in a Faroese fjord. From Østerø et al. (2022).

Harvesting mussels containing 40 ton of N would require a biomass harvest of 2920 ton of mussels (mussel N content from Taylor et al. (2019)). The settlement success of the mussels and thereby the density and biomass is very important for the nitrogen harvest. Figure 8 shows the area required to harvest mussel biomass after two years containing 40 ton of nitrogen, which is the amount released from the salmon farm during the phytoplankton growth season, with different densities and different farming strategies (self-thinning or optimally-thinned).

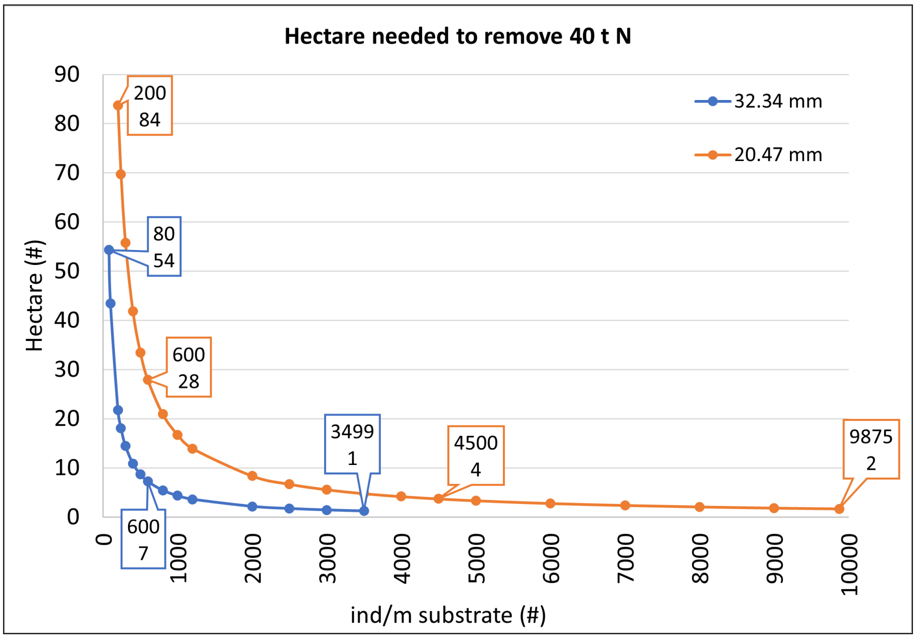

Figure 8: Area (hectare) needed to harvest 40 ton of nitrogen vs blue mussel density on lines. The blue line represents the average size of optimally thinned mussel lines after two years, while the orange line represents the average size of mussels on self-thinning lines after two years.

All of the above calculations assume even density distribution on all lines in the mussel farm and no mussel loss due to sinking, predation etc.

Self thinning lines have the advantage of minimal labour and thereby cost, but the end product is likely not a high value product, due to uneven sizes. The mussels could instead be used as e.g. animal feed or fertilizer. As the mussels on the self-thinning lines don't have to reach a certain size that is suitable for human consumption, the mussels can be harvested much earlier, preferably right after maximum growth of the mussels in order to optimize the nitrogen removal. Mussels on optimally-thinned lines have the advantage of possibly being used for human consumption, and thereby have a higher value of the end product. However, this requires more labour and cost during the farming period. Also, the mussels in the study by Danielsen and á Norði (2021) only reached a average size of 32.34 mm after two summers and 44 mm after three summers. Mussels for human consumption are usually around 50 mm, so the harvest of the mussels would be after three or four summers.

3.2 Examples

As shown in figure 8, the area needed for harvesting blue mussels containing 40 ton of nitrogen is highly dependant on the settlement success and thereby the biomass on the blue mussel lines. Figure 9 shows an example of areas with three scenarios: 600 ind/m, which was the average density observed in Sørvágsfjørður by Danielsen and á Norði (2021), 4500 ind/m, which is the density observed in Skálafjørður after settlement by Jensen and Patursson (2011), and 9875 ind/m, which is the density based on the relation by Holbach et al. (2020). The biomass is calculated based on the size of the blue mussels (20.47 mm) on the self thinning lines in Sørvágsfjørður in the study by Danielsen and á Norði (2021).

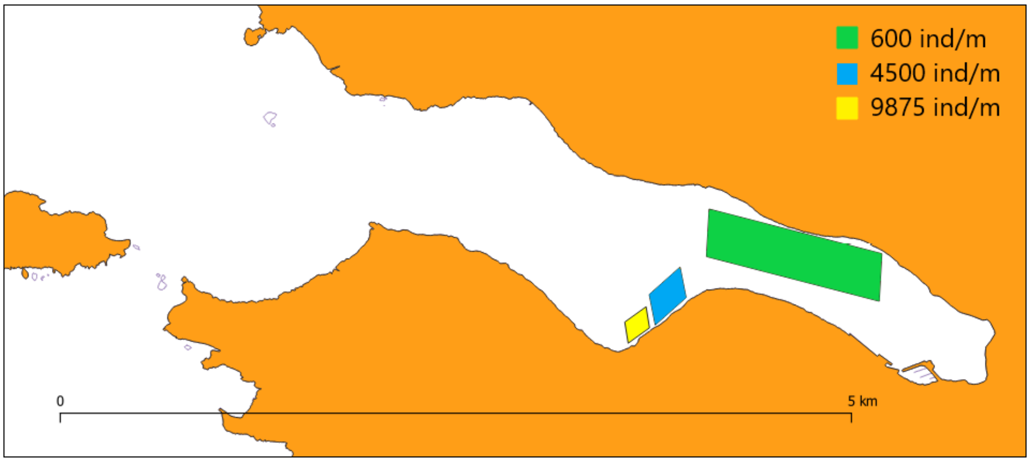

Figure 9: Area, with setup of figure 3, that is needed to farm and harvest blue mussels after two years (20.47 mm) containing 40 ton of nitrogen. The green area is 33.2 hectare, blue area is 4.4 hectare and the yellow is 2 hectare.

As the highest growth rate of the blue mussels was seen the second summer, the mussel farm could be divided into to areas, with harvesting every other year from each area. This way mussels with highest growth rates, and highest nutrient incorporation into mussel biomass, would be present in the area every summer.

4 Conclusion

Direct uptake of particulate waste from fish farming by blue mussels is minimal, and highly dependent on the size and settling velocity of the waste particles. However, mussels can be used in an indirect approach, where they can be useful in controlling phytoplankton biomass. Mussel spat settlement, density and growth varies greatly in different countries and regions, which is important for the nutrient harvest potential of an area. The size of the area needed needs to be adjusted to the farming strategy that is being used.

Data availability

Data on blue mussel settlement and growth in the investigated fjord (Danielsen and á Norði, 2021) are available at `https://zenodo.org/record/7515210#.Y7vpDv7P3-g`. All other data is available in the sources refereed in the report.

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