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Abstract

It is known that the fish farm industry is ever growing. They account for over 30% of the fish consumed in today’s world. However there is also a growing issue of Eutrophication due to the extra nutrients being added into the aquatic ecosystem. This is causing problems like harmful algal blooms in all ecosystems and low dissolved oxygen concentration in ecosystems of shallow water. Corresponding with these two types of ecosystems, the two case studies taken under consideration are a shallow water Danish fish farm and a deep water Norwegian fish farm. Both ecosystems present different variables that will affect algal growth in the vicinity of the fish farms. The aim of this project is to take four macroalgae and analyze them, then an educated assumption is made matching the algaes that best take up the nutrient load from the fish farms in the conditions presented by the case studies. The four algae that are under scrutiny are, $A. esculenta$, $S. latissima$, $U. lactuca$ and $C. sericea$. All of their assets will be taken into consideration, including their nutrient sequestration, biomass, preferred salinity, temperature and depth conditions.

To take account for all of the nutrients released by the fish farms there will need to be 0.82 Kg of Alaria esculenta grown to account for all the N deposits and 0.78 Kg to take up all of the P deposits per kilogram of fish. For Saccharina latissima there will have to be 1.56 Kg grown to take up all of the N and 1.67 Kg to take up all of the P deposited per kilogram.
of fish. *A. esculenta* and *S. latissima* are in ratios of dry weight calculated based on the numbers from the Norwegian case study, the numbers will vary for the Danish case study. Next, there will need to be 0.647 Kg of *Ulva lactuca* to take up all of the nitrogen in the water for the Norwegian case study and 0.730 Kg of *Ulva lactuca* to take up all the N in the Danish case study per kilogram of fish produced. Then there will need to be 3.03 Kg of *Ulva lactuca* to take up all of the P in the Norwegian case study and 2.77 Kg in the Danish case study per kilogram of fish produced by the farms. Lastly *Cladophora sericea* will need 0.470 Kg to take up all of the N from the Norwegian case study and 0.530 Kg in the Danish case study. As for the excess P *Cladophora sericea* will need to be produced at a ratio of 2.39 Kg of seaweed to one kilogram of fish for the Norwegian case study 2.19 Kg of seaweed to one kilogram of fish for the Danish case study presented.

Using this information compared with the data provided from the two case studies, it was concluded that the algaees *Ulva lactuca* and *Cladophora sericea* are not effective in taking up inorganic nutrients in the areas surrounding fish farms at all. In fact it would be surprising if they were able to even survive. However, the algaees *Alaria esculenta* and *Saccharina latissima* would both thrive in the conditions provided by both case studies. Although *Alaria esculenta* would be more efficient in taking up the nutrient load in the Norwegian case study than *Saccharina latissima* would be, and *Saccharina latissima* is more
effective in sequestering the nutrient load presented by the Danish case study than Alaria esculenta.

Knowing this information, there is a possibility of bringing a new light on the industry of aquaculture. By using macroalgae to get rid of the inorganic nutrients from eutrophication it can allow for the growth of the aquaculture industry which is already such an important source of food all around the world.
Aquaculture is a growing industry, it is said to be the fastest growing source of food in the world. The industry growth is higher than 10% a year, and accounts for more than 30% of all the worlds fish consumed today (Beveridge et al. 2002). Open cage fish farming has been carried out in many different countries over the years and this practice has since developed steadily over the last few decades. For example the global aquaculture production of marine *Salmon salar* and the rainbow trout *Oncorhynchus mykiss* increased from $0.92 \times 10^6$ tons in 1999 to $1.74 \times 10^6$ tons in 2009 (FAO, 2010).

Open cage fish farming is a type of aquaculture that takes place in the open waters with cages that allow water to flow in and out with the regular ocean current. It is known that this type of fish farming can have negative consequences at the environment’s expense. However, there are different types of Aquaculture, some of which have little to no effect on the environment. Recirculating Aquaculture System technology (RAS technology) is an indoor aquaculture system that filters their fish tanks with mechanical drum filters, biofilters and other heavy duty equipment. With the RAS technology they can produce 2000 tons of fish a year with a water consumption of 200L per kilogram of fish while their water waste is only 1% of that. It is a very efficient system but it has a lot of expensive equipment and the facility would cost millions of dollars to build and that idea is very unattractive to most fish farmers.
So the most abundant types of fish farms remain to be open cage even though the most environmentally friendly form continues to be the use of RAS technology. (AKVA Group. Sept. 12. 2014)

The global aquaculture community is growing exponentially and as a result the amount of effluents being released into the water increases as well. The excess feed and feces that are released from the industry of fish farming are the cause of the increased levels of inorganic materials like nitrogen and phosphorus found in the ocean. This nutrient enrichment can cause an increase in the growth of microalgae which can have a negative effect on the environment. Some microalgae can be toxic and as a result can cause harm to the ecosystem from the layers of toxic biofilm that they produce, while other microalgae can cause harm from their accumulation in large scums with a high biomass. These scums can cause mass mortality in the wild and areas of fish farms due to their density on the surface of the water, where they can block sunlight from reaching the organisms below. They do remove the inorganic nutrients from the water like most autotrophs, however microalgae can not be harvested. They serve their whole life cycle in these algal blooms and when they die they are decomposed by bacteria which can lower the dissolved oxygen content along with many other things. This project is designed to review the effects of using macroalgae through the idea of integrated multi-trophic aquaculture (IMTA) to counteract the dangers of nutrient loading that result from open cage fish farms.
Problem Formulation

How can Macroalgae be used in aquaculture to counter the problem of nutrient loading?

Research questions

1. Which of the four macroalgae will best compensate for the excess nutrient loading provided by our two case studies.
2. How do the conditions provided by the case studies affect the efficiency of the macroalgae to take up inorganic nutrients.

Nutrient Loading

The rapid expansion of the aquaculture industry has raised concern about the amount of solid and dissolved nutrients released into the aquatic environment. Open cage aquaculture can release a considerable amount of biogenic waste such as organic and inorganic materials that are generated throughout the life cycles of the fish (Troell & Noberg. 1998; cheschuck et al. 2003; vassallo et al. 2006). Fish farming releases nitrogen (N) and phosphorus (P) as inorganic waste and are released through
the dissolution of the solid feces and excess feed produced (Olsen & Olsen 2008). These different nutrients have the potential to affect the marine ecosystem. Inorganic nutrients such as the dissolved nitrogen and phosphorus are readily available for microalgae, as discussed later, as a result of eutrophication and the uneaten feed sinks rapidly and may accumulate in sediments on the bottom of the ocean (Troell et al. & Olsen 2008). The faecal matter on the seafloor (cromey et al. 2002, Olsen 2008, Nickell et al, 2009) will be consumed by filter feeding zooplankton, bacteria or visual feeders, such as fish. This can cause a problem with dissolved oxygen content on the ocean bed, however this is only an issue in areas where the fish farm is located close to the ocean floor (Olsen & Olsen 2008, Troell et al. 2009). The nitrogen and phosphorus that are dissolved from feed and faecal particles may be part of small N and P containing molecular species like amino acids and nucleotides, but is mostly comprised of complex dissolved chemical compounds that are available for bacteria and microalgae over a longer time scale (Palenik & Morel 1990,Fan et al. 2003,Stoecker & Gustafson 2003). Areas saturated with open cage fish farming become very rich in inorganic materials. An example of this is the release of a material like ammonium,
which is a source of inorganic nitrogen resulting from the protein metabolism of fish. (ahn et al. 1998; Sanderson et al. 2008). **Figure one** shows the release of nitrogen in kg/month with a sample size of 1000 tons of salmon in a 24 month cycle. **Figure two** shows the relationship between the concentration of Nitrogen and Phosphorous is mutual and as the concentration of one increases so does the concentration of the other. The combination of the two figures can tell us that it can be expected to have similar results for the graph representing the concentration of phosphorous discharges from the fish farms if the sample size is the same and over the same time period.
Problems with nutrient loading

The results of nutrient loading can be detrimental to the environment. The presence of having excess N and P in the ocean can cause microalgal growth in abundance. Microalgae are photosynthetic organisms, so like any plants they need inorganic nutrients like N and P to thrive and survive. With an excess of nutrients that are introduced into the ecosystem by an external source they can make “a large, deep, nutrient-poor lake” (Donald et al. 2002) start to have more plant life like algae blooms. These harmful algal blooms (HAB) are a concern because it is thought that the HAB’s can accelerate the process of eutrophication. As the blooms decay they are decomposed and release the inorganic nutrients back into the ecosystem for other microalgae to utilize (Wetzel. 1983). Also, in some areas of shallow ocean water and in lakes, when the algae falls to the bottom of the ocean and is decomposed, it can cause issues with the dissolved oxygen content causing death to the aquatic life that thrives in that ecosystem. Death can also come from the algal blooms because some algae species are very toxic, causing death in blooms of just a few hundred cells. An example of this is the blue-green algae called Microcystis aeruginosa that can cause harm to both humans and wildlife. In addition the toxins can leak into nearby water supplies and cause an even bigger problem for the public. The blooms that do not produce toxic
biofilms are also very dangerous because they can cause death due to a high biomass and their ability to block out sunlight to the underwater ecosystem. Furthermore, in areas of human leisure they can impede activities such as swimming, boating and fishing (Donald et al. 2002; Wetzel. 1988; Environment Canada).

All in all, The most general definition of remineralization /eutrophication is "the process of increased organic enrichment of an ecosystem, generally through increased nutrient inputs" (Nixon. 1995). The increased external nutrient inputs for eutrophication in this case are the fish, their feces and their uneaten food. However eutrophication can also be looked at as the the results coming from the external nutrient inputs. In the case of this project the issues with eutrophication are the resulting harmful algal blooms (HAB) that can cause damage to the ecosystem and death in aquatic animals, as well as the issue of decreased dissolved oxygen (DO) on the ocean floor killing any organisms that thrives off the bottom of the ocean. However the issue of DO concentration may be detrimental to the ecosystem on the depths of the sea but it does not affect the fish farms in areas where the water is very deep whereas HAB are a problem in all areas with an increased level of inorganic nutrients.
Case Studies

The two case studies taken under advisement are a deep water fish farm located in Norwegian waters, and a shallow water case study located off the coast of Denmark. The two studies have different conditions that the algae will have to survive and thrive in.

Norway

In the 2011 Norwegian case study, the fish farm produced 1,118,341 tons of fish and used 1,286,092 tons of feed. From this, the average percentage of inorganic nutrients released was 62% Nitrogen and 70% Phosphorous of the total N and P input. This results in approximately 29.49 +/- 4.20 grams of N and 2.26 +/- 2.25 grams of P per kilogram of fish (Norwegian Directorate of Fisheries, 2011; Wang et al. 2012; Reid et al. 2013). Along with the information about the inorganic waste the fish farms are releasing, information about the environmental conditions are crucial as well. From the Norwegian case study it is determined that the salinity is <34.5% and can drop to 27.3% in August and then peaks to 33.6% in the winter months. However, no matter the month of the year or the depth of the water (up to ~10m deep) the temperature mostly stays the same. It is recorded that the temperature stays within a range of 8 degrees celsius to 5.9 degrees celsius for most of the year (Aleksander et al. 2013). The total depth of the fish farm, as presented in Figure
6 under “Overview” can be anywhere from 200m to 1000m deep, leaving room for currents to come and filter the DO content of the water in the area to make sure that that is never a problem for the fish farms in the area. **Figure 3** shows the relationship between temperature and salinity over a 14 month cycle within the vicinity of a salmon fish farm.

**Denmark**

Danish open cage aquaculture has been industrialized since 1955. Most of the fish farms focused on the production of the Rainbow trout (Havbrugsudvalget, 2003). However presently, there are 18 marine fish farms in Denmark, which produced a total of about 10 000 tons of fish in 2010. (Danish ministry of environment). Fig. 4 shows the locations of the marine fish farms in Denmark, with most of this farms located in the Kattegat and sound zealand regions.
The Danish coastal area comprises of the Kattegat, and the belt sea known as the Danish straits, it is a shallow transition that cuts across the brackish Baltic Sea and the high saline Skagerrak or the North sea. It is a coastal ecosystem with an estuarine feature having a permanent halocline located at 15 m depth (Jakobsen, F et. Al.).

The waters in the Kattegat is a mixture of the inflow from the North Sea through the skagerrak waters and the baltic sea. (Gunni Ærtebjerg et al.). The Kattegat region has a surface area of about 21100 km, water volume of 455 km³ with an average depth of 22 m. Which is relatively small when compare with the North
sea, skagerrak and the baltic sea. The kattegat waters has a salinity which range from 20 to 26% and the winter surface temperature of 4°C and 17°C in the summer. (Aarup 1994).

Most marine fish farms in denmark are located in shallow areas with a depth ranging from 12 - 30 meters and many of the fish farms are located along the kattegat region and sounds zealand (peterson 2014).

![Net cage production & feed use in Denmark 1989-2003](image)

**Figure 5:** Danish net cage production and used feed

**Figure 5** shows the comparison between the amount of feed used and fish produced by Danish open cage fish farms from the year 1989 to 2003. To estimate the amount of Nitrogen and phosphorus released from an open cage fish farm in Denmark, a case study from one of the top marine fish farm in Denmark was taken into account. The farm is located in the shallow waters close to the island of mosholm and they have another farm located 1-5 kilometer west of mosholm at a depth of 10-15
meters. (Birklund 2001). In 2003, The fish farm recorded a total production of 947 tons of fish, used 1073 tons of feed, releasing 36 tons of N and 3.9 tons of P (punktkilder Vestsjællands Amt. 2003). This means that out of 947,000 kilograms of fish the fish farm uses 1,073,000 kilograms of feed and releases 36,000 kilograms of N and 3,900 kilograms of P. From this it can be calculated that there is approximately 38 grams of N and 4.12 grams of P released per kilogram of fish.

Overview

The problem with the shallow water is that when the feed or feces fall to the bottom of the ocean, they are decomposed by bacteria and the bacteria use up most of the DO while releasing inorganic nutrients at the same time (Environment Canada). The low DO content in areas of shallow water cause issues because the ocean floor where the DO content is really low is very close to the fish farm and the fish need the oxygen to survive. Furthermore, due to the shallow waters there is no strong current to bring in water with a higher DO concentration and flush out the water with lower DO concentration like there would be in the Norwegian case study.

Figure 6 shows the depths of the coastal area of norway compared to the coastal area of denmark. Both of which are the areas our case studies are located in. The area of norway is assumed to have a depth of 200m - 1000m, while our danish case
study shows on the map to be less than 200m. But as reviewed in our danish case study the depth of the coastal area where marine fish farms are located is a mere 12 - 30m deep.

![Map of coastal waters around Norway](image)

**Figure 6: Depth ranges of coastal waters around Norway**

Approximately 21% of the P and 45% of the N are distributed as dissolved inorganic nutrients, which can be absorbed by microalgae and macroalgae, both are photosynthetic organisms
that utilise the inorganic nutrients. As well there is 44% P and 15% N that are distributed in solid particle form (Handa et al. 2012; Redmond et al. 2010), which can be decomposed by bacteria through remineralization or filtered by mussels as it falls from the fish cages to the ocean bed releasing more inorganic nutrients (cloern 1982, et. al), these are general percentages and may change depending on the environmental conditions.

As presented above, there are a lot of extra inorganic nutrients being added to the ecosystem, this means that will need to be a way to counter the extra nutrient overload presented by the industry of fish farming. It is known that both macroalgae and mussels help take up the inorganic nutrients but is there a point in adding even more organisms to an ecosystem? The system of integrated multi-trophic aquaculture (IMTA) explains the benefits of using muscles and macroalgae to take up the excess nutrients in the ocean.
**IMTA**

A trophic level is a scientific name for a feeding level, so multi-trophic means two or more feeding levels. Therefore IMTA is an ideal that uses the remainder of one feeding level, in this case the fish in the fish farms, to feed a second or even third trophic level, in this case Macroalgae or mussels. IMTA in open cage fish farming uses macroalgae to uptake the dissolved inorganic nutrients that come from the fish waste and feed such as N and P. The macroalgae is then harvested and distributed for various purposes. *Saccharina latissima* is harvested in Norway and sold as sugar kelp while *P. yezoensis* aka *Nori* is sold as common sushi seaweed and is a crop of huge importance in Japan and China (Forbord et al. 2012; The Seaweed Site: information on marine algae; Neori et al. 2004; Chopin et al. 2001; Neori et al. 2007). IMTA relationship works so well because the limiting factor for normal seaweed growth is the lack of nitrogen and phosphorous in everyday ocean water (Dring. 1991; Lobban and Harrison. 1996). IMTA is a mutual relationship between two trophic levels, and helps the fish farmers get rid of the inorganic nutrients that is preventing them from expanding their industry, along with providing a little extra income on the side (Reid et al. 2009; Ridler et al. 2007). Macroalgae is not the only source of IMTA however, muscles are also an important factor in getting rid of inorganic nutrients in the ocean and can also be harvested and sold for commercial use.
Mussels have been taken into account as a middleman solution to the problem of nutrient loading because they help filter a high volume of water that may consist of microalgae and other suspended particulate matter like feed and feces. (clorn 1982, et. al). Mussels help reduce the accumulation of microalgae on the water surface and increase light penetration for submerged aquatic plants and animals (maar et al. 2010). Suspension feeding Mussels feed on the particulate matter by taking in water through their inhalant siphon and across their gill. The suspended particles are caught by the grill and are taken out of the water before it is released back into the ocean by the mussels exhalant siphon. The amount of feed they take-in is a morphological restriction of their gut volume, the time of digestion and the retention ability of their gills (Bayne 1998). An example of this is the blue mussels, Mytilus edulis, they can filter particles of appropriate size between 2 µm and 1000 µm and they have high retention efficiency when they feed on particles greater or equal to 4 µm (Møhlenberg & Riisgård 1978, Reid et al. 2009). Mussels can grow more consistently in environments with high amounts of nitrogen and phosphorus as these organic nutrients are used increasingly as a food source for their growth. However, their growth can be influenced by other factors as well, such as the concentration of the dissolved salt in the environment, the level of oxygen and the speed of the ocean current (Gosling 1992 et al.).
The blue mussels are recognised as a good example of integrated multi-trophic aquaculture (IMTA) because they can survive in a wide variety of different environments that fish farms can be located (Gosling 2003). *Mytilus edulis* is known today as the common edible mussel as suggested by its latin name. *edulis*, which is latin for edible and *Mytilus* which is latin for mussel at sea. The farming of Mussels close to fish farms has been proposed as one of the ways to the improve coastal water quality problem that is associated with the nutrient enrichment of the ocean (edebo et al).

Of course mussels can be an important factor in taking up inorganic nutrients, however in this project the focus is on the macroalgae and the potential for that algae to take up inorganic nutrients. The Macroalgae that will be taken under consideration are *Alaria esculenta*, *Saccharina latissima*, *Ulva lactuca* and *Cladophora sericea*. These algae’s properties will be reviewed and matched to which of them will best compensate for the excess nutrient loading provided by our two case studies and how do the conditions provided by the case studies affect the efficiency of the macroalgae to take inorganic nutrients.
Macroalgae can be planted in close proximity to the fish farms to take up any unwanted inorganic material produced, but then harvested and sold for commercial use. The macroalgae are strung from longlines on the surface of the ocean as to hold the seaweed steady so it does not flow away with the current and stays in the optimal nutrient zone around the fish farms. The longlines are also used so the macroalgae continue to grow at the right depths. This is very important because the macroalgae are photosynthetic so to make good use of the nitrogen and phosphorous that they consume they need sufficient sunlight (Dring. 1991; Lobban and Harrison. 1996). With nutrient pollution as high and the conditions presented in the case studies, a few different types of macroalgae should be reviewed. Also the percentage of salinity in the water is related to the amount of different species that are able to survive in the environment. The higher the salinity the more kinds of species that can grow (Lea et al. 2012). Figure 7 represents this, the graph shows areas of high salinity to low salinity (left to right) starting with kattegat from our danish case study compared to the number of species that grow in the area (figure translated from Dahl et al. 2003).
Alaria esculenta is a brown seaweed, which is commonly called Edible wings, it belongs to the family Alariaceae and in the order of laminariales also known as Kelps. It is a perennial seaweed that can grow up to 4 m in length (Guiry, 1997). It is an arctic Kelp that can not survive in high summer due to a temperature above 16 °C (Munda luning 1977). Compared to S. latissima the nutrient sequestration of A. esculenta is two times higher (Reid et al. 2013).

The amount of A. esculenta needed to take in all the N, P and C that the average fish farm releases, in a mean ratio of
kilograms of seaweed wet weight (WW) to kilogram of fish is approximately 6.7 +/- 1.5:1 for N and 4.8 +/- 3.0:1 of P. In this project however it is smart to use the kilogram of seaweed dry weight (DW) to kilogram of fish (Reid et al. 2013). To calculate this it first needs to be known that on average, the approximate percentage of DW compared to WW is about 10% (Westlake, D.F. 1965) For the amount of seaweed needed to take up all of the N, it is smart to take the absolute highest value as to not leave any room for the possibility of leftover nutrients left by the macroalgae. So, this means that if 8.2 Kg of Alaria esculenta per kilogram of fish WW needs to be grown, then, still assuming that 10% of this is equal to what would need to be produced in terms of DW it would be equal to 0.82 Kilograms of Alaria esculenta DW:1 Kilogram of Fish produced by the fish farms to account for the excess N. For the amount of seaweed needed to be grown to take up all of the P, the ratio 7.8 Kg of A. esculenta WW: 1 Kg of fish (again, using the maximum ratio) will again be multiplied by 0.10 to calculate the 10% of the WW that is equal to the Dry weight that is needed to take up the P. This will be equal to 0.78 Kg of Alaria esculenta DW:1 Kg of fish.

*S. latissima*

*S. latissima* can grow in a wide range of temperature and light conditions but thrives best when it is planted in the August cycle at a depth of 5 meters, as presented in Figure 8, and in a temperature range of 10 - 15 degrees celsius. And the
culture densities of *S. latissima* are 1.5 times greater than that of *A. esculenta* but when weighed the wet weight of *S. latissima* is reduced by 1-1.5 times. This means that although *S. latissima* can grow in areas with greater nutrient density they can not sequester or hold as many nutrients as *Alaria esculenta* (Reid et al. 2013).

**Figure 8:** Growth of *S. Latissima* at depths 2, 5, 8 m, in two cycles, at the fish farm and a controled area
For *S. latissima* the average amount of seaweed in kilogram of wet weight that is needed to take up the average amount of N and C that the fish farms release per kilogram of fish is 12.9 +/- 2.7:1 kilograms of N and 10.5 +/- 6.2:1 kilograms of P. Of course this is in Kg of WW again, and will need to be converted to Kg of DW using the same methods as used in calculating *Alaria esculenta*. Considering that approximately 10% of the WW is equal to the DW it can be calculated that from 15.6 kilograms of *Saccharina latissima* needed to take up all of the N produced by 1 Kg of fish, there will need to be 1.56 Kg of *Saccharina latissima* in DW to sequester all of the N. Just the same for the ratio of Kg *Saccharina latissima* needed to take up all of the P, the ratio of 16.7 Kg:1 Kg will be multiplied by 0.10 to transfer the Kg WW into Kg of DW. After calculating this it can be seen that to take up all of the P produced by the fish farms there will need to be 1.67 Kg of *Saccharina latissima* DW per kilogram of fish produced by the fish farms. The numbers for *Saccharina latissima* and *Alaria esculenta* are calculated from the information based on the Norwegian case study and will vary slightly based on the Danish case study.

**U. lactuca**

*U. Lactuca* has a maximum growth rate between the temperatures of between 12 - 18 degrees celsius (Steffensen, D.A. 1974. Steffensen, D.A. 1976)
Ulva lactuca is known as the sea lettuce algae. It is given this name for its resemblance to the lettuce that people consume daily. It has a C:N:P ratio of 336:35:1 respectively. This means that for every unit of P intake it has to intake 35 units of N and 336 units of C (Atkinson, M.J. Smith S.V. 1983). Using this information it is possible to calculate the amount of Ulva lactuca that will need to be grown in Kg of DW to take up the nutrients from the two case studies.

- Norway

First of all the amount of U. lactuca needed to take up the N and P depositions from the norwegian case study will be calculated. To do this it needs to be known that the approximate biomass of a macroalgae is 50% carbon (Werst, M.D. et al. 2010). Knowing this it can calculated that from a C:N:P ratio of 336:35:1, the C:N ratio is 9.6:1. However due to the biomass equaling approximately 50% carbon 9.6:1 is equal to 19.2:1. So using the maximum concentration of N released from the case study it can be determined that to take up 33.69 grams of N the ratio would need to be 646.8480 grams of C: 33.69 grams of N. Thus concluding that to take up all of the nitrogen produced by the fish farms per kilogram of fish, there will need to be 0.647 Kg of Ulva lactuca produced. To calculate the amount of P needed to take up all P produced per kilogram of fish, the same method will be used. A C:P ratio of 336:1, this means that due to the biomass equaling approximately 50% carbon the ratio is equal to 672:1. The maximum concentration of P released from the Norwegian case study is 4.51 g, meaning that to take up all of
the P the ratio would be 3030.72 g of C: 4.51 g of P. This means that to take up all of the P produced per kilogram of fish there will need to be 3.03 Kg DW of Ulva lactuca produced.

- Denmark

Next the amount of Ulva lactuca in DW needed to take up the nutrients of the Danish case study will need to be reviewed. From a C:N:P ratio of 336:35:1, the C:N ratio is 9.6:1. However due to the biomass equaling approximately 50% carbon 9.6:1 is equal to 19.2:1. So using the maximum concentration of N released from the case study it can be determined that to take up the 38 grams of N the ratio would need to be 729.6 grams of C: 38 grams of N. Thus concluding that to take up all of the nitrogen produced by the fish farms per kilogram of fish, there will need to be 0.730 Kg of Ulva lactuca produced. Next the amount of Ulva lactuca needed to take up all P produced per kilogram of fish will need to be calculated. A C:P ratio of 336:1, this means that due to the biomass equaling approximately 50% carbon the ratio is equal to 672:1. The maximum concentration of P released from the Danish case study is 4.12 g, meaning that to take up all of the P the ratio would be 2768.64 g of C: 4.12 g of P. This means that to take up all of the P produced per kilogram of fish there will need to be 2.77 Kg DW of Ulva lactuca produced.

C. sericea
According to a Miami case study, C. sericea grow most abundantly at a depth of 9-10 meters but can grow with a surface cover of >20% at depths of 34 meters. The conditions in Miami present low salinity of approximately 20% and a high nutrient concentration. From this case study it can be assumed that C. sericea grows best under high nutrient conditions, low salinity and warm water (Jennifer, E.S et al. 2005).

Cladophora sericea has a C:N:P ratio of 265:38:1. The lower amount of carbon in the ratio can be assumed to be a result of a lower mass than Ulva lactuca (Atkinson, M.J. Smith, S.V. 1983). Using the C:N:P ratio from this macroalgae it can be determined how much DW of Cladophora sericea will be needed to account for the deposition of nutrients from the fish farms in the case studies.

- Norway

First the amount of Cladophora sericea needed to take up the N and P depositions from the Norwegian case study will be calculated. To do this it will need to be recalled that approximately 50% of the plants biomass is carbon (Werst, M.D. et al. 2010). Knowing this information it can be calculated that from a C:N:P ratio of 265:38:1, the C:N ratio is 6.9737:1. However due to the biomass equaling approximately 50% carbon 6.9737:1 is equal to 13.9474:1. Using the maximum concentration of N released from the case study it can be determined that to
take up 33.69 grams of N the ratio would need to be 469.8868 grams of C: 33.69 grams of N. This concludes that to take up all of the nitrogen produced by the fish farms per kilogram of fish there will need to be 0.470 Kg of Cladophora sericea produced. To calculate the amount of P needed to take up all the P produced per kilogram of fish by the case study, the C:P ratio of 265:1 will be considered. Considering what is known about the biomass equaling approximately 50% carbon, the ratio will be equal to 530:1. The maximum concentration of P released from the Norwegian case study is 4.51 g, meaning that to take up all of the P from the Norwegian fish farm the ratio would be 2390.3 g of C:4.51 g of P. It can then be resolved that to take up all of the P produced per kilogram of fish there will need to be 2.39 Kg DW of Cladophora sericea produced.

- Denmark

Now the amount of Cladophora sericea in DW needed to take up the nutrients of the Danish case study will need to be reviewed. From a C:N:P ratio of 265:38:1, the C:N ratio is 6.9737:1. However due to the biomass equaling approximately 50% carbon 6.9737:1 is equal to 13.9474:1. With the information of the maximum concentration of N released from the Danish case study it can be determined that to take up the 38 grams of N the ratio would need to be 530.0012 grams of C: 38 grams of N. Thus concluding that, to take up all of the nitrogen produced by the fish farms, there will need to be 0.530 Kg of Cladophora sericea produced per kilogram of fish. Next the amount of Cladophora
sericea needed to take up all of the P produced per kilogram of fish will be calculated using the C:P ratio of 165:1, this means that because of the biomass equaling approximately 50% carbon the ratio is equal to 530:1. The Danish case study produces a maximum P nutrient pollution of 4.12 g, meaning that to take up all of the P the ratio of 530:1 would be multiplied by 4.12 g as to see how much Cladophora sericea will need to be produced. After doing this it can be seen that the ratio would be 2183.6 g of C:4.12 g of P. This means that to take up all of the P produced per kilogram of fish there will need to be 2.19 Kg DW of Cladophora sericea produced.
**Discussion**

The information gathered about the four macroalgae above were taken from various articles and then calculated to fit the format that is required. The numbers calculated are always rounded up as to account for all of the possible nutrients that have been released by the fish farms. Also it is important to keep in mind that these numbers are not exact and may vary as the conditions and weather patterns around the world are changing daily, along with ocean water properties. The numbers, however are calculated as accurately as is possible with the information gathered. Keeping this in mind, let’s review the information gathered in order to make an assumption concerning our two research questions.

First of all, what of the four macroalgae best compensates for the excess nutrient loading presented by our case studies. To understand this, it is required to have a look at the conditions that our two case studies present in a more condensed easy to understand format.

**Norwegian case study**

- 1,286,092 tons of feed
- 1,118,341 tons of fish
- Salinity between 27.3% - 34.5%
depth between 200-1000 meters
Water temp can go as high as 14 degrees, but ranges between 8 - 5.9 degrees celsius on a regular basis
29.49 +/- 4.20 grams of N released per kilogram of fish (33.69 grams)
2.26 +/- 2.25 grams of P released per kilogram of fish (4.51 grams)

For the sake of making comparisons easier the maximum amount of nutrients released per kilogram of fish will be taken into consideration. This means that the numbers 33.69 grams of N and 4.51 grams of P will be used, just as it was in our calculations.

**Danish Case study**

- 1,073 tons of feed
- 947 tons of fish
- 36 tons of N and 3.9 tons of P
- Salinity between 20 - 26%
- Water temp
  - Summer it can peak at as high as 17 degrees celsius
  - Winter it can drop to as low as 4 degrees celsius
- 38 grams of N released per kilogram of fish
- 4.12 grams of P released per kilogram of fish
Now that all of the information from the case studies are all compact and easier to understand, the same needs to be done for the macroalgae.

**Alaria esculenta**

- Perennial
- Can grow up to 4 meters in length
- Thrives in temperatures below 16 degrees celsius
- Nutrient sequestration is two times that of *Saccharina latissima*
- Needs to be 0.78 Kg of *Alaria esculenta* to take up the N released from one Kg of fish
- Needs to be 0.82 Kg of *Alaria esculenta* to take up all the P released from one Kg of fish

Nutrient sequestration means that it can sequester, or hold more nutrients than that of *Saccharina latissima*, this can be an important factor in areas of a really intense nutrient load if you need to take up the nutrients quickly.

**Saccharina latissima**

- Can grow in a wide range of temperature and light conditions
- Best in the august cycle *(figure 8)*
- Grows best at a depth of 5 meters *(Figure 8)*
- Optimum growth temperature of 10 - 15 degrees celsius
Also can grow at temperatures as low as 5.9 degrees celsius

- *Saccharina latissima* can grow in culture densities that are 1.5 times greater than that of *Alaria esculenta* but has a WW from 1 - 1.5 times less
- Needs to be 1.56 Kg of *Saccharina latissima* to take up all the N released from one Kg of fish
- Needs to be 1.67 Kg of *Saccharina latissima* to take up all the P released from one Kg of fish

The fact that *Saccharina latissima* can grow in culture densities that are 1.5 times greater could mean that it can grow in areas that are even richer in nutrients than that of *A. esculenta* but it can not hold as many nutrients due to the fact that nutrient sequestration from *Alaria esculenta* is two times greater.

*Ulva lactuca*

- C:N:P ratio of 336:35:1
- Prefers a temperature of between 12 - 18 degrees celsius
- Norway
  - 0.647 Kg of *Ulva lactuca* needed to take up the N released from one Kg of fish
  - 3.03 Kg of *Ulva lactuca* needed to take up all the P released from one Kg of fish
- Denmark
  - 0.730 Kg of *Ulva lactuca* needed to take up all the N released from one Kg of fish
2.77 Kg of Ulva lactuca needed to take up all the P released from one Kg of fish

**Cladophora sericea**

- prefers a higher water temperature based off a Miami case study
- Prefereed depth of 9 - 10 meters, but can grow as deep as 34 meters with a surface cover of >20%
- likes to grow at a salinity of about 20%
- Norway
  - 0.470 Kg of Cladophora sericea needed to take up the N released by one kilogram of fish
  - 2.39 Kg of Cladophora sericea needed to take up all the P released by one kilogram of fish
- Denmark
  - 0.530 Kg of Cladophora sericea needed to take up the N released by one kilogram of fish
  - 2.19 Kg of Cladophora sericea needed to take up the P released by one kilogram of fish

And then using all of this condensed information it is possible to solve the research questions formulated.
Results

1. Which of the four macroalgae will best compensate for the excess nutrient loading provided by our two case studies.
2. How do the conditions provided by the case studies affect the efficiency of the macroalgae to take up inorganic nutrients.

To answer the first research question, the information from above will need to be utilized. The least amount of seaweed needed to take up the nutrients is ideal for a fish farmer as it makes the process go quicker and with less extra biomass. However an algae farmer may have a different perspective, but the focus of this project is on the fish farmers so the algae that most efficiently take up the extra nutrients that the fish farms emit into the environment will be the focus.

To start, it is wise to eliminate the algae that will do the worst job of taking up nutrients effectively. These algae are Ulva lactuca and Cladophora sericea. They are very efficient at taking up inorganic N in the water with a ratio of 0.647/0.730 Kg of Ulva lactuca: 1 Kg of fish and 0.470/0.530 Kg of Cladophora sericea: 1 Kg of fish for the Norwegian and Danish case studies respectively. But unfortunately both algae are very poor at taking up inorganic P from the water coming in at a huge ratio of 3.03/2.77 Kg of Ulva lactuca: 1 Kg of fish and 2.39/2.19 Kg of Cladophora sericea: 1 Kg of fish for the Norwegian and Danish case studies respectively. Due to this
large ratio of Kg of seaweed to Kg of fish it is very inefficient to use either of these algaes to take up the inorganic nutrients released by the fish farms. If the N ratios are only considered then the excess P in the water will be completely ignored and will continue to corrode away at the ocean ecosystem. Alternatively if the P ratios are only considered then there will need to be a lot of algae produced, resulting in all the N being used up long before all of the P, starving the algaes of the essential N nutrients that they require. After reviewing all of this information it is very unlikely that these two algaes will even survive in these environments, nevermind effectively taking up the inorganic nutrients released by the fish farms both in the Danish case study and the Norwegian one.

Next the algaes that have potential to effectively and efficiently take up nutrients from the ocean water. These two algaes are Alaria esculenta and Saccharina latissima. Alaria esculenta will need to be grown at a rate of 0.78 Kg of seaweed DW:1 Kg of fish produced to take up all of the P, and 0.82 Kg of seaweed DW:1 Kg of fish produced to take up all of the N released. From this it can be concluded that Alaria esculenta is more effective taking up P than it is N. It is also very important that the two ratios are very close meaning as discovered when reviewing the algaes U. lactuca and C. sericea. As for Saccharina latissima there will need to be 1.67 Kg of the algae produced:1 Kg of fish as to take up all of the P produced from the fish farms and 1.56 Kg:1 Kg of fish to take up all of
the N produced. Once again it can be concluded that for Saccharina latissima N is more easily sequestered than P is. It can be seen that they are both very valid candidates in taking up inorganic nutrients; at this point it is only a matter of which of these algae will more effectively take up nutrients compared to the different case studies.

If the Norwegian case study releases 33.69 g of N per kilogram of fish along with 4.51 g of P per kilogram of fish, and the Danish case study releases 38 g of N per kilogram of fish and 4.12 g of P per kilogram of fish. It can be observed that the Norwegian case study releases less N per kilogram of fish than the Danish fish farm but it also releases more P, and vise versa. The Danish case study releases less P and more N than the Norwegian case study. Matching what we know about the algae Alaria esculenta and Saccharina latissima, they can be matched to the case study they best fit with in order to intake the most amount of nutrients the efficiently. As is known, Alaria esculenta is more effective at taking up P then S. latissima. This is perfect for the Norwegian case study as the Norwegian case study produces more P than the Danish case study, meaning that in the Norwegian case study Alaria esculenta will have more P to take up per kilogram of fish. Also, S. latissima is known to be more effective at taking up N than A. esculenta. This is perfect because the Danish case study releases more N per kilogram of fish than the Norwegian case study, providing even more N for Saccharina latissima to utilize. Thus concluding that even though both Alaria esculenta and Saccharina latissima
are both very effective at taking up nutrients, A. esculenta will be more efficient in the Norwegian case study than the Danish case study and S. latissima will be more efficient in the Danish case study rather than the Norwegian case study.

As for the second research question, “do the conditions provided by the case studies affect the efficiency of the macroalgae to take up inorganic nutrients”, both the algae A. esculenta and S. latissima can thrive under the conditions in both case studies. The Danish case study provides conditions of water temperature below 16 degrees celsius for Alaria esculenta to grow in and temperatures between 10 - 15 degrees celsius for Saccharina latissima to grow in. The Norwegian case study is the same, temperatures under 16 degrees celsius to match both algae. Also the salinity of the case studies will have no affect on these two algae, and no other conditions can be measured to make any type of conclusion that will affect the ability of these two algae to sequester the nutrients from the two case studies.
Conclusion

From the results presented above, we can conclude that Alaria esculenta and Saccharina latissima are the two best algae out of the four that will best compensate for the excess nutrient loading from the fish farms. As reviewed Alaria esculenta will be best for taking up the nutrients presented by the Norwegian case study, and Saccharina latissima will be best for taking up the nutrients presented by the Danish case study. This information corresponds with what was found in the article “Weight ratios of the kelps, Alaria esculenta and Saccharina latissima, required to sequester dissolved inorganic nutrients and supply oxygen for Atlantic salmon, Salmo salar, Integrated Multi-Trophic Aquaculture systems by Reid et al. 2013. These two macroalgae are used in aquaculture in many areas of the world as a way of taking up inorganic nutrients and supplying oxygen for areas of open cage fish farms. The information gathered in this project and the results concluded, verify the effectiveness of S. latissima and A. esculenta in compensating for the environmental pressures set forth by the two case studies.

The growing of this macroalgae in close proximity to the fish farm will not only remove the inorganic waste but will also be of value to the fish farmers as this will help them expand their industry. Using the macroalgae near the fish farms helps find a secondary use for all of the inorganic nutrients polluting the ocean water and causing problems in the ocean
ecosystem. Without the presence of macroalgae or some other way of getting rid of the excess inorganic matter in the water, the fish farm industry would not be as important of a food source as it is in today’s world, and would not have room to expand in the near future. Furthermore, the macroalgae have many different uses for once they are harvested from the ocean water like sugar kelp or seaweed wrap, or even as agriculture crop fertilizer. There are many different reasons for fish farmers to use macroalgae to take up the excess nutrients from the fish farms and this project presents the best algaes to take up those nutrients dependant on the conditions provided.

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