Co-culture of blue mussel (*Mytilus edulis*) and sugar kelp (*Saccharina latissima*) as a strategy to reduce the predation rate of diving ducks on mussel farms in the Cascapedia Bay (QC, Canada)

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Monitoring the production rate of blue mussel (*Mytilus edulis*) and sugar kelp (*Saccharina latissima*) in co-culture and farmed kelp effectiveness in reducing the predation rate of diving ducks on mussel farms in the Cascapedia Bay (QC, Canada)  
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Declaration

I hereby confirm that I am the sole author of this thesis and it is a product of my own academic research.

Pierre-Olivier Fontaine
Abstract

Mussel farming is a well-established industry in eastern Canada that has become, over the last 45 years, an economical pillar for coastal communities. However, production is not consistent, and many factors such as duck predation can influence profitability. In order to reduce the predation rate of diving ducks on blue mussel (*Mytilis edulis*) farms in Caspapedia Bay, spools of sugar kelp (*Saccharina latissima*) and an artificial kelp line were introduced above the mussel’s fertilized rope, aiming to act as a visual shield. The survival rate, thus indirectly the predation rate, was calculated by comparing both treatments at 2 specific times: before the ducks arrival and following their departure. The seaweed yield harvested in June 2017 was significantly lower than regional yield obtained in the past (more than 100 fold difference), with an average yield of 25.3g ± 20.3g·m⁻¹. While no difference was observed between treatments preceding the ducks arrival in the amount (p>0.1), the weight of mussels per linear meter (p>0.3) and the length (p>0.2), a significant increase of weight of mussels per linear meter (7.0%) in favor of the artificial kelp treatment was found (p= 0.02003) after the ducks departure. Although this experiment is believed to represent a valid starting point to explore the possibility of introducing co-culture as a way to financially protect mussel farmers, it does not represent, as of yet, a profitable solution to protect the lines from predation as the yield was not found to be sufficient to sustain the producers.
To my wife

So long Iceland, and thanks for all the fish
# Table of Contents

Abstract ......................................................................................................................................................... iv

List of Figures ............................................................................................................................................. viii

List of Tables ................................................................................................................................................ x

Acronyms ....................................................................................................................................................... xi

Acknowledgements ........................................................................................................................................ xii

1 Introduction ................................................................................................................................................ 1
   1.1 The place of mussel farming in the aquaculture industry ................................................................. 1
   1.2 Mussel farming techniques .................................................................................................................... 3
   1.3 Seaweed farming .................................................................................................................................. 6
   1.4 Polyculture ........................................................................................................................................... 12
   1.5 The multiple uses of geotextile in ocean management ......................................................................... 14
   1.6 Diving ducks predation on mussels ....................................................................................................... 15
   1.7 Experimental site .................................................................................................................................. 18
   1.8 Previous deterrents used in aquaculture ............................................................................................... 19
       1.8.1 Active deterrent .......................................................................................................................... 19
       1.8.2 Passive deterrent ........................................................................................................................ 20
       1.8.3 Isolation ...................................................................................................................................... 20
   1.9 Economic rationale ............................................................................................................................... 21
       1.9.1 Economic impact ........................................................................................................................ 21
       1.9.2 The circular economy principle .................................................................................................. 22
   1.10 Environmental cost ............................................................................................................................. 24
       1.10.1 The impact on duck communities ............................................................................................... 25
   1.11 Aim and objective ............................................................................................................................... 27

2 Material and methods ............................................................................................................................... 29
   2.1 Location of the experimental site ......................................................................................................... 29
   2.2 Collection of mussel spat ..................................................................................................................... 31
   2.3 Pre-culture of *S. latissima* in the marine hatchery ............................................................................ 31
   2.4 Artificial kelp confection ...................................................................................................................... 32
   2.5 Design of the kelp-mussel polyculture longline ................................................................................... 32
   2.6 Transfert of the kelp plantlets to the marine farm ................................................................................ 35
   2.7 Sample collection .................................................................................................................................. 36
   2.8 Environmental condition ..................................................................................................................... 38
   2.9 Laboratory measurements .................................................................................................................. 38
   2.10 Duck observation ............................................................................................................................... 39
   2.11 Statistical analysis ............................................................................................................................. 40

3 Results .......................................................................................................................................................... 41
   3.1 Presence and behaviour of the ducks .................................................................................................... 41
Appendix G
Appendix F
Appendix E
Appendix D
Appendix C
Appendix B
Appendix A

References

Appendix
List of Figures

Figure 1: Canadian aquaculture by species .......................................................... 1
Figure 2: Canadian shellfish aquaculture production by province ......................... 2
Figure 3: M. edulis life cycle and production technique ....................................... 4
Figure 4: M. edulis longline farming technique used in Canada ......................... 5
Figure 5: Seaweed production around the world ................................................. 7
Figure 6: Seaweed production and wild harvest ................................................. 7
Figure 7: Life cycle of S. latissima ................................................................. 8
Figure 8: Integrated Multi Trophic Aquaculture model ...................................... 12
Figure 9: The Coastal CO² Removal belt ......................................................... 14
Figure 10: Maximum diving depth of sea duck species .................................. 16
Figure 11: Long tailed duck abundance and mussel landing ................................ 17
Figure 12: Map of Canada ............................................................................. 18
Figure 13: Site location for the experimentation ............................................. 19
Figure 14: Shematic of the economic rationale ............................................... 23
Figure 15: Site location: The on-shore ducks observation point and lines .......... 29
Figure 16: Layout of the experimental longline and treatment ......................... 30
Figure 17: S. latissima gametophyte on nylon rope and spools covered with plantlets.. ................................................................................................. 31
Figure 18: Experimental layout of coculture between M. edulis and S. latissima .... 34
Figure 19: Installation of the kelp culture .......................................................... 35
Figure 20: Installation of the artificial kelp .......................................................... 36
Figure 21: Star wheel ...................................................................................... 36
Figure 22: Initial data collection, April 2017 .................................................... 37
Figure 23: Analysis of the data collected ......................................................... 38
Figure 24: Ducks observation three horizon’s ................................................. 39
List of Tables

Table 1: Geographic position of the longlines. ................................................................. 30
Table 2: Calendar of the experiment. .................................................................................. 31
Table 3: Other avians organisms observed on the site in minor abundance. ........... 42
Table 4: Wet biomass of *S. latissima* sample taken during the final harvest .......... 44
Table 5: Average length of *S. latissima* sampled at the final harvest .................. 44
Table 6: Mussel biomass before and after predation ................................................... 48
Table 7: Mussel length before and after predation ....................................................... 49
Table 8: Mussel number before and after predation ..................................................... 49
Table 9: Evolution of water transparency on the mussel farm ................................. 54
Acronyms

AAC: Aquaculture association of Canada
AK: Artificial kelp
BCI: Body condition index
C: Carbon
CWS: Canadian Wildlife Service
DIN: Dissolved inorganic nitrogen
DFO: Department of Fisheries and Ocean
DPSIR: Framework to describe the interaction between society and the environment
Dw: Dry weight
EBM: Ecosystem based management
FAO: Food and Agriculture Organization of the United Nations
IMTA: Integrated multi-trophic approach
ICZM: Inter coastal zone management
LK: Living kelp
MSP: Marine spatial planning
N: Nitrogen
NIMBY: Not in my backyard
P: Phosphorus
PSU: Practical salinity unit
RAQ: Ressource Aquatique Québec (Quebec Aquaculture Society)
SWOT: Study to analyse the strength, weaknesses, opportunities and threats
UPS: Underwater playback system
UV: Ultraviolet
WAS: World Aquaculture Society
Ww: Wet weight
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From left to right, Pierre Olivier Fontaine and Dr. Éric Tamigneaux

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*The sampling team, from left to right: Clément Durette, Pierre-Olivier Fontaine, Rosie Leblanc, Éric Bujold, Alex Gely, Grégoire Cholat-Namy. The lab team, from left to right: Sophie Chabot and Pierre-Olivier Fontaine.*
1 Introduction

1.1 The place of mussel farming in the aquaculture industry

Shellfish aquaculture is a well-established industry that has been flourishing worldwide for a long time. Globally, blue mussels total production has been around 200,000 tons since 2010 (FAO, 2016) with most of its activities being concentrated around the North Atlantic and on the West Atlantic Coast. As it is the case for the whole aquaculture industry, it is still growing, with a production that has more than doubled since 1960. With a long production history, technique and expertise are considerable but some problems continue to threaten the viability of many farms and aquaculture companies around the world. Above all, toxic phytoplankton blooms, mussel seed shortage and mussel predation have major impact on this industry, and have to be addressed to allow continued production and profitability.

Mussel aquaculture in Canada is also a well-established industry and in eastern Canada it has been thriving for more than 45 years. In Canada, mussels are cultivated on both

![Figure 1. Canadian aquaculture production by species in 2010 (DFO, 2012)](image_url)

the East and the West coast, and they accounted for a farm gate value of 49.5 million Canadian dollars in 2013 with 29,100 tons of production (DFO, 2013). The importance
of this species in the Canadian aquaculture industry is illustrated in figure 1. As a whole, the Canadian aquaculture industry is growing rapidly, with a production that has more than doubled in the past 15 years. The largest mussel cultivating province of the country being the Prince Edward Island with 80% of the Canadian production. Even though aquaculture per se is generally believed to have a positive impact on aquatic resources through a reduction of the fishing pressure, the farming of carnivorous fish, which are usually fed feed made with low value wild fish, is often criticized for having the opposite effect (Naylor et al., 2000; Granada et al., 2016). Also, it is sometimes mentioned that aquaculture could impact the genetic pool of the wild stocks when individuals from genetically selected aquaculture strains escape and reproduce with those of wild populations, lowering the genetic diversity and adaptiveness of the wild stocks. Until now, in the literature, this concern has been raised mainly for farmed Atlantic salmon (Salmo salar) and species where selection occurs although the studies on this issue have been providing conflicting results (Noakes et al., 2000; Glover et al., 2016; Quintela et al., 2016).

On the other hand, the problems and limitations cited above are related to the cultivation of carnivorous species and do not affect the whole aquaculture industry. Some other types of culture such as kelp and shellfish have been found to have a positive effect on their surrounding ecosystems. In Sweden, research has shown that the introduction of farmed blue mussels (Mytilus edulis) covering a small area (less than 2%) could reduce

![Figure 2. Canadian shellfish aquaculture production by province, between 2009 and 2013 (Statistic Canada 2013)](image-url)
the eutrophication level of surface water in fjords by lowering the concentration of dissolved inorganic nitrogen (DIN) by 20% (Haamer, 1996). Eutrophication is a state in which the oxygen dissolved in a water mass has been depleted, usually by an excess of primary production caused by an abundant input of nutrients such as DIN and phosphorus. Likewise, it has been observed in the Kiel fjord, in Germany, that blue mussels culture, even in a small size operation context, can increase surrounding water quality by removing nutrients, thus increasing water transparency (Schröder, T et al., 2014).

In other studies, mussels have shown great potential for reducing the impacts of other forms of aquaculture when introduced into a system referred to as Integrated Multi-Trophic Aquaculture (IMTA), involving multiple species in a way that allows one species' wastes to be used by another as sustenance. In the Bay of Fundy, Canada, the blue mussels introduced in this type of IMTA system have demonstrated the capability of capturing and storing uneaten fish feed nutrients from salmon farms, reducing the nitrification level while improving profits for the farmer by offering him a second income (MacDonald et al., 2011). Other important uses of bivalve culture have only begun to be studied, but, by ingesting the small larvae of parasitic copepod species, they have already shown great potential in reducing the concentration of sea lice around the Salmo salar production site, thus limiting the need to use toxic chemicals (Webb et al., 2013).

### 1.2 Mussel farming techniques

Mussels have been fished for over 8000 years around the world and harvested for many centuries. Historically, the culture started with wooden poles, called bouchots, inserted in the bottom of the intertidal zone and this technique is still used in Brittany, France. Another historically and relatively inexpensive technique that was used, and still is in some areas, is the on-bottom culture technique. This is the method where wild mussel spat are transferred to specifically chosen culture plots and dispersed on the bottom substrate. However, these techniques are not the most effective to increase the
meat/shell ratio, making them less profitable. Also, those methods are more vulnerable to a wider array of predators: sea star, crabs, ducks (Gouletquer, 2004).

More recently, the culture of mussel on longlines, also known as rope culture, has been introduced and is rapidly becoming the most common type of culture for blue mussels.

![Diagram of M. edulis life cycle and production technique (FAO, 2016)](image)

With these floating ropes at 10-40 meter depth in open water, this technique is known to maximise yield and contributes to reduce benthic predation (Lucas & Southgate, 2012). The production on these structures can average between 18-20 tons/ha/years, before predation (DFO, 2016). Another advantage of this technique is that the location of the marine farms, nearshore or offshore, poses a lesser problem to general aesthetic and beach tourism compare to bouchot and on-bottom intertidal culture. For the harvest, the method for longline culture is relatively simple. However, as it will be further discussed, this technique doesn’t protect the mussel from sea ducks, putting farms at financial risk despite the highest scope for growth of those longline cultures.
On this project, the mussel were cultivated using the *collecteurs autogérés* (self regulated collectors), a technique developed by Éric Bujold from Ferme Marine du Grand Large. In this approach, the U-shaped mussel collectors are floating under a specially designed longline that will progressively sink in depth as the weight of the mussels increases. In contrast with the traditional mussel sleeve approach where the mussels on the collectors are harvested and sorted after one year and then transferred into net sleeves and re-suspended below a longline for another year until they reach their commercial size (50 mm), here the mussels are left on the collectors for three years, with absolutely no manipulation to manage the mussel density or the longline depth nor mussel husbandry, which considerably reduce the production cost (Lekang *et al.* 2003). After 12-15 months and regular check on the stock, mussels are harvested using a hydraulically powered harvesting machine.

![Figure 4. M. edulis longline farming technique used in Canada (McKindsey *et al.*, 2006)](image)

Several studies have been conducted in the shellfish aquaculture zones of the Gaspé peninsula (Québec) in order to understand the ecosystem dynamics and the mussel response to the natural variations of different factors such as water temperature, pH, photoperiod, salinity, dissolved oxygen, feed availability. As a result, three phytoplankton blooms have been generally observed, one at the end of May, in July and a last one in October (Cartier *et al.*, 2004; Toupoint *et al.*, 2012). Another particularity of this area that requires adaptation of the mussel farming techniques is the presence of drifting sea ice during winter. Moving sea ice not only prevent navigation but can also destroy the longlines (Dionne *et al.*, 2006), the culture gears on the marine
farms must be lowered to 9m deep between December and April. During the period between January to April the seawater surface temperature is often close to the freezing point (-2°C), which limits the choice of farmed species. However *M. edulis* is tolerant to those temperatures and some research has even found that they continue to grow during those months (Mallet *et al.*, 1987).

Mytiliculture is considered as an extractive form of aquaculture since mussels are actively filtering the water with their gills to retain phytoplankton and particulate matters they feed on. Studies have shown that the organic particular matter tend to decrease in the surrounding of the shellfish farms which makes them a great candidate for IMTA (Piercey *et al.*, 2005). Also, mussels are considered to be an excellent bioindicator of water quality as they can bioamplify certain particles of interest such as zinc, cadmium, cooper, lead, mercury and others found in water, thus can be used as a pollutant indicator (Hamer *et al.*, 2008). By the same process, these bivalve can be used in a biofiltering process to remove certain pollutant and particles (Ostroumov, 1998) and even carbon that get trapped in mussel shell and meat, which can make it a carbon sink (Grant *et al.*, 1998).

### 1.3 Seaweed farming

Seaweed farming is among the fastest growing sector in aquaculture with the vast majority of its production happening in Asia (figure 5). As a result, this field of aquaculture is still marginal in the Western world but interest is in rise in Atlantic coastal countries such as United States, Canada, France, Ireland, Scotland, Spain and Norway. Many companies are currently trying new site, species and strain. Of the total production, 26.1 million metric tons of aquatic plant (mostly seaweed) (Moffitt & Cajas-Cano, 2014) were farmed in 2013, which represent the vast majority of it (figure 6). On the species of interest, most of the commercial enterprise in the Northern Atlantic are focused on *Saccharina latissima*, *Undaria pinnatifida* and *Alaria esculenta* and research interest are currently on *Palmaria palmata*, *Chorda filum* and *Saccorhiza dermatodea*. 
The sugar kelp, *Saccharina latissima* (Linnaeus), previously known as *Laminaria saccharina* is a temperate-cold water seaweed, member of the family Laminariaceae (class Phaeophyceae). This edible brown alga is abundant around the northern Atlantic basin where it forms dense kelp forest up to 20 m depth. It has a yellow-brown color and can grow up to a length of 7 m. The sugar kelp life cycles follows the different stages of the laminaria as illustrated in figure 7. The cycle starts with a planktonic stage where the zoospores will develop and differentiate in male or female gametophyte (haploid stage). The gametophytes will then spawn eggs and spermatozoids. Following fertilization, the sporophyte (diploid stage) will then rapidly grow until the next summer where it will develop its sorus from which the zoospore will be released, completing the cycle (Andersen, 2005; Redmond *et al.*, 2014). The condition and reproduction

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**Figure 5. Seaweed production around the world (Farmer *et al.*, 2014)**

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**Figure 6 Seaweed production and wild harvest (Cottier-Cook *et al.*, 2016)**
phases are conducted in hatchery between August and September. The conditioning is usually done in tank in a controlled area, the reproduction in bucket or tank (depending on the volume), the zoospore are kept in latency in 4 liters round bottomed flask. The zoospores will then be fixed to culture twine and be transferred to a controlled tank until it reach the length of 1-5 mm. The culture twine will then be transported in specially designed cooler where the PVC support with the twine will be strongly fixed. The outplanting takes place at sea between September and November at specifically chosen site to respect the tolerance and optimal growth thresholds. The harvest will usually take place between May and June depending on the area. Kelp are cultivated using nylon or kuralon twines seeded with kelp seeds, i.e zoospores or gametophytes. Once the twine is seeded, there is a 4-6 weeks pre-cultivation stage in a marine hatchery until small sporophytes appear. The twines are then outplanted on a marine farm where the sporophytes grow until they can be harvested.

The limiting variable for *S. latissima* growth are mainly the temperature, salinity, light intensity, photoperiod, pH, and nutrients (C,N,P). For the tank culture to condition the seaweed, a temperature between 10-15°C, a light intensity between 100-200μmoles m"
and a 8:16 day and night photoperiod ratio (Tamigneaux et al., 2013) are necessary. At sea, a salinity of 30PSU, a temperature between 10-15°C, a moderate wave action dynamic, a light intensity between 30-100μmoles m$^{-2}$ s$^{-1}$ and a turbidity estimated with a Secchi disk of 6-8m are considered optimal (IFREMER; Bolton & Lüning, 1982). During its life cycle, the kelp’s growth is not constant. During summer, when the surface layer of the coastal water is poor in nitrogenous nutrient (NO$_3$, NO$_2$, NH$_4$), the growth rate of the kelp is slowing and the sporophytes are storing carbohydrates in the blade tissues. In contrast, during winter, when the nitrogen concentration of the seawater is at its highest, the growth rate of the sporophyte increases and the carbohydrates stocks of the blade decrease. (Broch & Slagstad, 2012).

In Quebec, at the region of experimentation in the Baie des Chaleurs, the highest growth rate of Laminaria longicruris occurs between May and June (2.3cm·d$^{-1}$, Gendron, 1989), whereas the minimum growth rate is observed in winter (0.6cm·d$^{-1}$, Gendron, 1985). The temperature range for growth is generally between 0°C and 20°C (Gendron & Tamigneaux 2008) but it has also been observed under 0°C (Chapman, 1987). At the same time, as energy is invested differently and the abiotic condition changes, the chemical content of S. latissima also varies greatly, as observed on an Icelandic farm (Sjøtun & Gunnarsson, 1995). Saline stress, under 25PSU, would reduce the value and survival rate of the kelp, and temperature over 23°C could be lethal (Gendron & Tamigneaux, 2008). The optimal temperature for growth of S. latissima is approximately 10°C.

Local environmental conditions such as wave exposure may influence the development of kelp morphotypes and this may be considered as an example of phenotypic plasticity, or the ability of kelp to adjust its morphotype throughout its life cycle (Fowler-Walker et al., 2006). Indeed, different morphologies of S. latissima have been described in the literature as S. longicruris or S. latissima forma angustissima (Augyte et al., 2017). Of these different strains, the S. longicruris and the general morphotype of S. latissima are currently found around Gaspésie. Aquaculture production of S. latissima is at the moment quite marginal globally when compared to other marine cultures, and the core of it is harvested for human consumption, fertilizer, animal feed component and potentially for ethanol production (Murphy et al., 2013). The seaweed are also the subject of many biomedical researches about its potential dietary benefits on human
health, its prebiotics composition (De Jesus Raposo et al., 2016) and its overall positive effect on the human brain (Cornish et al., 2017)

In Gaspésie, two strains are presently used in the culture trials. The first one, known as *Saccharina longicuris*, is characterized by a long stipe and a broad blade and is harvested in the wild kelp beds near Bonaventure inside Chaleurs’s bay. The second known as *S. latissima* is characterized by a short stipe and a narrow blade and is harvested in the wild kelp beds near Newport, at the mouth of the Chaleurs bay.

Different techniques are used around the world to produce kelp plantlets in marine hatcheries. The approach used for this research (Tamigneaux et al. 2013) combines artificial sorus maturation as developed by Pang et Lüning (2004), the vegetative multiplication of gametophytes *in vitro* (known as free-living) before seeding them on the culture twine (Pérez et al., 1992) and the seeding of the culture twine with the kelp zoospores (Druehl, 1980, 1988). The two main techniques that will be referred to in this document are known as the Korean technique (twine seeded with spores) and the free living technique (twine seeded with gametophytes). Both techniques present an array of particularities but the main difference is in the method of fixation of the seeds and the time spent in the nursery. For the free living technique, pulverisation of the fertile gametophytes on the twine is performed in Grande-Rivière using equipment analog to pressure spray painting as explained by Arbonna and Molla (2006). The Korean technique will be briefly explained in the method section using the protocol by Tamigneaux et al., 2013.

The technique to cultivate kelp is on individual longlines or on a raft (interconnected longlines). With this method, the kelp are maintained at the optimal depth to limit the destructive effects of waves while insuring a high primary production rate, as kelps depend on the quantity of light available and the presence of sufficient concentration of inorganic nitrogen. *S. latissima* grows best on moderately exposed sites. For example, in Spain, Peteiro & Freire (2013) found that the final biomass of *S. latissima* cultivated on a sheltered aquaculture site was significantly lower (12 fresh kg•m⁻¹ of longline), compared to that (16 fresh kg•m⁻¹) in a moderately exposed site. In Norway, when cultivated at different depths (2m, 5m and 8m) it was found that depth affects growth. The authors recommended that in Central Norway *S. latissima* should be cultivated at a depth lower than 5m. The authors also recommend that stratification and seasonal
changes should be taken into account to assess the right depth in other countries (Handå
et al., 2013).

In colder area such as Canada, where drifting sea ice is often present during winter in
marine aquaculture area, the depth of the aquaculture longlines is a crucial component
to take in consideration as shallower line could be wiped off by ice during the colder
months and following the spring debacle (Dionne, 2006). Also, following those months
where the ice and snow start to melt, a strong input of freshwater flows down the rivers.
Since the lines are close to the shore, this freshwater layer can affect the culture if the
line are not kept under the halocline (Gendron et al., 2007, Gendron & Tamigneaux
2008).

In Québec, the kelp culture lines are now kept at 6-7m deep between December and
April-May, in order to avoid drifting ice in the winter and, in solme places, the contact
with freshwater in the spring. The culture lines are then moved to the suface (1-4m)
between April-May and June to increase the access to light and therefore the kelp
growth rate. The culture schedule of S. latissima in Québec was also designed to protect
the kelp from an invading colonial bryozoa, Membranipora membranacea. The
planctonic larvae of M membranacea attach to the blades of the kelp at the begining of
the summer and, in July, the colonies are rapidly covering the whole blade which
reduces its flexibility and increase its breakage rate and loss of biomass. It is believed
that a bad timing in the outplanting and harvest schedule in 2006 led to an infestation
of this bryozoa which caused the loss of the crop (Gendron et al., 2007). To prevent the
infestation, the technique used nowadays is to outplant the small kelp plantlets on the
marine farms after August and to harvest the large kelp sporophytes before July, since
the bryozoa larvae are mostly present in the water in July and August.
1.4 Polyculture

A polyculture is a culture of more than one species. This polyculture can then be of an integrated multi-trophic aquaculture (IMTA) kind if there is a transfert and compatibility between the species or just a structure that includes two or more species in close vicinity without any interaction. Polyculture is often used either to diversify the production, enhance the production, bioremediate problematic such as parasite or reducing the impact of those production on the environment. The classic design of these systems is illustrated in figure 8 and often contain a species of fish, shellfish, detritivorous, and seaweed. A classical example would be the IMTA experiment in northwest Scotland located near a 500 tons salmon farm (Sanderson, 2012). In this situation, S. latissima biomasses yield was found to be enhanced by 61% in summer and 63% during growth season while decreasing up to 5% of the waste nitrogen,
confirming the compatibility. Sometime, the effect can also be indirect, as an improvement of social acceptance. In the Sanderson experiment, the salmon growth was not enhanced, but the seaweed brought the benefit of making it more socially acceptable by the production of a second species which represent a sustainable source of food, fish feeds, biofuel, cosmetic and a many other derivative products (Chopin, 2012). As more studies are being conducted, a more precise protocol is taking shape with precise weight ratio of seaweed to effectively bio-remediated the impact of carnivorous finfish (Reid et al., 2013).

Although the classical schematic of recreating an ecosystem with carnivorous finfish at the top had raised many interest, there is much more to experiment in the field of polyculture. Many of them were conducted in Asia, where the culture of many shellfish and seaweeds are extensively used. Of those, the sea cucumber (Apostichopus japonicas) was found to be an effective scavenger to reduce the waste produced by an abalone (Haliotis discus hannai) farm (Xia et al., 2017). On the Red Sea coast, the sea lettuce (Ulva lactuca) was used to capture and reduce the nutrient concentration on the effluent of a sabaki tiliapia (Oreochromis spilurus) culture (Al-Hafedh et al., 2015). Different design including different fish, shrimps (Binh et al., 2014) and macro algae (Putro et al., 2016) were also tried with promising results. However, the avenue of a polyculture of blue mussels and sugar kelp have not been thoroughly tested yet. Small scale model have been unsuccessful (Rlössner, 2013) but offered some insight on the right direction to take for further experiment. In China, kelp-mollusk (Laminaria japonica-Chlamys farreri and Laminaria japonica-Haliotis discus hannii) polyculture have been tried for a while but, due to a depressing selling price of the mollusk and the additionnal complexity of the culture, farmers have gave up the concept and returned to kelp monoculture notwithstanding of the environmental externalities that they were producing (Lance et al., 2017). To answer this problem, Lance stressed the importance of a monetary incentive through government support.

Contrary to the common paradigm that the different components in IMTA should be in close vicinity, it is now accepted that the co-culture effect could be seen in a more regional scale than a few structure piled up in a small area. This vision of IMTA (figure 8) is more suited to organisms that target the particulate matters than the dissolved nutrients, which diffuse through the water column. In that instance, a culture of macro
algae is believed, if given the space, to have the potential to benefit a whole bay instead of a closely located salmon cage (Chopin et al., 2010). The potential benefits also extend to more than a rapid growth, but also an ecosystemic role where kelp farming could be used to reduce eutrophication risk (Chopin et al., 2008), used as a biofilter (Neori et al., 2004), used as a bioremediation tool (Marinho et al., 2015) and even has carbon sink as shown in figure 9 (Chung et al., 2013) when integrated in a coastal integrated management approach. The excess nutrient removal potential of these algae seemingly begins to arouse interest following production growth. The major species farmed are now believed to remove the amount of approximately 65,000 tons of nitrogen per year and 760,000 tons of carbon per year (Kim et al., 2017). Extrapolation have also already been made for a more global scale where it has been estimated that a culture covering 0.03% of the ocean surface could be sufficient to remove 30% of the introduced nitrogen (Bjerregaard et al., 2016).

![Figure 9. The Coastal CO2 Removal belt model by Chung et al., (2013)](image)

### 1.5 The multiple uses of geotextile in ocean management

The use of geotextile in ocean management is not something new. Previously, it was a material well proven to protect bare soil from erosion, both wind and water provoked (Rickson, 2006; Mc Doug al et al., 1984). But since then, it has been studied for far more than its initial role. Of these non-standard roles, it has been used in
aquaculture to provide shelter and growth substrate for algae and microorganisms or act as artificial seaweed and as a biofiltration substrate (Wilson & Hopkins, 2001). Even though these roles were explored in freshwater pond environments, the possibility to transfer them into a marine environment was also tested at the Harbor and Marine Technology Research Center in Taiwan. In this experiment, geotextile made of black polypropylene were not found to be affected by the seawater immersion, although UV exposure seems detrimental on their strength properties (Hsieh et al., 2006). Geotextiles represent a good substrate for organisms, with a potential of rapid accumulation of algae, microorganism and grazers (Wilson & Hopkins, 2001) but also disease (Lucas & Southgate, 2012). One could predict that geotextile presence could increase the densities of the above mentioned on surrounding cultures. Because kelp farming in the Cascapedia Bay suffers from epiphytes parasitism, it would be important to verify if the use of geotextile in this experiment could have any effect on the occurrence of epiphytes on kelp blades.

1.6 Diving ducks predation on mussels

In many mussel farms around the North Atlantic Ocean, several factors such as the presence of toxic phytoplankton blooms, mussel seed shortage and predation by diving ducks can affect the global yield. Duck predation has proven to be particularly persistent and hard to reduce in the long term. Even after many attempts at reducing the impact of this predator, losses caused by diving ducks are still limiting the economic potential of many farms and, in some cases, even threaten their existence. For example, in 2011, in the Cascapedia Bay (Québec) all mussel farms were severely affected by scoters (Melanitta spp.), causing the losses of all the mussel seeds on the seed collectors and more than 30% of their 1-2 years old mussels (Varennes et al. 2013). A similar situation was also observed in Scotland between 1992 and 1996 with losses related to the duck predation representing 10 to 30% of the total stock (Ross & Furness 2000). Most predation can be attributed to a few species responsible, most of them being sea duck species including eider (Somateria spp.), scoters (Melanitta spp.) and long tailed ducks (Clangula hyemalis) (Varennes, 2013). On their feeding behavior, those ducks are mainly visual predator and can dive down to 25m (figure 10). Since the mussel larvae are concentrated in the upper layer of the ocean, the longlines used for mussel
seed collection are maintained at the surface of the water with the collector loops suspended below, not deeper than 10m. It follows that these longlines and their surface buoys are easily detected by the ducks and the seed collectors are particularly vulnerable to predation.

As they tend to form large migratory flocks during spring and falls, several hundred thousands of birds can forage the same area eating at an impressive rate causing severe depletion on stock and farmed biomass in a short period. Also, when those flock migrate, their exact time of arrival is usually hard to predict making it hard to put in place deterrent. Even worse, climate change tend to alter (even more) the predictability of those migration (Jenni & Kéry, 2003). As shown in figure 11, the number of diving sea ducks seems to correlate with the amount of mussels farmed in a particular area (Dionne, 2004). Additionally, ducks has been observed to show preferences on farmed mussels instead of wild ones, aggravating the already threatening problem (Varennes et al., 2015). Finally, as duck abundance has been observed to increase rapidly following the growth of the mussel aquaculture (Figure 11), one is lead to believe that this problem will not be solved by itself or by increasing the amount of mussels on site.

Many factors influence the preference of sea duck on farmed mussel over wild mussels, and could be linked to the particular morphology of the farmed mussel and their overall

![Figure 10. Maximum diving depth of sea duck species (Žydelis et Richman, 2015)](image-url)
ease of access. Among the factors possibly affecting the morphology of cultivated *M. edulis*, there is the genetic selection (not often), the higher density of biomass when compared to natural mussel beds, the higher food availability when located at the right site and depth (Camacho et al., 1995) the absence of important predator such as the starfish *Pisaster spp.* and the absence or reduction of abiotic stress like intertidal desiccation (Kirk et al. 2007). Thus, it has been hypothesized that those factors, reducing the overall stress on the produced mussel population, were the causes behind the higher meat to shell ratio generally found on those farms (Bustnes & Erikstad, 1990). By having more meat and less shell, those mussels then represents a high quality prey as they contain more energy per wet weight and are more easily digestible compared with the larger, with thicker shell, wild mussels (Varennes et al., 2015). Farmed mussels are easier to eat and to metabolize because their shell is generally thinner. Ducks have to spend less energy to find the next prey as mussels are in dense population on those rafts or ropes. Finally, the ease of access to the prey as the structure are always accessible independently of the tide, unprotected by vegetative cover and generally attached more loosely.

*Figure 11. Total Long Tailed Duck Abundance in function of the mussel landing. (Dionne, 2004)*
1.7 Experimental site

The project takes place in the Gaspésie peninsula, in the province of Québec, on the East coast of Canada (Figure 12). The region is mainly maritime and relies on its fisheries, aquaculture, tourism, agriculture and forestry sectors (Robert, 2012). As it is the case in many other rural agglomerations in Canada that depend mainly on only a few primary resources, its overall economy has been in constant decline for many years. However, a surge in regional investment have been observed since 2014 (Desjardins, 2016). For 2017, it has been estimated that this region would reach an unemployment rate two times higher (15.4%) than the provincial rate (7.2%) (Desjardins, 2016). Furthermore, the demography has shown a considerable decrease of more than 5% between 2011 and 2014 (Québec Statistics Institute, 2015) despite many governmental programs and economic incentives to repopulate the region.

![Figure 12. Map of Canada highlighting Québec province and the Gaspésie region (Google earth 2017)](image)

During the last decade the Cascapedia Bay has been repeatedly affected by diving duck predation, forcing many farmers into financial problems and closure. In 2012, one of the biggest farms closed after losing hundreds of thousands of dollars, inflicting a hard hit to the community. However, many farmers are still trying to find a solution to reach
the 2000 to 3000 tons potential of production in the Bay, as evaluated by Éric Bujold, a major mussel producer in the area (Breault, 2012).

1.8 Previous deterrents used in aquaculture

To respond to this considerable problem among mussel farming, many creative methods have been tested with various results. Those methods, by their nature can be divided in three categories: active, passive and by isolation.

1.8.1 Active deterrent

The active deterrents method contain sudden stressful elements repeated over time such as gas cannon, fireworks, electronic distress call, boat chase, firing of blanks, falconry, laser, radio-controlled aircraft and lethal shooting and have all been tested. For all of those methods, the outcomes were generally quite similar: results were quite promising at first, with immediate stress and scaring effect, but ducks finally habituate or find a way to bypass the stressor after some time. Also, because it often produces load and sudden noise, many complaints were expressed by local population, enhancing the ‘‘not in my backyard‘‘ (NIMBY) effect. In response, Environment Canada qualified many of those techniques, such as the gas cannon and fireworks, unacceptable to use at night, reducing even more its effectiveness since sea ducks have also been observed to feed at night (Bergan et al., 1989). On falconry, even though it was found to be relatively effective and promising avenue, the technique was quite expensive and the availability of such service was marginal in the few countries where it was legal. Other
active deterrents, like radio controlled aircraft, were found to be of minimal effect while being cost and labor intensive as well as weather dependent. Laser use was also quite expensive, required special equipment, training and proved to be inefficient during daylight. As for boat chasing, results were positive for small flocks, but effectiveness tends to decrease with the number of birds involved (Richman et al., 2012). Moreover, it was one of the most expensive techniques because of fuel cost. To improve this technique, stressed ducks sounds were being recorded when being boat chased, to be played on site by underwater playback systems (UPS). While showing great results with a reduction between 50-80% of eider duck presence (Ross et al., 2001), it is probable that this technique provokes great stress on the duck population and has negative effect on the long term well being of these animals. Also, to keep it effective, regular boat chase to reinforce the UPS deterrent were needed, adding to the costs. It is also important to specify that many of the technique mentioned previously required special permit and were only permitted following certain conditions.

1.8.2 Passive deterrent

Concerning the passive methods, where no active threat or action is used, multiple techniques and tools have also been tried such as the presence of human activity, scarecrow and plastic owl, scary eye buoy, mirror, duck corpses. About the plastic animals and scary eye buoys, those deterrents were generally cheap to implement but with low to no effect due to rapid habituation. The same trend was also observed with mirrors, reflector and light in general. On the uses of corpses, the effect was also found to be minimal and not very practical, as special permits were required and many of those birds are protected under migratory birds law. Human activity and presence on site seems to be one of the most effective repellent, although it was only effective during day time and quite expensive as it requires to have people on site almost at all time (Furness, 2000).

1.8.3 Isolation

Regarding the isolation techniques, nets, cages and protective socking material have all been tried and the results were generally promising. However, those technique represent a danger for surrounding biota since every net and cages introduced in marine environment can cause by-catch and entanglement. To improve the technique,
laboratory studies using captivity bird have tested different net types and mesh sizes to observe duck response and safety. As a result, mesh size between 10-15cm, depending on targeted species, were found to be the best match (Varennes et al., 2013). Even though they were effective, those techniques also represent great expense, especially when the cleaning cost due to biofouling are taken into account. Biofouling is the settlement and fixation of undesired species such as barnacle, ascidian, algae and others on free surfaces. Another isolation technique that has shown great potential is the protective socking material. The protective socks contains a biodegradable protective layer against predation was tested in Prince Edward Island, Canada. Following its application, a reduction of the predation rate was observed. However, the mussel scope for growth also decreased (Dionne et al., 2006), demanding improvement in the technique and choice of material.

In conclusion, many technique have been thoughtfully tested over the past decades without any significant breakthrough. However, those experiments certainly provide the industry with more information about diving duck behavior and rate of habituation. While not all the methods took in consideration the well being of the biota and the amount of stress caused to the ducks by some of the technique, further design improvement and developpement of new idea should focus on passive actions for a better fit on ecosystem based approach.

1.9 **Economic rationale**

1.9.1 **Economic impact**

In Canada, the average losses rate due to ducks foraging in mussel farms is around 30% of total production and in Scotland it was evaluated to be between 10-30% over the studied period (1992-1996) (Ross & Furness 2000). The total production was of 394 tons of blue mussels in the Québec province (2011), with an associated total value of 411 000 CAD$. The average losses caused by duck was then evaluated at 30% in the province of Québec, resulting in a provincial losses of 123 000 CAD$ (Statistic Canada, 2011). In a positive scenario where the tested design would reduce the predation rate, or where the kelp production could compensate the production losses, this could be a breakthrough in the aquaculture industry.
In Québec, the government is often reluctant to erect new site for aquaculture and as a result, old abandoned sites have to be reused for a newcoming farmer. As those abandoned site in the Cascapedia bay, have been struggling with sea duck in the past, a new mussel farmer would need a solid plan to succeed where others have failed. If an effective repellent was to be found, those abandoned sites could bounce back and, perhaps, help reaching the regional production potential estimated by Éric Bujold, between 2000-3000 tons for the Baie des Chaleurs only (Breault, 2012).

Also, following the Porter Induced Innovation hypothesis (Porter & Van der Linde, 1995), the effectiveness of such repellent could self-promote more experimentation of this kind, potentially leading farmers toward polyculture and circular economic model that may provide more stable economical revenue in struggling regions.

### 1.9.2 The circular economy principle

As a simple rule of thumbs, a good duck repellent has to reduce the cost of mussel losses so that the mussel production gain is greater than the cost of implementation of the repellent. Generally, deterrent only add to the mussel production costs. The deterrent that will be used in this thesis, will be made of farmed kelp that can later be sold for alimentation, cosmetic purpose, biofuel, fish feed and others, representing a model of circular economy. The principle of circular economy, mainly developed in Asia and to some extent in Europe, can also be applied to environmental economics. In the economics world, circular economy is defined as a symbiosis where the waste of one industry is reuse by the next (Andersen, 2007).

By adopting this paradigm in the production scheme, a farmer could either benefit to or from another one cultivating a compatible species or benefit from its own diversified culture (Ridler et al., 2007). A good example of the benefits of circular economy in aquaculture is the polyculture experimentation of Chen et al. (2007). The circular economy in this case was produced by the addition of mussels around a fish pond to filter the water column. This approach reduced the cost of filtration and the amount of pollution produced by the farm, while creating a second income from the sale of mussels.

In the case of this study, this kind of system will be characterized by the market value of the repellent and the potential positive influence it could have on the culture of
interest. Accordingly, when the calculation will be made, the cost of introducing such
culture will have to be subtracted from the benefit of the mussel production, but the
value of the seaweeds produced will be added to the farm production value (Figure 14). In
this case, effectiveness will be defined as the point where marginal benefit equal
marginal cost, therefore the implementation cost would be covered and any further
decrease on the predation rate would result in benefit. As a result, such design will need
to be less effective at repelling duck than other design to produce the same benefit,
assuming than its value is superior to its implementation cost. The main difference
when compared to other deterrent thus resides into the diversification of production.

On the other side of the spectrum, previously tried repellents can be considere[d as part
of the linear economy where no additional product is created. Consequently, those
repellent have to be much more efficient at reducing duck predation to equal the benefits
from the kelp shield design. For example, when considering the boat chase technique,
the price of the fuel used, the boat rental and the salary of the driver have to be deduced
from the net benefit of the mussel produced and still sum into an higher benefit than
without the technique. Often, the only situation where it can result in profits is when
many producers in the same area unify their forces and divide the cost of the boat chase
among the farmers.

On a smaller scale, when farmers are more spatially isolated, they can only rely on other
techniques such as predator net, scare crow, fireworks, falconry and many others

![Figure 14: Conceptual model comparing the economics of (A) the diving duck deterrent
methods traditionally used by the mussel industry and (B) the new kelp shield design](image)
(Furness, 2000). However those are of limited effect and also represent additional costs perpetuating the problem and the losses of revenues.

1.10 Environmental cost

Human activities tend to affect the environment in many different ways. One notion that is often used in environmental economy is the Pareto optimal. This optimal in this case, would be where the marginal cost of producing a mussel will equal the marginal benefit of producing it (Pareto, 1971).

When active repellent are being used such as firing blank, boat chase, fireworks, underwater playback and others, a certain amount of stress is induced to the ducks reducing their fitness. Unlike those repellent, the kelp shield technique is believed to cause no any additional stress or marginal cost as the cultivated seaweeds will only visually shield the mussels. One more marginal cost to the environment will be the shading effect on the bottom flora, i.e. the reduction of light under the kelp aquaculture site. However, the effect is estimated to be almost irrelevant because photosynthetic organisms are rarely found in those depth in the area and because the added coverage would also only be concentrated on a small area of a maximum of 0.00225km$^2$.

Another marginal cost of protecting a mussel farm from duck predation is a potential increase in pseudofeces sedimentation, produced by the mussels, which could affect the benthic communities located under the farm. As found in a study in Ireland, the resulting effects could be concentrated in a relatively small area, but the input of nutrient rich sediments could alter the composition of the seabed (Chamberlain et al., 2001). Finally, contaminant in the water column could also be bioamplified by blue mussels and cause harm to predators that feed on them such as surf scoters (Bendell, 2011)

Regarding the marginal benefits, a better and more stable production of mussels in the area is projected to reinforce the market of the region and possibly keep employers from potentially more environmentally damaging activities (fishing, carnivorous finfish aquaculture). Also, since more mussels could survive the duck migration, the concentration of dissolved inorganic nitrogen in the area of the farm may decrease, which could be beneficial in the case of other area where eutrophicated coastal waters can be found. In Sweden for example, Haamer (1996) has shown that the introduction
of farmed mussels covering a small area of a eutrophied fjord (less than 2%) could reduce the eutrophication level of the surface water by lowering the concentration of dissolved inorganic nitrogen (DIN) by 20%.

Regarding the kelp, *S. latissima* is also considered as an extractive species since it efficiently absorbs and sequesters CO₂ and dissolved mineral phosphorous and nitrogen compounds from the seawater. A good example of this extractive effect was demonstrated in the Integrated Multi Trophic Aquaculture experiment in northwest Scotland where *S. latissima* was found to decrease up to 5% of the waste nitrogen in the water column (Sanderson, 2012). In that situation, the pollution from agricultural runoff such as an excess of phosphorus and nitrogen could be used by the seaweed production, which could also represent a circular economy model for those polluted regions.

Finally, because the kelp shield technique involve no noise pollution (firing blank, boat chase, electronic playback system, gas cannon), no visual pollution (fireworks, laser, flashing light) and no air pollution (boat chase), the externalities are expected to be much less to the surrounding population thus preserving the ecosystem and fostering social acceptance (Whiteley, 2000). In conclusion, it is hazardous to try to affirm if such enterprise would reach a Pareto optimal since it is hard to put a monetary cost to a reduction of light penetration, increase in pseudofeces or a decrease in DIN. However, the overall negative impact of this enterprise tends be minimal while potentially providing considerable benefit to the area.

**1.10.1 The impact on duck communities**

Duck predation tends to cause severe impact in small communities that often are already struggling with employment, as it is the case in Canada. Little interest so far has been given on the stress inflicted on duck and their possible impact. Notwithstanding, migrating birds and specifically *Anatidae* have a special status around the world and Canada does not make the exception (Environment and Climate Change Canada, 2017). They are protected on 2 different levels: on the Federal legislation, it is under the Migratory Birds Convention Act (Act, E. P.,1994), and under Provincial governance by the Act Respecting the Conservation and Development of Wildlife (Act C-61.1, 2007). Diving ducks are specifically included in Article 1 of the Migratory Birds Convention (Act, E. P.,1994) as amended by the 1995 protocol. In article 5.5(1)
it is specified «that no person or vessel shall deposit a substance that is harmful to migratory birds (...) in waters or an area frequented by migratory birds» (Act, E. P., 1994).

To be allowed to use scaring technique such as active repellent, farmer must subscribed and follow the Canadian Wildlife Service (CWS) policy for the issuance of scare permits for the quaculture industry. There is no permit that allows specifically the killing of ducks predating on mussels (CWS, 2000). Nevertheless, there is a provision in the law in the section 24(1) providing the right to any person without a permit to scare birds, without an aircraft or firearm, that are or likely to cause damage to crops or other property. To be able to use aircraft and or firearm, the applicant should ask a permit under the section 24(2) to the chief game officer of the province. While it is permitted under certain circumstance to use firearms, it is under the article 24 (3) usually forbidden to kill, wound or take migratory birds on the exception prescribed in the section 26(1) when a game officer issue to a person who owns leases or manages an area of land where damage is being caused by migratory birds. In the later part, it is important to stress the word “land”, because under the section 27(b), it is also specified that no person should discharge a firearm within 50 meters of any water area, which is complicated to be translated to sea farming.

Many of the deterrent techniques may directly or indirectly cause stress to those birds and losses of energy which may reduce their fitness, especially when they are migrating. When birds are actively chased or scared, energy is lost into the process of escaping (Wingfield et al., 1997). As they always have to be on guard, it is hypothesised that, during their migration breaks, they would not recover their energy as they would if there was no disturbance from humans activities. Finally, by the risk of being entangled or directly killed in some cases, collateral deaths of endangered species could pose a serious risk for the whole ecosystem diversity. A passive deterrent that would not cause any additional stress and potential of entanglement would then be a great improvement on the one already used.
1.11 Aim and objective

To tentatively respond to the problem of duck predation on the cultivated mussels, in the present project, *S. Latissima* was cultivated above the *M. edulis* culture lines so that kelp would act as a visual shield for the birds. Because diving ducks are believed to be visual predators, these long kelp are expected to provide the necessary protection without adding any direct stress to the ducks. Mussel lines without kelp and mussel lines with artificial kelp made from geotextile were also used as control treatments.

The idea has grown out from empirical observations from George Mamelonet, a local diver who repeatedly reported that he was observing more wild mussels on the sea bottom in the vicinity of kelp beds than on barren rocky bottoms. It was therefore hypothesized that kelp beds may either hide the mussels from the birds or disturb the foraging birds when kelp blades are moving with the currents. After further analysis in the literature and discussion with an avairy biologist specialized in diving duck behavior, also working in the Cascapedia Bay, it has been concluded that even though some ducks have been observed to feed under kelp during her study, the presence of a new structure and the movement of the kelp over the mussels might decrease the predation of the ducks on *M. edulis*. The projet was therefore set up as a proof of concept for these hypothesis.

The present project will also be the first multi-trophic aquaculture attempt in Québec where different species are cultivated on the same aquaculture longline. Even if this type of system to reduce duck predation is a new avenue in the literature, cohabitation of the two species has already been studied in the Baltic Sea with promising results (Rößner, 2013) and with relatively similar species (Langdon et al., 2004). A structure inspired by Rößner protocol will be developed and further on explained in the methods section. It is believed that by their nature, the mussel and kelp introduced together might benefit from their proximity. Accordingly, the mussel might benefit from an environnement more concentrated in O2, a more stable pH and a particular source of organic matter from the kelp blade. The kelp might in return benefit from an environment more concentrated in CO2 and less turbid. However, a special interest would have to be given to the possible negative impact of the blade hitting the mussel, and the increased of substrate for biofoulant and parasite.
To test our structure design, three questions are proposed with Popperian non-directional hypothesis.

1) The first research question, to be tested between November 2016 and April 2017, in Cascapedia Bay, is how *M. edulis* production (kg\(\cdot\)m\(^{-1}\)) would be affected by the proximity of *S. latissima* and an artificial kelp line made of geotextile in this polyculture system?

2) The second research question to be tested between November 2016 and June 2017, in Cascapedia Bay, is how a co-culture of *M. edulis* with a cover of *S. latissima* and an artificial kelp line made of geotextile will affect duck’s mussel consumption of blue mussel spat on the studied floating lines systems as determined with (nb \(\cdot\)m\(^{-1}\)) and (wet kg\(\cdot\)m\(^{-1}\))? 

3) The third research question, also to be tested between November 2016 and June 2017, in Cascapedia Bay, is will the resulting *M. edulis* physiology, to be quantified by the analysis of an average of 30 representative mussel lengths (mm) per 10 m replicate, be different when a *S. latissima* cover or an artificial kelp line made of geotextile is present?

Following positive outcomes, it could become a stepping stone to lead to a safer polyculture model as an alternative to the more risky monoculture production and perhaps contribute to reach the full productive potential of the Bay. As studied before, seaweed based aquaculture not only makes economics sense by their extractive character, but also constitute an essential element in coastal zone management (Neori *et al.*, 2004).
2 Material and methods

2.1 Location of the experimental site

The experimentation took place in a private mussel farm, La Ferme Maricole du Grand Large, 3km away from the shore, in front of the city of Maria, near Carleton (figure 15). This site is a bay with many rivers, the closest of large scale being the Caslapedia river by Gesgapegiag. The whole bay is of shallow depth (~50m) and the widest part is 50km wide, between Bathurst and New Carlisle (Smith, 2017). The area where the line are anchored have mostly between 20-30m of depth. The farm have 84 lines of 160 meters and they have an estimated potential of production of 5000 kg each (Bilodeau et al., 2008).

Preliminary tests have already been started in the previous years to verify that the site is suitable for S. latissima culture, with harvest showing variable results, but showing good potential (Gendron et al., 2007; Gendron & Tamigneaux, 2008; Gendron et al., 2010). Each of the three experimental longlines (51, 31 and 21) was 160 meters long and each longline was 30m away.
from the next one. The position of the western end of each line was recorded using a GPS (table 1). The layout of each experimental treatment on those lines is illustrated in figure 16. The line 41, currently used for another experimental project was secured as a negative control. On this line no treatment is in place, only the u-shape mussel spat collectors are present, without any repellent.

The duck observation point was located on-shore, in a motel parking lot, and was the closest point on the shore to the experimental line, providing an about 10 meter high elevation and offering a good panoramic view.

*Table 1. Geographic position of the experimental longlines and of the onshore observation point*

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<thead>
<tr>
<th>Line</th>
<th>Geographic position</th>
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<tr>
<td>Line 21</td>
<td>48° 7' 0.22&quot;N, 66° 0'00.86&quot;W</td>
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<tr>
<td>Line 31</td>
<td>48° 7' 0.54&quot;N, 66° 0'00.92&quot;W</td>
</tr>
<tr>
<td>Line 51</td>
<td>48° 7' 0.94&quot;N, 66° 0'01.29&quot;W</td>
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<tr>
<td>On shore observation point</td>
<td>48° 7'56.76&quot;N, 66° 1'57.26&quot;W</td>
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*Figure 16. Layout of the experimental longlines on the marine farm and of the experimental treatments on the longlines.*
Table 2 Calendar of the experiment

<table>
<thead>
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<th>September 2016</th>
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<td>Final data collection</td>
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<td>Mature S.</td>
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<td>Ducks observation</td>
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<td>Initial data</td>
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<td></td>
<td></td>
<td></td>
<td>collection</td>
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</table>

2.2 Collection of mussel spat

For the collection of mussel spat, the fuzzy polypropylene rope were suspended on the site in July 2016. The fuzzy rope were attached to the main line each 20m. The fuzzy ropes were placed in the u shape position.

2.3 Pre-culture of S. latissima in the marine hatchery

The kelp plantlets were produced in a local private marine hatchery (Fermes Marines du Québec) using the Korean technique described in Tamigneaux et al. (2013).

Following reception and cleaning of the blades in the marine hatchery, the distal portion of the sporophyte were kept for several weeks in tanks where the temperature and photoperiod were adjusted in order to artificially stimulate sporogenesis. The collectors or spools are made from a twine length (nylon) enrolled around a PVC pipe (Werner & Dring, 2011). The young kelps were cultivated on thirty meter long braided nylon twine, 2mm diam., which were enrolled

Figure 17. S. latissima gametophytes on nylon rope (100X) and spools covered with S.latissima plantlets. On the left, picture of the gametophyte in free living solution (100X). On the right, kelp spools covered in plantlets ready to be transfered at sea.
around 30cm height PVC pipes called spools (Figure 17). The collectors were put directly in contact with the swimming spores for direct fixation and germination of the spore on the twine.

Once the twine on the spools were seeded with kelp spores, the spools were transferred in small aquaria and cultivated for 6 weeks (figure 17). The tanks were filled with natural seawater, filtered at 0.1µm and UV sterilised, and enriched with the addition of Guillard’s f/2 (F/2 algae food : www.fritzpet.com). Germanium dioxide and Kanamycine solutions were also added to the culture medium as biocides to prevent any undesired competition by microalgae. The culture solution was entirely renewed once per week. The light intensity above the tanks and the air bubbling in the tanks were progressively increased until the ouplanting at sea. During this pre-culture period in the hatchery, the density, length and appearance of the plantlets on the spools were followed closely once per week using a Leica DMIL led inverted microscope with an Infinity 1 microscope camera. When the plantlets reached an adequate length (1-5mm), they were transported by road to the marine farm in a specially designed cooler box.

Concerning the sugar kelp collector quality, the average length of the plantlet and the overall aspect of the collectors (colors, patchiness, uniformly distributed) were assessed visually using a microscope (Leica Microsystems CMS) at the hatchery stage.

2.4 Artificial kelp confection

The artificial kelp line were all prepared in Grande-Rivière to accelerate the launching at sea. The geotextile rolls of 3.81m x 109.72m of black polypropylene, ≈2mm thick, were cut into 25cm width to a length of 5m. Using a 15cm splicing wand, the strip of geotextile was passed through the strands of the rope and knotted in the middle offering two strip of ≈2.5m on each side. One double strip would then be installed every 25cm on the rope. A regular working knife was used to cut the geotextile without any difficulties. The textile where attached to tens meters 0.95cm thick ropes to facilitate the transport. Each rope with the geotextile attached was carefully rolled into individual garbage bag.

2.5 Design of the kelp-mussel polyculture longline

A structure model inspired by Rößner with some modifications to the protocol (2013) was proposed to the producer during a meeting in August 2016. The modifications were mainly related to the upscaling of the model and the translation of it into a 2 dimension setting instead of a 3 dimension structure, as tried by Rößner. To limit the negative effects experienced by
Rößner’s previous experiment, a flexible vertical buffer distance of 1.5m between the mussels and the kelp was designed for the winter. In spring, the design allowed to unfold the rope allowing the vertical buffer distance to be increased to 3m following the algae growth. With this design and by using the already existing mussel floating lines, buoys and anchors, new investment on material were kept to the minimum. The only new material on the site was a 0.95cm diam., 480m long twisted polypropylene rope carrying the braided nylon twine and the artificial kelp. Extra buoys were also added to the original structure to insure that the system was kept afloat even with the artificial kelp increasing the weight and drag. The whole structure design is illustrated in figure 18. The lines each measured 160m and were anchored by 0.5 tons cement blocks. The mussel line were recorded at 8m on the launching and the kelp line at 6.5m depth. The kelp lines were lifted at 5m following April data collection.
Figure 18. Experimental layout of *S. latissima* culture lines above the *M. edulis* longlines. A) Line 21; B) line 31 and C) line 51.
2.6 Transfert of the kelp plantlets to the marine farm

On November 14, the kelp spools and the artificial kelp lines were transported by road from the marine hatchery in Newport to Carleton harbour (2.5h driving) and then by boat from Carleton harbour to the mussel farm in Cascapedia bay (1h sailing). The kelp spools were transported in cooler boxes with ice packs. The boxes were modified to reduce the possibility of friction between spools and a wet textile was put on top of the spools to keep a high level of humidity in the coolers. Every hour, the spools were sprayed with cold saltwater to keep them wet.

Once on the mussel farm, the twines carrying the kelp plantlets were unrolled from the spools and wrapped around twisted polypropylene 0.95cm diam. carrying rope with a spiralling movement so that the distance between each loop of the twine on the carrying rope was 20cm. Thin metals clips were inserted every 1 meter to keep the kelp culture twine tightly attached to the carrying rope. The technique is illustrated in figure 19. The 10m long ropes with the artificial kelp were tied together beforehand on the boat and attached directly between buoys as the core line (Figure 20).

![Figure 19. Installation of the kelp culture twine on the carrying rope, above the mussel culture longline](image)
2.7 Sample collection

On the 21st of April 2017, the project team went to the mussel farm to verify if the culture longlines were intact after the winter storms. On that day, preliminary samples (before the arrival of the ducks), were taken and analysed.

For the mussel and kelp data collection, each of them were separated in 16 replications of 10 meters (Appendix B). On each of the line 21 and 31, 8 replications of the co-culture and the artificial kelp treatment were present. On each replications, 3 samples of 10cm of mussel on the top of the U shaped loop were taken and put into a specifically assigned bag. The position on the replicate where the samples were taken have been beforehand determined using the randomization function in Excel 2013. On the site, the line was lifted on the boat with a crane and put onto the star wheels (figure 21). The lines were then rolled on the two star wheels and
measured using a specifically annotated rope to visualize the different position on the 10 meter sample. Kelp samples were randomly selected on two 25 cm strips using the same function in Excel but no kelp were present on those. Two sample of artificial kelp were also took.

On the 7th of June, the mussel samples were taken when mussels were present, which was only on a few randomly selected area on the polyculture lines. On each replication, the three 10cm samples were taken using a mussel box as illustrated in figure 22B. The samples were bagged and tagged and put in the cooler. Kelp samples were randomly selected on two 25cm strips of the three experimental lines (21, 31, 51). All remaining artificial kelp were removed from the longlines in June in order to avoid that mussel spat fixation occur on the geotextile during autumn.

Figure. 22. Initial data collection, April 2017. A) Mussel line being pulled on board. B) The mussel box C) The artificial kelp D) the kelp line
2.8 Environmental condition

Concerning the environmental conditions on the marine farm, vertical profiles of temperature and salinity from the surface to 15 meters deep were recorded using a Multi-parameter Water Quality Sonde (YSI-6600). Measurements were made at 50cm intervals between the surface and 2m depth, and at 1m intervals from 2m depth to 15m depth. The turbidity was measured using a 15cm Secchi disk. Three profiles were achieved in November, April and June. A set of Hobo temperature data logger (H08-001-02) was also collecting data every hours during the whole experiment.

2.9 Laboratory measurements

All the kelp and mussel biomass measurements were performed at the laboratory the day of the sampling, in order to limit weight losses due to desiccation. The analysis of the mussel is shown in figure 23.

![Figure 23. Analysis of the data collected: A) The mussel are being washed. B) Mussel sample ready to analysis. C) The mussels are being measured. D) The sample are weighted.](image)

The mussel samples were briefly washed, filtered on a mesh and sorted from the biofouling. The analysis performed on blue mussels were the wet biomass (g/10cm) of sample ≥ 1g to limit the high variation in the smaller sample due to residual water, the abundance (nb of mussel
>10mm per 10cm) and the average length (mm) observed in each sample. These measurements were recorded before and after the ducks predation period (21st April and 7th June). The biomasses were measured with a digital analytical balance (Mettler AE160) with a precision of 0.1mg. The lengths of the mussel shells were measured using a vernier caliper with a precision of 0.1mm.

For the kelp analysis, densities of kelp (nb of kelp >5cm per linear meter of longline) was analysed on site. The kelp length was measured using a measuring tape. Their weight (wet g m⁻¹) were measured at the laboratory using a digital analytical balance (Mettler AE160) with a precision of 0.1mg. The overall aspect (% of coverage of epiphyte per blade) was also assessed at the laboratory.

### 2.10 Duck observation

Regular observations were scheduled between the 15th April and the 6th of June to collect data on the migrating ducks. The time of the period of observation were determined using observer on site to precisely concur with their arrival in the bay. The arrival of the flock scout was used as a starting point. The frequency then varied with one per week until the flock arrived, then it changed to one every two days to finally go back to once per week when the abundance of duck drastically declined. The abundances were observed through a bird watching telescope.

![Ducks observation three horizon’s (15°, 30°, 60°) (Google Earth, 2017)](image)
(Vortex Sandpiper 15-45-65mm angled spotting scope stokes birding series) using different degree in the horizon \(60^\circ,30^\circ,15^\circ\) in the direction of the line from one fixed point located at \(48^\circ 7'56.76"N, 66^\circ 1'57.26"W\) (figure 24). The protocol was similar to the one used in the studies of Varennes (2015), which was presented during the duck observation workshop given by the author to the student in charge of the observation. An example of the form to fill following observation can be found in Appendix E.

### 2.11 Statistical analysis

To further analyse the data, and assess any significant differences between the different treatments, standard tests were performed using the R environment (3.4.1). The observations of amounts, biomasses and length were measured in interval data and the independent variable, the presence or absence of the living kelp and artificial kelp, was recorded as nominal data. Data were transcribed in a .csv file and opened with the R environment. As a first step, a box plot analysis was performed to visualise the data. Then, the distribution was analysed with a Shapiro Wilk test to be followed by a variance analysis, either an F test or a Fligner-Killeen test depending on the situation. The Welch two samples analysis was performed to assess any significant difference on the weight, amount and length of the sample between the polyculture treatment and the artificial kelp treatment because of the inequalities in group size due to the loss of one artificial kelp replicate. A Welch two samples analysis was also performed on the data recovered from the June outing to assess any significant differences with the same variable between both treatments. Finally, to assess if there were any multivariate correlation variance between the two treatments, four different MANOVA (Hotelling-Lawley, Roy, Pillai, Wilks) were accomplished.
3 Results

3.1 Presence and behaviour of the ducks

A total of 15 observations were performed and in all of them *Melanitta perspicillata* was the dominant species. The first observation happened on the 15th April, on that day, only 10 ducks were seen. Between the 21st of April and the 26th of April, the number increased rapidly from 350 to 825. The numbers then stayed high until the 4th of May and began to decrease from the 6th of May to the 2nd of June. On the 6th of June, no birds were seen on the site. The highest

![Figure 25. Number of Melanitta perspicillata observed from the shore during horizontal screening in the surrounding (~500m) of the mussel line. The red line represent the 60° horizon, the blue line the 30° and the green one the 15° centered horizon.](image)
number of ducks observed (825 individuals) was observed on the 26-04-2017. On the figure 25, it appears that the difference between the 3 horizons observations (figure 24) did not follow any linear correlation i.e. there should be 4 times more birds in the 60° horizon than in the 15° horizon. This suggests that the ducks tended to stay around the culture line instead of around the site.

The results of the daily identification are shown on table 3. The duck flock hanging around the site was not found to be really diverse, *M. Perspicillata* being the dominant species every day. The second species in importance was *Morus bassanus*, appearing in 21% of the observations and the last one was *Clangula hyemalis* which was present in 7% of the observation. It is important to specify that of the two last species, only *C. hyemalis* is molluscivore.

**Table 3. Other avians organisms observed on the site in minor abundance.**

<table>
<thead>
<tr>
<th>Common name</th>
<th>Species</th>
<th>Percentage of occurance</th>
<th>Alimentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surf scoter</td>
<td><em>Melanitta perspicillata</em></td>
<td>100</td>
<td>Bivalves</td>
</tr>
<tr>
<td>Northern garnet</td>
<td><em>Morus bassanus</em></td>
<td>21</td>
<td>Mainly fish</td>
</tr>
<tr>
<td>Long tailed duck</td>
<td><em>Clangula hyemalis</em></td>
<td>7</td>
<td>Bivalves</td>
</tr>
</tbody>
</table>

**Figure 26. Melanitta perspicillata behavior observed on the mussel farm during on-shore telescope observation (n= 15 )**
Regarding the behavior observed, in 100% of the observation, the ducks were seen in flight (figure 26). On 92.9% of the observation, the ducks were also seen resting and on 64.3% of the observation the ducks were seen feeding on the mussel lines. From the 26th of April to the 4th of May when the ducks were in their highest abundance, they were seen actively feeding. As of the distribution (Fig. 21), the ducks were randomly distributed in 92.9% of the observations and in small group in 71.4% of the observations.

![Distribution Pattern](image)

*Figure 27. Melanitta perspicillata distribution observed during on-shore telescope observation (n=15)*

### 3.2 S. latissima results

#### 3.2.1 Wet biomass

Due to the paucity of the samples collected, there were not enough data to run statistical analysis. The average wet weight per line varied between 2.44g/25cm (n=2) and 8.95g/25cm (n = 2). The difference in yields between the lines, shown in table 4, can only be considered as anecdotal.
Table 4. Wet biomass of S. latissima samples collected on June 7

<table>
<thead>
<tr>
<th>Line 21 (g/25cm)</th>
<th>Line 31 (g/25cm)</th>
<th>Line 51 (g/25cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.95</td>
<td>7.56</td>
<td>2.44</td>
</tr>
</tbody>
</table>

3.2.2 Lengths

The average length, from the holdfast to the distal end of the blade, were 21.2 cm (± 10.9; n = 5), 17.3 cm (± 6.4; n = 5) and 13.8 cm (± 3.3; n = 7) respectively for the line 21, 31 and 51 (table 5).

Table 5. Average length of S. latissima individuals sampled on June 7

<table>
<thead>
<tr>
<th>Line</th>
<th>Average length cm</th>
<th>Standard deviation cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>21.2</td>
<td>10.9</td>
</tr>
<tr>
<td>31</td>
<td>17.3</td>
<td>6.4</td>
</tr>
<tr>
<td>51</td>
<td>13.8</td>
<td>3.3</td>
</tr>
</tbody>
</table>

3.2.3 Visual aspect

No macroscopic epiphytes were found on any of the living kelp sampled. The kelp were in good shape with a slight pale green color (figure 28).
Figure 28. Saccharina latissima samples collected on June 7. Each picture gather the kelp collected on 2 x 25cm of the culture line. A) line 21. B) line 31. C) line 51.
3.3 Artificial kelp

No macroscopic epiphytes were found on the artificial kelp sampled in April. In June, a few starfishes and some commercial size (50mm) blue mussels were found on the artificial kelp. The geotextile seemed undamaged and the edge of the textile were unworn. Only one section of the artificial kelp line detached from the structure (16th sample of line 31).

3.4 Mytilus edulis results

The results of the mussels lines were collected on the line 21 and 31 on both occasions and on line 51 for the final data collection. The mussels on line 41, the negative control were not collected.

3.4.1 Wet biomass

During the initial sampling on April 21, there were an average of 92.33g (±50.34g; n=45) of mussels (meat + shell) per 10cm under the artificial kelp line and 128.86g (±79.20g; n=48) of mussel per 10cm under the living kelp line. The data was found to have a normal distribution and an homogenous variance, following a Shapiro Wilk test and an F test.

During the final sampling on June 7, there was an average of 7.21g of mussels (±8.19g; n=45) per 10cm under the artificial kelp treatment and 1.89g of mussel (±2.72g; n=48) per 10cm under the living kelp line. The distribution of the data was not normal but the variance was found homogenous following a Shapiro Wilk test and a Fligner-Killeen test.

Between these two sampling, the wet biomass of the mussels decreased by 92.18% under the artificial kelp line treatment and by 98.53% under the living kelp line.

3.4.2 Lengths

During the initial sampling on April 21, the length of the mussels ≥ 1cm were on average 14.41mm (±6.12mm; n=45) under the artificial kelp line and 17.23mm (±2.09mm; n=48) under the living kelp line. The data were found to have a normal distribution and an homogenous variance following a Shapiro Wilk test and an F test.
During the final sampling on June 7, the length of the mussels ≥ 1cm were on average 21.97mm (±11.25mm; n=30) under the artificial kelp line and 14.66mm (±3.24mm; n=30) under the living kelp line. The distribution of the data was not normal but the variance was found homogenous following a Shapiro Wilk test and a Welch t-test.

Between these two samplings, the average length of the mussels increased by 52.50% under the artificial kelp line and decrease of 14.91% under the living kelp line.

### 3.4.3 Abundance

During the initial sampling on April 21, there was an average of 102.7 mussels (±56.4; n=45) ≥1cm per 10cm of culture line, under the artificial kelp, and 122.1 mussels (±61.1; n=48) under the living kelp. The data were found to have a normal distribution and an homogenous variance following a Shapiro Wilk test and an F test.

During the final sampling on June 7, there was an average of 3.7 mussels (±4.1; n=45) ≥1cm per 10cm of culture line, under the artificial kelp, and 2.08 mussels (±2.9; n=48) under the living kelp. The data was not found to show normal distribution and shows homogenous variance following a Shapiro Wilk test and a Welch t-test.

Between the two sampling, the number of mussel decrease by 96.21% under the artificial kelp and by 98.3% under the living kelp.

### 3.5 Interaction between *Mytilus edulis* and the treatments

To analyse the relation of the mussel biomasses, lengths and numbers between the treatments, two mean analysis were performed for each variable. A visual example of the difference in mussel abundance before and after ducks passing on a living kelp line is shown in figure 29. A Welch two sample t-test analysis was performed in all case. Four different types of MANOVA (Hotelling-Lawley, Roy, Pillai, Wilks) were also performed. The detailed results sheet obtained with R is shown in Appendix C-D.
3.5.1 Relation between mussel biomass and treatments

No significant differences in the mussel wet biomass were found between the two treatments before the ducks arrived (p=0.1798, confidence level of 95%). A significant difference was found in June, following the ducks departure (p=0.02003, confidence level of 95%). Boxplot analysis are shown in figure 30.

Table 6. Mussel biomass before and after predation

<table>
<thead>
<tr>
<th></th>
<th>Biomass per treatment</th>
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<tr>
<td></td>
<td>Living kelp</td>
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<tr>
<td>(gr/10cm)</td>
<td></td>
</tr>
<tr>
<td><strong>Before ducks</strong></td>
<td></td>
</tr>
<tr>
<td>Average weight</td>
<td>128.86</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>79.21</td>
</tr>
<tr>
<td><strong>After ducks</strong></td>
<td></td>
</tr>
<tr>
<td>Average weight</td>
<td>1.89</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>2.72</td>
</tr>
</tbody>
</table>

3.5.2 Relation between mussel length and treatments

No significant differences in mussel lengths were found between the two treatments before the ducks arrived (p=0.2086; confidence level of 95%). No significant difference was found in June, following the ducks departure (p=0.064; confidence level of 95%). Boxplot analysis are shown in figure 31.
Table 7. Mussel length before and after predation

<table>
<thead>
<tr>
<th></th>
<th>Living kelp</th>
<th>Artificial kelp</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length per treatment (mm)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Before ducks</strong></td>
<td>Average length</td>
<td>17.23</td>
</tr>
<tr>
<td></td>
<td>Standard deviation</td>
<td>2.094</td>
</tr>
<tr>
<td><strong>After ducks</strong></td>
<td>Average length</td>
<td>14.66</td>
</tr>
<tr>
<td></td>
<td>Standard deviation</td>
<td>3.24</td>
</tr>
</tbody>
</table>

3.5.3 Relation between mussel abundance and treatments

No significant difference were in mussel abundance was found between the two treatments before the ducks arrived (p=0.4485; confidence level of 95%). No significant difference was found in June, following the ducks departure (p=0.1529, confidence level of 95%). Boxplot analysis are shown below in figure 32.

Table 8. Mussel abundance before and after predation

<table>
<thead>
<tr>
<th></th>
<th>Abundance per treatment (nb/10 cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Before ducks</strong></td>
<td>Living kelp</td>
</tr>
<tr>
<td>Average abundance</td>
<td>122.10</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>61.14</td>
</tr>
<tr>
<td><strong>After ducks</strong></td>
<td>Average abundance</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>2.89</td>
</tr>
</tbody>
</table>

3.5.4 Relation between the treatments and all the variables

No significant difference was found between the two treatments and the weight, number and length before the ducks arrived (p=0.1778; confidence level of 95%) in all of the four MANOVA test used. No significant difference was also found with the final results, sampled in June, following the ducks departure (p=0.05256, confidence level of 95%).
Figure 30. Boxplot analysis of the weight of mussels under the two experimental treatments using the R environment 3.4.0 (R, 2017)
Figure 31. Boxplot analysis of the shell length of mussels >1cm under the two experimental treatments using the R environment 3.4.0 (R, 2017)
Figure 32. Boxplot analysis of the abundance of mussels >1cm under the two experimental treatments using the R environment 3.4.0 (R, 2017)
Figure 33. Duck predation on blue mussels under the two experimental treatments. (AK: Artificial kelp, LK: Living Kelp). A) Weight B) Length C) Abundance
3.6 Vertical profile of the water column

The results of the three vertical profiles achieved on the site are shown in figure 34. The graphic analysis of the temperature trend observed during the 7 months is illustrated in figure 35.

The launching (14th November 2016) (figure 34A):

The temperature was relatively constant with a range between 5.76 and 6.75°C. The salinity was also quite constant with a slight increase in deeper levels (27.76-29.95). The depth of disappearance of the Secchi disk was 8.5m.

The initial data collection, before ducks arrival (21st April 2017) (figure 34B):

The temperature decreased with depth from 2.70 to 0.13°C. The salinity was quite constant with a slight increase in deeper levels (26.36-29.51). The depth of disappearance of the Secchi disk was 3.8m.

The final harvest, after ducks departure (7th June 2017) (figure 34C):

The temperature decreased rapidly with depth from 13.11 to 4.39°C, showed a thermocline between 9 and 14m. The salinity also varied greatly with a constant increase in deeper levels (20.35-27.40). The depth of disappearance of the Secchi disk was 6.5m.

*Table 9. Evolution of water transparency on the mussel farm, measured with a Secchi disk.*

<table>
<thead>
<tr>
<th>Depth of disappearance of the Secchi disk</th>
<th>14th November 2016</th>
<th>21st April 2017</th>
<th>7th June 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.5m</td>
<td>3.8m</td>
<td>6.5m</td>
<td></td>
</tr>
</tbody>
</table>
Figure 34. Thermal and saline vertical profiles at the experimental site. A) 14th November 2016, B) 21st April and C) 7th June.
Figure 35. Temperature at the experiment site from November 10, 2016 to May 24, 2017
4 Discussion

4.1 Duck foraging on the cultivated mussels

A crucial variable that had to be validated before the mussels and kelp analysis could be done was the presence of ducks foraging on the mussels cultivated on the experimental longlines. The protocol used to assess the presence and the behaviors of the ducks was discussed with Dr. Élisabeth Varennes, a scientist well known in mussels predation and ducks ecology in Québec who used to work in the same area.

The presence on-site of many observers (colleagues, captain of the boat, other scientists living around the site) and our own intern eased the organisation and choice of the first data collection date. With those in place, it was made possible for us to take measurements only 3 days before the ducks arrival, in order to assess the initial variations in mussel biomass, shell length and mussel numbers, without the effect of the spring migration. The final sampling was planned less than a week after the ducks flock left, to minimize the noise in data due to natural mortality.

The highest number of ducks observed (825) (figure 25) on the experimental site has been following similar trends accepted as sufficient to validate a test on duck predation in the literature. Previously, the effect have been observed in the past with 24 ducks (Dunthom, 1971), 200-300 (Ross & Furness, 2000) and in Prince Edward Island with 2000 birds (Dionne, 2004). The main species observed on the mussel farm was *Melanitta perspicillata*. (table 3), a molluscivore duck that is considered as one the main predator of cultivated mussels in estern Canada.

Also, the fact that a 98% decrease (figure 33A) in mussel biomass was observed on the unprotected experimental lines (Figure 29) confirmed that the mussels on those lines, as observed with binocular, where foraged by the ducks. Consequently, it was considered that the predation part of this experiment could be validated and the data analyzed as initially planned.

4.2 Changes in the scope of the study

This experiment was initially designed and carried out as a proof of concept to observe the effect of a kelp and mussel co-culture on the survival rate of mussels and on multiple
variables on both species. After 5 months at sea, the sugar kelp final biomass was abnormally low (25.3g ± 20.3g•m⁻¹) (table 4) with a wet weight more than 100 times lower than the biomass previously obtained in the same area 3354.3 ± 643.7g•m⁻¹ (Gendron et al., 2010). The seaweed density on the rope and their length was also abnormally low with only 1 to 2 individuals per 25cm of rope and no individual greater than 10cm length in April.

In light of this low growth and survival rate of the kelp plantlets on the experimental lines, where the biomasses were even lower than the one found where natural biofouling occurs (Braithwaite et al., 2007), the line previously considered as the living kelp treatment were thereafter considered as an unprotected mussel line and used as a negative control. The artificial kelp line will be used as a proof of concept to assess if a cover similar to a living kelp line over the mussel has an effect on the foraging behavior of the ducks and on the survival rate of the mussels. The line 41, was cast out of the analysis due to protocol uncertainty caused by the presence of two different research team and replaced for analysis by the living kelp line. Only the part of the research question on the artificial kelp would be discussed further on.

### 4.3 Kelp growth on the marine farm

On the seaweed component of the experiment, kelp biomass was very low as shown in table 4. There are many reasons that could explain this absence of growth but the ones related to the physico-chemical characteristics of the seawater on the mussel farm should be ruled out as previous and current culture trials of kelp on the same mussel farm have been conducted with

![Figure 36. Artificial kelp and S. latissima at the final harvest, 7th June 2017. On the left, the artificial kelp being towed away from the line. On the left, the sugar kelp line being pulled aboard for analysis.](image-url)
success, with a yield of around $3.35 \pm 0.64$ kg m$^{-1}$ (Gendron et al., 2010) for a similar time frame (November-June). Other kelp lines less than 100m away from the experimental lines had also a significantly higher biomass with an average of $3.97 \pm 0.97$ kg m$^{-1}$ (Anonymous) recorded in June 2017. Accordingly, other variables i.e. the light intensity, the salinity, the temperature, the O$_2$ level and DIN could also all be set aside as other lines have succeeded in the same area and year.

Among the parameters that could have played a role in the low growth of the kelp in this study, the most probable are: the late outplanting of the kelp plantlets, on November 14, 2016, the geographical origin of the kelp blades providing the spores used to seed the spools, the production batch in the hatchery and the modifications to the design of the culture longline.

Regarding the time of the outplanting of the kelp plantlets to the marine farm, the salinity and temperature vertical stratification (figure 34) were within the growth limits of the species with a temperature between -2-10°C (figure 35) and a salinity over 25PSU (Gendron & Tamigneaux, 2008) except on the final data collection. However, the kelp were already absent during the first data collection where the salinity was kept within the optimal. Even though, the outplanting was achieved at a time were the salinity and temperature were within the optimal, it has been advise to outplant earlier in fall when possible to allow the plantlet more growth week before the winter arrived (Gendron et al., 2010).

As mentionned by Tamigneaux et al. (2014), the kelp culture sites must be specifically selected for a specific strain in order to optimize the growth and survival rate of the seaweed. However, due to the lack of information on kelp population genetic in Québec and the absence of studies comparing the performance of kelp strains from different location, kelp farmers in Québec do not pay attention to the origin of the wild blades used to seed the spools. The commercial kelp culture lines around our experimental longlines were seeded with spores from kelp blades harvested around Bonaventure (48.033855N, -64.497175W) in Gaspésie where the kelps are found to be significantly bigger than other population around the coast. In contrast, the spools for the present study were seeded with spores from kelp blades harvested around Newport bay (48.290639N, -64.716182W), where the sugar kelp have a smaller stipe and blade compared to the one from Bonaventure. On another experimental kelp farm in Paspébiac (Québec, Canada), it was observed in June 2017 that the morphology and yields (kg m$^{-1}$ of rope) of $S. \text{latissima}$, from parent strains harvested in Newport and Bonaventure, and cultivated on the same longline,
were significantly different, with the kelp from Bonaventure having higher yields and longer stipes and blades. Therefore, the origin of the parent strain could partly explain the low kelp yields observed in the present study.

Kelp plantlets on spools were cultivated in a private marine hatchery using well tested protocols. For the need of the present project, the nylon twine on the spools were seeded following the Korean technique (seeded with spores) (figure 17), and this technique is considered to have a bigger potential to produce patchier collectors than when the spools are seeded with gametophytes (Tamigneaux et al., 2013). The plantlets were cultivated in small aquaria and their densities on the spools were regularly observed. The average length of the pantlets at the time of their transfer to the longlines on the marine farm was 2mm which is within the optimal (1-5mm). In conclusion, the spool were not optimal but according to previous results, using the Korean technique, this is unlikely to be the only reason but could have contributed to such a low density of kelp in June.

Finally the design of the co-culture longlines, with a secondary line (kelp line) floating above the main longline (mussel line) (figure 18) may have contributed to the loss of the plantlets. As explained in the introduction, the depth of the kelp line was carefully planned to reduced negative interaction, but it may not have been enough. Because the ropes between the two lines were flexibles, the two lines might have gotten intertwined, causing the sharp edge of the mussel to grate off the kelp. At the second sampling, in April, when the research team had to leave the site due to the bad weather condition, the waves were only 0.50m high and already, the two lines were seen to intertwine. Also, on the 30th December 2016 a major storm caused severe damage in the area and coastal roads and houses were damaged. This storm might have shaken and lift each lines on the other. Although, these are only speculations, and further tests should be conducted to observe the interactions of both lines and possible improvements to the structural design should be considered. A similar design is planned to be tested in Maine which would be quite interesting to follow the result.

4.4 The foraging effect on the blue mussels lines

The effect of the predation on the mussels were quite important, with a recorded mussel survival rate average of 1.7% for the living kelp treatment and 3.8% for the artificial kep
Before the ducks arrived, an analysis of mean was conducted to verify if the presence of an artificial kelp cover would affect the survival rate and morphology of the blue mussels during the winter. The artificial kelp has the potential to rip the mussel off the culture line or to chemically stress the mussels with biofouling as experienced by Rößner (2013). No significant differences in term of density, biomass and length were found between the artificial kelp treatment and the control line (aborted living kelp) (Appendix C) which seems promising for further test as the proximity of the kelp and the mussels on the same longline does not seem to have affected the mussels. However, it is important to be careful in interpreting these results as the test was not successful in observing the interaction between actual kelps and mussels. Further experiments have to be conducted.

On the mussel survival rate after the duck left the area, one could argue that the mussels density and biomass might have been different on the different lines, protected or not, since these parameters are often highly variable within the same culture line (Seed, 1969). Accordingly, a large amount of samples were taken (Appendix B) to increase the statistical power and no significant differences between the length, biomass, and number were observed in April, before the arrival of the ducks. The body condition index has not been analysed but should be included in the next experiment to investigate if the duck could have chosen the mussels based on their preference range, which is not yet completely understood (Bustnes, 1998).

In the post-predation results, in June, the biomass of mussels on the culture lines were significantly higher than in April, with a 6.3% difference in favor of the line protected by artificial kelp (figure 33A). Because there was a 2 months interval between the two observations of the weight, the mussels would have grown during this period. To reduce the effects of this variable and isolate the duck foraging effect the analysis, the general growth at this specific time of the year has been subtracted from the final weight using data and calculation formulated by Mallet and Carver (1989) on Eastern Canada blue mussel. With this correction, the gap between the two treatments increases to 7.03% in weight. The number of mussels (figure 33 B) on the lines and the shell length (figure 33 C) were significantly different between the two treatments (Appendix C). Therefore since the mussels are significantly heavier under the kelp shield, it could be the result of thicker shells and/or higher meat yields but it could not be precisely single out, since no body to shell ratio were performed.
With those results, the first part of the second research question on the survival rate have to be answered by a null effect, but the second part, on the surviving weight can be answered partially, since only the artificial kelp have been fully tested. The third research question, was also found to have no effect on the length, but once more, the question had only been theoretically tested since no significant amount of kelp grew. Finally, the multivariable analysis shows some interesting trend with a p value of $p=0.05256$ between the two treatments and all the studied variable (Appendix D). This could indicate that there is some kind of difference even though it did not reach the normally accepted limit $p \leq 0.05$ that may not always be the best fitted way to analyse correlation in ecological studies where natural noise are that important (Yoccoz, 1991). However, it is also needed to point out that these multivariables analysis can hide lower correlation of one variable with another which can lead to a type 1 error where the null hypothesis is wrongly rejected (Moran, 2003). A replication of the experiment with an even greater amount of sample would be suggested to increase the test power and potentially reduce the standard deviation and obtain normality in variance.

Finally, even though the statistical analysis shows a correlation in term of biomass, when the artificial kelp cover is present, the low numbers of surviving mussels and their length are not believed to represent a yield sufficient for a farmer (figure 37).

![Figure 37. Mussels line under artificial algae cover after the ducks departure.](image)
4.5 Future design improvement

As Environment Canada mentionned while presenting a lecture on ducks and mussel aquaculture in Prince Edward Island in 2012 (McAloney, 2012) the 15 species of sea duck that causes problems to the mussel farming industry are the least understood group of North American Waterfowl as even the natural history and population size of some species are unknown.

Consequently, it is imperative to further investigate the species that cause problems rather than focusing on their effect. Further fundamental and ecological studies such as the ones conducted by Varennes et al. (2013) should be encouraged and the results should be implemented in the management approach and on improving the existing repellent design.

In light of the results, the proof of concept was not completed and cannot be implemented in a commercial mussel production context. To fully explore the potential of this design, many improvements should be carried out on the production protocol, the timing of the experiment (table 2) and the structural design (figure 18).

Regarding the kelp culture strategy, the most recent results from culture trials by Gendron-Lemieux et al. (pers.comm., July 2017) strongly suggest that S. longicruris from Bonaventure, near Cascapedia bay, is best adapted to the cultivation in open waters, resulting in longer blades and higher culture yields than the S. latissima collected in Newport. Even if the parent strain origin of the kelp was not the primary factor explaining the poor yields, working with the best strain would surely increase the potential of the kelp curtain as visual shield (Tamigneaux et al., 2014). The use of the free living technique, where kelp gametophytes are cultivated in vitro and kept in latency in controlled environment before they are sprayed onto the culture spools, should not only help to get spools with homogeneously distributed plantlets but it should also allow to better control the culture schedule. Lastly, to increase the productivity of those collectors and reduce competition (Chopin, 2007). and predation, where only 10 of the 16 spools produced where showing enough initial density to be put at sea, further studies should be organised to clarify and reduce the effect of grazer found in Quebec hatcheries.

The distance between the kelp and the mussel line (1.5m) seems to have been appropriate. Even though there is a possibility that the absence of kelp was due to damages done by the mussel line, it is probably not because of the distance between both lines per se but rather because of
the flexibility of the separation between both lines (figure 18). To prevent the damage to the kelp, PVC pipes could be introduced around the separation lines to improve structural design. Fixed in regular intervals ≈5m, both lines could be kept separated at all time and also prevent entanglement (figure 38B). Interview with farmer would however be needed beforehand to verify the workability of those with a star wheel.

Also, because sea ducks are not only migrating in spring but also in fall, a combination of artificial and natural kelp could be tried to maximise the surface of coverage from September to June, allowing the natural kelp to grow. Spraying kelp gametophytes on a specially designed

![Figure 38. Future design improvement suggestion. A) The artificial kelp as a substrate for kelp farming. B) The PVC pipe rigid separation between both lines.](image-url)
fabric similar to the one developed by At-Sea Technology project in Belgium (European Union, 2014), would allow to have a visual shield above the mussel line from early on and would also provide a much larger culture surface than nylon ropes used, thus increasing the production yield of the kelp line (figure 38A).

To complement the proposed design, other repellents could be combined to possibly synergistically scare the ducks or hide the mussels. Other technique such as, a knotted line, as the one patented by Fréchette (2014), could be used to increase the mussel spat collection and the mussel survival rate. Preliminary trials on the same mussel farm in Cascapédia bay has shown that this knotted rope allows to increase the survival rate of the young mussels by ≈5% (Fréchette, pers.comm., June 2017). Tori lines, a colored line that physically and visually repel seabirds, similar to the ones used to reduce bird bycatch in fisheries (Yokota et al., 2011) could also be put at the surface to scare the birds away. In another context, the polyculture could possibly also be installed over isolation repellent to increase the productivity per meter exploited and perhaps help recover the cost of utilisation of these other conventional technique (figure 14).

In future attempts, the culture schedule may also be modified. The young kelp could be outplanted on the marine farm in September in order to maximise the growth potential of seaweeds (Gendron et al., 2010) but not sooner, otherwise the kelp blades could be covered by the invading bryozoa Membranipora membranacea (Gendron & Tamigneaux, 2008). The final

Figure 39. Blue mussels attached on the artificial algae
harvest could be delayed further in late June to maximise the final yield of kelp. However it should not be delayed too much in summer since, in Cascapedia bay, there is a seasonal peak of mussel larvae in the water column in July and the geotextile could collect the mussel spat (Bayne, 1965). In the present project, the mussels showed the potential to attach on the artificial kelp (figure 39).

### 4.6 Management implication

#### 4.6.1 Ecosystems based management

In an Integrated Coastal Zone Management (ICZM) approach, it is nowadays impossible to ignore the relevance of adding the aquaculture in the model (Chopin, 2012). Aquaculture can offer extractive ecosystemic services while offering many products for the area. On the kelp culture, the positive effect are widely accepted and are even believed to have the potential to be used as a mean of mitigation and adaptation against climate change (Chung et al., 2013; Duarte et al., 2005; Tamigneaux & Johnson, 2016). However, those culture and polyculture are not a one-size-fits-all scenario. To properly benefit the environment, these types of culture have to be carefully planned, located and distributed with respect to the ecosystem carrying capacity (Nunes et al., 2003).

To facilitate the introduction of those cultures that show some difficulties in the first years to be properly implemented, credit and funding should be allowed and extended. This could be through a nutrient assimilation credits (Stephenson & Shabman, 2017) or even with a specific fund created on taxes imposed to other user on a polluter payer basis. With such credit, the monetary potential would be drastically increased with an added value for sugar kelp calculated between 430 and 1600 USD$ by ha\(^{-1}\) for N extraction and between 24-400$ for C extraction (Kim, et al., 2015). A SWOT analysis demonstrating the main strength, weakness, opportunities and threats of the proposed design for future experiment is shown in the figure 40.
**Strenght**  
-Diversification of crops  
-Passive deterrent  
-Easy to operate at sea  
-Extractive effect on the environment

**Weakness**  
-Variability of growth of kelp  
-Low survival rate of mussels  
-The surviving mussels were not of commercial size  
-Vulnerability to drifting ice and debris

<table>
<thead>
<tr>
<th><strong>Opportunities</strong></th>
<th><strong>Threats</strong></th>
</tr>
</thead>
</table>
| -Upcoming market value of the kelp  
-Possibility of future introduction of phosphorus and nitrate credit market  
-Double stream of revenue when polyculture would be more understood  
-Combination with other passive deterrent | -Potential of mussel spat catchment by the kelp  
-Uncertainty on the market acceptability  
-Ducks habituation  
-Acceptability of the design by the farmer |

Figure 40. SWOT analysis of the proposed repellent

### 4.6.2 Marine spatial planning

Aquaculture is often a problem in marine spatial planning as it represents a fairly new activity in the Canadian portrait and many other actors already have historical rights on waterways. The Canadian wildlife Service have expressed some reserves about continuing to operate marine farms in sites that are already being used by ducks, and preferred the alternative solution of prospecting new sites (Lepage *et al.*, 2015). However, this is a tedious and onerous work for farmers that may already be on the verge of bankruptcy. Opening of new coastal zones to seafarming imply to carry out public consultations, to establish new zoning and sometime, to set up special legislation. In the present study, the co-culture strategy, with a seaweed culture lines on top of a mussel longline, needs no additional zoning or deviation of maritime routes as it takes place on already existing installations that had gained recent historical rights in the area.

Also, because the new longline design represents an alternative to deterrents that produce light, visual and sound pollution, it has a high potential of acceptability in the population. Further studies involving interviews and perhaps surveys, could be prepared to verify if the social acceptance would be as high as with IMTA project (Rifler *et al.*, 2007).
5 Conclusion

This proof of concept experiment was the first of its kind, where polyculture was tested as a deterrent. After 7 months at sea, the design did not work as expected with a disappointing growth of sugar kelp that is mainly believed to have been caused by the contact between the kelp and the mussel culture lines. However, the artificial kelp treatment allowed some extrapolation on the potential of a kelp cover and even though there were no difference in survival of the young mussels, the final mussel biomass per length of rope was 7.0% higher (p=0.02003, confidence level of 95%) on the mussel line under the artificial kelp line than on the unprotected mussel line. This suggests that the kelp curtain may have protected the heavier mussels that are normally in the preference range of the ducks. Since mussels are sold by weight, this may be a step in the good direction. It is also believed that a kelp culture line could easily be combined with other passive repellent and perhaps have a cumulative effect on the mussel survival rate.

One of the main problem of the Gaspesian region being the unemployment rate and demographic, polyculture may offer diversification and employment of qualified people that are difficult to retain in distant coastal towns. As of now, the management recommendation is to not use this design yet to repel ducks. Instead, the recommendation would be to promote polyculture as an economical solution for these farmers. Notwithstanding of the disappointing results showed in this study, kelp farming already is a thriving business that is growing rapidly in the area. With an expanding value of the kelp, it is possible that a normal growth could already recover a considerable part of the losses due to predation by growing them directly, or even renting the boat and lines to other enterprise with the expertise.

Additionally, it is important to present a bigger picture where - despite of the direct economic gain that this polyculture offers - it presents great potential in ecosystemic service. While ongoing political discussion are being held on carbon taxes and others nutrients capitation credits, it will be important to closely follow the results as this could engage in a management paradigm shift were the benefit of Ecosystem Based Management would then become tangible for farmers.
References


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MacDonald, B. A., Robinson, S. M., and Barrington, K. A. (2011). Feeding activity of mussels (Mytilus edulis) held in the field at an integrated multi-trophic aquaculture (IMTA) site (Salmo salar) and exposed to fish food in the laboratory. Aquaculture, 314(1), 244-251.


latissima (Linnaeus) CE Lane, C. Mayes, Druehl & GW Saunders adjacent to fish farm cages in northwest Scotland. *Aquaculture*, 354, 128-135.


## Appendix

### Appendix A

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<th>Time table</th>
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<tr>
<td>Protocol and system design</td>
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<tr>
<td>Installation of algae structure</td>
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</tbody>
</table>

*Time table of the project*
Appendix B

Welch Two Sample t-test (weight in April 2017)

data: weight by treatment t = -1.3839, df = 22.76, p-value= 0.1798

alternative hypothesis: true difference in means is not equal to 0

95 percent confidence interval: -84.74005  16.82955

sample estimates:

mean in group geo 94.75875

mean in group kelp 128.71400
Welch Two Sample t-test (amount in April 2017)
data: amount by treatment t = -0.7687, df = 27.859, p-value = 0.4485
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval: -60.14245  27.32578
sample estimates:
mean in group geo 104.7917
mean in group kelp 121.2000

Welch Two Sample t-test (Length in April 2017)
data: length by treatment t = -1.2862, df = 28.828, p-value = 0.2086
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval: -25.67228   5.85228
sample estimates:
mean in group geo 163.0167
mean in group kelp 172.9267

Welch Two Sample t-test (Weight in June 2017)
data: Weight by Treatment t = 2.6282, df = 14, p-value = 0.01985
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:  1.451196 14.327534
sample estimates:
mean in group Geo 11.912222
mean in group Kelp 4.022857
Welch Two Sample t-test (Amount in June 2017)
data:  Amount by Treatment t = 1.4678, df = 29, p-value = 0.1529
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval: -0.7348376  4.4710043
sample estimates:
mean in group Geo 3.889333
mean in group Kelp 2.021250

Welch Two Sample t-test (Length in June 2017)
data:  Length by Treatment t = 1.9734, df = 18, p-value = 0.064
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval: -4.72247 150.92447
sample estimates:
mean in group Geo 219.786
mean in group Kelp 146.685

Appendix D

MANOVA with april, before ducks data
summary(dataset_a)
treatment  weight  amount  length
treatment  weight  amount  length
treatment  weight  amount  length
treatment  weight  amount  length
treatment  weight  amount  length
geo :16  Min. :18.54  Min. :19.67  Min. :127.8
kelp:15  1st Qu.:51.22  1st Qu.:60.17  1st Qu.:150.7
      Median :111.11  Median :124.67  Median :168.2
      Mean :111.19  Mean :112.73  Mean :167.8
      3rd Qu.:145.50  3rd Qu.:152.50  3rd Qu.:185.1
      Max. :262.45  Max. :243.00  Max. :210.4
>
> mussel.manova <- manova ( cbind(weight, amount, length) ~ as.factor(treatment), data=dataset_a)
> summary(mussel.manova)

    Df Pillai approx F num Df den Df Pr(>F)
as.factor(treatment)  1 0.16389   1.7642      3     27 0.1778
Residuals            29

> summary(mussel.manova, test ="Hotelling-Lawley")

    Df Hotelling-Lawley approx F num Df den Df Pr(>F)
as.factor(treatment)  1 0.19602   1.7642      3     27 0.1778
Residuals            29

> summary(mussel.manova, test ="Roy")

    Df Roy approx F num Df den Df Pr(>F)
as.factor(treatment)  1 0.19602   1.7642      3     27 0.1778
Residuals            29

> summary(mussel.manova, test ="Pillai")

    Df Pillai approx F num Df den Df Pr(>F)
as.factor(treatment)  1 0.16389   1.7642      3     27 0.1778
Residuals            29

> summary(mussel.manova, test ="Wilks")

    Df Wilks approx F num Df den Df Pr(>F)
as.factor(treatment)  1 0.83611   1.7642      3     27 0.1778
Residuals            29

MANOVA with final harvest data

[1] "Treatment" "Weight" "Amount" "Length"
> summary(dataset_b)

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<th>Length</th>
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<td>Min.</td>
<td>0.000</td>
<td>Min.</td>
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<tr>
<td>Kelp:16</td>
<td>1st Qu.:</td>
<td>0.000</td>
<td>1st Qu.:</td>
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<tr>
<td></td>
<td>Median :</td>
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<td>Median :</td>
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<td>Mean :</td>
<td>4.471</td>
<td>Mean :</td>
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<tr>
<td></td>
<td>3rd Qu.:</td>
<td>5.895</td>
<td>3rd Qu.:</td>
</tr>
<tr>
<td></td>
<td>Max.</td>
<td>22.690</td>
<td>Max.</td>
</tr>
</tbody>
</table>
NA's :11
> mussel.manova <- manova ( cbind(Weight, Amount, Length) ~ as.factor(Treatment), data= dataset_b)
> summary(mussel.manova)

Df Pillai approx F num Df den Df Pr(>F)
as.factor(Treatment) 1 0.3736 3.1809 3 16 0.05256 .
Residuals 18
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

> summary(mussel.manova, test ="Hotelling-Lawley")

Df Hotelling-Lawley approx F num Df den Df Pr(>F)
as.factor(Treatment) 1 0.59643 3.1809 3 16 0.05256 .
Residuals 18
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

> summary(mussel.manova, test ="Roy")

Df Roy approx F num Df den Df Pr(>F)
as.factor(Treatment) 1 0.59643 3.1809 3 16 0.05256 .
Residuals 18
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

> summary(mussel.manova, test ="Pillai")

Df Pillai approx F num Df den Df Pr(>F)
as.factor(Treatment) 1 0.3736 3.1809 3 16 0.05256 .
Residuals 18
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

> summary(mussel.manova, test ="Wilks")

Df Wilks approx F num Df den Df Pr(>F)
as.factor(Treatment) 1 0.6264 3.1809 3 16 0.05256 .
Residuals 18
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Appendix E

Protocole d’observation de canard pour le projet MAC.
Document de l’observateur
Avant propos

Ce document est écrit à l’intention du stagiaire chargé de l’observation de canards pour le projet Moule Algue Canards. Le présent projet portant sur le potentiel camouflant de la laminaire sucrée, lorsque placée au-dessus de la ligne de culture de moule, l’observation des canards est primordiale afin de valider la présente information et d’en documenter l’effet comportemental, s’il y a lieu.

Il va de soi que le document doit être rempli sérieusement et au meilleur de la connaissance de l’observateur. Comme toute recherche scientifique, il est attendu que le stagiaire applique la rigueur scientifique en tout temps et qu’il fasse preuve d’autonomie. Une rencontre préparatoire aura lieu en amont du projet et des contacts réguliers auront lieu entre le stagiaire et la personne responsable du projet. Étant donné la nature des observations demandée, il va de soi que ce document doit être protégé le plus possible des intempéries. Il est recommandé de prendre une photo par semaine des feuilles remplies et de les envoyer à la personne responsable.

Les premières pages de ce document contiennent l’information nécessaire afin de remplir les feuilles d’observation. Une petite clé polychotomique sera aussi présentée pour faciliter la taxonomie des espèces observée. En annexe, vous retrouverez les feuilles à remplir concernant les conditions observées pendant l’observation et un tableau pour y entrer les données variables observées.
Personnes ressources

Étudiant gradué sur le projet :
Pierre-Olivier Fontaine, 418-385-2251 (4525), pofontainecegepgim.ca

Chargée de projet :
Estelle Pedneault, 418-385-2251 (4282), epedneault@cegepgim.ca

Mariculteur :
Éric Bujold, 418-392-0145
Clé d’identification des canards

Les canards les plus fréquents dans les environs sont normalement les eiders, les macreuses, le garrot d’Islande et le harelde kakawi. Cette clé est spécialement conçue pour différencier ces principales espèces à l’aide de questions courtes. Des images de ces espèces et d’autres canards pouvant être présents dans les environs seront à votre disposition pour vous aider, mais n’oubliez pas d’avoir à porter de main un livre plus complet d’identification ornithologique au besoin. N.B. Chez les canards, le dimorphisme sexuel est très fréquent, c’est pourquoi il y aura tout le temps deux chemins pour la même espèce dans cette clé.

Question 1 :
De quelle couleur est le plumage au niveau du corps ?

- Noir et blanc
- Noir
- Brun
- Brun et blanc
- Brun tacheté
- Gris tacheté avec du blanc et brun
- Grisâtre

question 2

question 3

question 4

question 5

question 6

question 7

question 8

Question 2 :
De quelle couleur est la tête ?

Noir et l’œil jaune, un cercle blanc est visible à la base de l’œil. 42cm de long. Fuligule à colier (Aythya collaris)

Blanc et noir. Le derrière de la tête est jaune. Forme du bec distinctive. 62 cm de long Eider à duvet (Somateria mollissima)

Vert foncé avec un rond blanc sur la joue. L’œil est jaune vif. Le bec est noir et court. 46 cm de long Garrot à œil d’or (Bucephala clangula)

Noir avec des reflets verts. La tête est couronnée d’une huppe. Son collier est blanc et distinct. Son bec est effilé et rouge. Harle huppé (Mergus serrator)
Tacheté avec un col blanc et un bec jaunâtre. La tête est noire violacée avec une tache blanche en forme de croissant à la base du bec. Garrot d’Islande (*Bucephala islandica*)

Question 3 :

De quelle couleur est la tête ?

Noire avec une protubérance noire au début du bec. Présence d’une tache jaune-orangé sur la mandibule supérieure. Macreuse noire (*Melanitta nigra*)

Noire et blanc avec le font blanc, Présence de deux lunettes noires a la base du bec coloré. Macreuse à font blanc (*Melanitta perspicillata*)

Le plumage est sombre, la queue est courte est le ventre est blanc

Harelde kakawi (*Clangula hyernalis*)

Question 4 :

Est-ce que la couleur du plumage est franche ou tachetée ?

Franche

Coloration brun noir tirant sur le gris. Les flancs et le ventre sont blanchâtres et la tête brune foncée. Le bec serait orange vif au moment de l’année ciblé. Garrot d’Islande (*Bucephala islandica*)

Question 5 :

Petit canard avec une longue queue effilée. Harelde kakawi (*Clangula hyernalis*)

Coloration de la tête allant du brun foncé au brun pâle, le reste du corps est blanc pour le mâle Fuligule milouin (*Aythya ferina*)

La femelle a la tête brune, la poitrine brun-gris. Le bec est foncé et court. Les pattes sont orangées. 46 cm de long. Garrot à œil d’or (*Bucephala clangula*)

Question 6 :

Tacheté avec un col blanc et un bec jaunâtre Garrot d’Islande (*Bucephala islandica*)

Question 7 :
La tête est foncée avec des reflets violets, le bec est gris bleu  
Petit fuligule (*Aythya affinis*)

La tête est surmontée d’une crête, la poitrine est blanchâtre et le cou brun roux. Le bec est effilé et rouge.  
Harle huppé (*Mergus serrator*)

**Question 8 :**

Le bec est très distinct. 62 cm de long.  
Eider à duvet (*Somateria mollissima*)

Plumage gris avec la tête et la poitrine plus sombres et plus brunes. Joues très distinctes.  
Fuligule milouin (*Aythya ferina*)

**Question 9 :**

Macreuse brune (*Melanitta fusca*)

Plumage brun-noir. Les bordures sont plus claires sur le dos. Le bec est noir. Deux tâches sont présentes sur le côté de la tête.  
Macreuse brune (*Melanitta fusca*)

Plumage brun, plus foncé que sur la tête. Les joues, la gorge et les côtés du cou sont brun-gris clair. Le bec est noir ou verdâtre.  
Macreuse noire (*Melanitta nigra*)

Plumage brun avec des nuances de gris et des reflets roux. L’œil est foncé avec le contour blanc. 42 cm de long.  
Fuligule à colier (*Aythya collaris*)

Plumage brun avec deux tâches claires sur le côté de la tête.  
Macreuse à font blanc (*Melanitta perspicillata*)

Le plumage est brun, une bande pâle est présente à la base du bec. Le bec est gris bleu. Très difficilement distingueable du Fuligule milouin.  
Petit fuligule (*Aythya affinis*)
Identification photographique

Fuligule à colier (*Aythya collaris*)
Femelle à gauche et mâle à droite
Crédit : allaboutbirds.org

Eider à duvet (*Somateria mollissima*)
Mâle à gauche et femelle à droite
Crédit : commons.wikimedia.org

Garrot à œil d’or (*Bucephala clangula*)
Mâle à gauche et femelle à droite
Crédit : hbw.com
Harle huppé (*Mergus serrator*)

Mâle à gauche et femelle à droite

Crédit : hbw.com

Garrot d’Islande (*Bucephala islandica*)

Mâle à gauche et mâle à droite

Crédit : gerritvyn.photoshelter.com

Macreuse noire (*Melanitta nigra*)

Femelle à gauche et mâle à droite

Crédit : davidstimac.photoshelter.com
Macreuse à font blanc (*Melanitta perspicillata*)

Femelle à gauche, mâle à droite

Crédit : Planetscott.com

Harelde kakawi (*Clangula hyernalis*)

Femelle à gauche et mâle à droite

Crédit : allaboutbirds.org

Fuligule milouin (*Aythya ferina*)

Mâle à droite et femelle à gauche

Crédit : orientalbirdimages.org
Petit fuligule (*Aythya affinis*)
Mâle en haut et femelle en bas
Crédit: dereila.ca

Macreuse brune (*Melanitta fusca*)
Femelle en haut et mâle en bas
Crédit: arthurgrosset.com
Patron de répartition

Dispersion linéaire, suivant les filières

Dispersion uniforme

Crédit : Thomas Bancroft Photography
Dispersion aléatoire

Crédit : Cepolina

En amas

Crédit : 123RF.com
Cartographie des lieux et des filières:
Ajustement du télescope :

1. Fixer solidement le télescope sur le trépied.
2. Aligner le plus petit grossissement (15X) à l’aide de la vis de grossissement (A) devant le point rouge.
3. Faites la mise au point avec la vis d’ajustement.
4. Augmenter le grossissement jusqu’à l’atteinte du grossissement optimale en recommençant les étapes 2 et 3 pour chaque agrandissement.
5. Ranger le télescope dans son étui après l’utilisation et assurer vous de gérer la lentille propre en tout temps.
Observation des canards : Fiche des conditions d’observation

Date : ________________ Initiales des techniciens(ne)s ______________________

Observation au site 51 : Début : _______ Fin __________
Observation au site 31 : Début : _______ Fin __________
Observation au site 21 : Début : _______ Fin __________

Conditions atmosphériques : □ Ensoleillé   □ Partiel. ensoleillé   □ Nuageux
□ Pluie faible   □ Pluie moyenne

Pluie forte

Température atmosphérique : __________ °C

Direction du vent : N  NE  E  SE  S  SO  O  NO

Force du vent : _________ □ km/h □ noeuds □ m/s

Conditions de mer (échelle de Beaufort) :

<table>
<thead>
<tr>
<th>√</th>
<th>Appellation</th>
<th>Vitesse du vent (nom)</th>
<th>État de la mer</th>
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<tbody>
<tr>
<td>0</td>
<td>Calme</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>Très légère brise</td>
<td>1-3</td>
<td>1-5</td>
</tr>
<tr>
<td>2</td>
<td>Légère brise</td>
<td>4-6</td>
<td>6-11</td>
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<tr>
<td>3</td>
<td>Petite brise</td>
<td>7-10</td>
<td>12-19</td>
</tr>
<tr>
<td>4</td>
<td>Jolie brise</td>
<td>11-16</td>
<td>20-28</td>
</tr>
<tr>
<td>5</td>
<td>Bonne brise</td>
<td>17-21</td>
<td>29-38</td>
</tr>
<tr>
<td>6</td>
<td>Vent frais</td>
<td>22-27</td>
<td>39-49</td>
</tr>
<tr>
<td>7</td>
<td>Grand-frais</td>
<td>28-33</td>
<td>50-61</td>
</tr>
<tr>
<td>8</td>
<td>Coup de vent</td>
<td>24-40</td>
<td>62-74</td>
</tr>
<tr>
<td>9</td>
<td>Fort coup de vent</td>
<td>41-47</td>
<td>75-88</td>
</tr>
<tr>
<td>10</td>
<td>Tempête</td>
<td>48-55</td>
<td>89-102</td>
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<td>11</td>
<td>Violette tempête</td>
<td>56-63</td>
<td>103-117</td>
</tr>
<tr>
<td>12</td>
<td>Ouragan</td>
<td>64 et +</td>
<td>118 et +</td>
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Commentaires :
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<th>Date</th>
<th>Heure</th>
<th>Espèce dominante</th>
<th>Autres espèces</th>
<th>Nombre d’individus</th>
<th>Comportement</th>
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<td>jj/mm</td>
<td></td>
<td>Nom commun</td>
<td>Nom commun</td>
<td>(-si l’observation est confuse, y allez à la dizaine)</td>
<td>repos (r) vol (v) alimentation (a) autre (définir)</td>
<td>ligne (l) aléatoire (a) petits groupes (pg) grands groupes (gg) uniforme (u)</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>21 31 51 ±150 m</td>
<td>21 31 51 ±150 m</td>
<td>21 31 51 ±150 m</td>
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Appendix F

Co-culture of blue mussels (Mytilus edulis) and sugar kelp (Saccharina latissima): Exploring the potential of seaweeds in deterring ducks predating on mussels, Cascapedia Bay (Qc, Canada)

P-O. Fontaine1, E. Buikfil2, I. Gendron – Lemieux3, E. Pedrennec4, E. Tamignoux1,4

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3 École des Pêches et de l’Aquaculture du Québec, Cigale de la Gaspésie et des Îles, 158A Grande-Allee Est, Grande-Rivière, Qc, GQC 1V1

Abstract:

This proof of concept experiment aims to reduce the predation of diving ducks such as surf scoters (Melanitta nigra), common eider (Syringomela cucullata) and the long-tailed duck (Clangula hyemalis) on farmed blue mussels (Mytilus edulis). In October 2016, a long line was set on a long-term cultured kelp (Saccharina latissima) and a long line of polypropylene ribbons mimicking the kelp will be installed above the cultivated mussel lines in order to visually shield the mussels from the ducks. In Spring 2017, the variation in mussel body condition index, scope for growth and survival rate will be observed to assess the proximity effect of these two species.

Introduction:

In many mussel farms around the world, several factors can affect the culture yields but duck predation has proven to be particularly detrimental and hard to control in the long-term. After many attempts at reducing the impact of this predator, losses caused by diving ducks are still slowing the development of mussel farms and in some cases threaten their existence. For example, in 2013, in the Cascapedia Bay, all mussel farms were severely affected by scoters (Melanitta spp), causing the losses of all their spat collectors and more than 30% of their 1–2 years old mussels (Vaimves et al., 2013). A similar situation was also observed in Scotland with losses related to the duck predation averaging between 10 and 30% of the total stock (Ross & Furness 2008).

To address this problem, many creative but expensive methods have been tested, with various results. Those methods, can be divided into two categories: passive and active. Active deterrent methods, such as gas cannons, fireworks, boat chasing, harassment, lasers, and passive methods such as cages, nets, protective coating have all been tested. For the active methods, the outcomes were generally quite similar: ducks generally habituate to it or find a way to bypass the stressor after some time (Richman & al., 2012). As regards the passive methods, they are generally very expensive to implement and they sometimes affect the mussel growth. However, some anecdotal evidence from divers suggest that moving kelp blades may protect mussel from diving ducks. Since there is growing interest for kelp cultivation in the aquaculture industry, the timing was perfect to test the co-cultivation of blue mussels (M. edulis) and sugar kelp (S. latissima) and verify if the deterrent effect of kelp on mussels eating ducks is real.

Figure 1: Relative position of the different treatment to be tested on the marte farm in Maria, Cascapedia Bay, Canada.

![Figure 1](image1.png)

Methods:

The five experimental mussel lines will be in a marine farm near Maria, Cascapedia Bay (Fig. 1). Each line will be 150 m long and will carry mussel spat collected in July 2016. Empty lines will separate the different treatments. Two mussel lines will be used as control treatments. Two mussel lines will be topped by a floating line seeded with living kelp (Saccharina latissima) plantlets produced in a local marine hatchery (Fig. 2). Finally, one mussel line will be topped by a floating line with artificial kelp made of 3 m long polypropylene ribbons. All lines are subdivided into 12 sections of 10 m. The living kelp line is expected to reach 2.5–3 m long in June 2017. The kelp line will be maintained at 4 m deep and will be brought down to 7 m deep at the end of November to protect them from sea ice.

During spring, visual observation of the migrating duck flock will be made on the farm to record their appearance, the length of their stay, the species and the overall behaviour of the birds. Between April and May 2017, depending on the sea ice coverage, mussel lines will be harvested and one sample of 100 mussels per section will be analyzed in the laboratory to determine mussel size distribution, biomass and body condition index (BCI). Two mussel sock of each section will also be analyzed to assess the mussel densities (indels.m-2) on the culture rope. Standard statistical analysis using the R environment will be achieved to verify if there is any correlation between the presence of kelp covers and one of the variables tested.

Future possibilities:

The project aims to offer an alternative solution to the existing duck deterring approaches, one that causes no harm to the ducks and no disturbance to coastal communities. By helping mussel farmers, this project contributes to support the development of the shellfish aquaculture industry in low employment communities. Since the profit margin is already low in the mussel industry, it makes sense to adopt a circular economic rationale (Figure 3) where the deterrent is also a valuable product. In this regard, diversification through kelp farming also opens up new opportunities and provide access to new markets. Finally, as the first multi-specific aquaculture attempt in Quebec it could lead to an economically sustainable polyculture model.

References:


Appendix G

Co-culture of blue mussels (*Mytilus edulis*) and sugar kelp (*Saccharina latissima*): Exploring the potential of seaweeds in deterring ducks predating on mussels, Cascapedia Bay (Qc, Canada)

P.O. Fontaine1, É. Bujold2, E. Pelissoul1, É. Tamigraux1,2

1 Université Centre de l’Environnement, 12 Sallandsgata, 2001 Jótv, Iceland, 480, pierre@islandi.is
2 Farm Marine du Grand Lafi, 580 boulevard Pinton, Carleton-sur-Mer, QC, G0C 1B1

Introduction:

This proof of concept experiment aims to reduce the predation of diving ducks such as scoter (Melanitta spp.), on farmed blue mussels (*Mytilus edulis*) using sugar kelp (*Saccharina latissima*) collectors as a visual shield. Losses caused by diving ducks are still slowing the development of mussel farms and in some cases threaten their existence. For example, in 2011, in the Cascapedia Bay, all mussel farms were severely affected by scoters (Melanitta spp.), causing the losses of all their spat collectors and more than 30% of their 1-2 years old mussels (Vandermau & al. 2013). A similar situation was also observed in Scotland with losses related to duck predation averaging between 10 and 30% of the total stock (Robertson & Forrester 2000). Several replicates have been tried in the past without any long-term success and or profitability. This is the first experiment testing kelp as a duck deterrent.

Production of kelp at the hatchery:

The plantlets of sugar kelp (*Saccharina latissima*) were produced in October 2016 on koralan twine seeded with gametophytes (Tamigraux et al., 2013) (Fig. 1). The plantlets length averaged 5 mm when transferred from the hatchery to the marine farm.

Mussel spat collectors:

Mussel (*Mytilus edulis*) spat collectors made of fuzzy ropes were suspended below 5 longlines of the marine farm in July 2016 (Fig. 2).

Transfer of the kelp on the farm:

The experiment started in November 2016. Living kelp plantlets (80 m) and artificial kelp made of textile (80 m) were attached above the mussel collectors of two 160 m aquaculture lines (Fig. 3). Only living kelp and mussel were on the third culture line. The mussel lines were kept at 7 m depth and the kelp lines were at 5.5 m below the surface.

Results:

The yields on the living kelp culture lines in June 2017 were, lower than those recorded in the past (more than 100 kg), with an average of 23.26 wet g/kg. At the same moment, high numbers (500 ind.) of diving ducks were observed above the experimental lines and they were actively feeding on the mussels as is shown on figure 6. Before the arrival of the ducks, there was no difference between the yields of mussels cultivated below the living vs the artificial kelp (number of mussels p > 0.1; mussel weight p > 0.2; mussel length p > 0.2). After the birds left, the mussel weight per meter of rope was significantly higher on the lines protected by the artificial kelp (p = 0.01) (Fig. 7) but the number of mussels were highly reduced by duck predation on all lines.

Future possibilities:

The project aimed to offer an alternative solution to the existing duck deterring approaches, one that causes no harm to the ducks and no disturbance to coastal communities. As such, the new approach proved relatively successful since there were more mussels left on the lines protected by artificial kelp. However, if the predation by the ducks was slightly reduced, the total loss of mussels is still considered too high. While kelp sales might theoretically compensate for the economical losses due to predation, the plantlets should be outplanted earlier (September) on the farm and kelp strains with high growth rate should be selected. Other kelp-mussel set-up might also be tested to increase the deterring effect of the kelp.

References:

[Insert references here]