GENEVIÈVE LE BLANC

August 15, 2016
Supervisor: Frances Pick
Second Reader: Dan Lane

Institute of the Environment
University of Ottawa

Strategies for the mitigation of environmental impacts from aquaculture: An international comparison

Research Project

- Acknowledgement -

The methodology used in this research project to assign the strength of evidence, the mass of evidence and the weight of evidence was made possible by Professor Scott Findlay. The method was taught in his class EVD-5108, Evidence-based methods for environmental decision-making, in the Winter 2016 semester.

Table of Content

Executive summary

This research project was conducted to analyse and compare the environmental effectiveness, economic efficiency, fairness and simplicity of two policies supporting the reduction of the environmental impacts from the farming of Atlantic salmon in Canada and in Norway. Reduction of biodiversity loss, potentially caused by aquaculture, has led to new regulations by governments. In Canada, licenses impose quality standards for the installation and the equipment that must be used in aquaculture facilities. Detailed maintenance routines must also regularly be made on the equipment. These measures should reduce fish escapes and reduce biodiversity loss. In Norway, the Ministry may establish protected areas for wild Atlantic salmon populations, preventing aquaculture activities from occurring within the boundaries of these areas. Norway's longer history and higher production might suggest a policy with greater environmentally effectiveness, economic efficiency, fairness and simplicity. However, the comparison suggested that both countries have policies that are not based on sufficient scientific evidence to support strong environmental effectiveness, although Canada's is slightly higher than Norway. Furthermore, while both policies have similar economic efficiency, the Canadian one is fairer and it has greater simplicity. Overall, the poor weight of evidence supporting the environmental effectiveness of both policies suggests that governments should probably promote policies that define an end goal rather than the methods to achieve a particular goal. This might encourage the industry to take greater responsibility and adopt adaptive management strategies.

1. Introduction

Following the declines in several fisheries around the world and concerns surrounding overexploitation and increasing demand, the global fishing industry intensified aquaculture production. Aquaculture now produces about half of all the world's edible seafood consumed and is an industry in full expansion (Chopin et al., 2013; Gallardi, 2014; Jones et al., 2014; Marschke & Wilkings, 2014). It is an important food source across the world and across cultures. Furthermore, fish farming provides livelihood, alleviates poverty, and generates economic benefits to farmers, countries, and governments (Jones et al., 2014; Krause et al., 2015; Ting et al., 2015).

However, aquaculture also has environmental impacts, with social and economic repercussions (Jones et al., 2014; Krause et al., 2015; Ting et al., 2015). Biodiversity loss, habitat destruction, diseases, parasites, and pollution discharges are the main impacts on ecosystems (Boyd, 2003; Jones et al., 2014). Significant economic and social considerations are attached with these effects, including the cost inflicted on the surrounding communities and the related risks to human health (Fry et al., 2014; Schaffner, Bader, & Scheidegger, 2009; Whitmarsh et al., 2006). These environmental considerations appear more strongly in the farming of salmonids and shrimps (De Silva & Davy, 2010). Norway is the largest producer of farmed Atlantic salmon in the world, Chile is second, and Canada is the third.

Aquaculture is an interesting industry, since its intensification is quite recent, while other resource-based businesses, such as forestry or mining, have been done on large scale for centuries. Fish farming faces pressures that were not present in these earlier days. It is emerging in a liberal economy where private organizations are responsible for the development of the industry, while governments are mostly reactive regulators (Young & Matthews, 2010). Furthermore, the progression of aquaculture is also occurring in a time where knowledge and information are being shared at an incredible rate, thus increasing social pressure. As such, companies can easily be targeted and face public opposition if negative publicity pertaining to health, environment or aboriginal rights issues arise (Young & Matthews, 2010).

The conflicts between the benefits and the impacts of aquaculture and public pressure have created a need for the use of mitigation strategies for the reduction of environmental risks. Multiple mitigation strategies have been suggested by the scientific community and have sometimes been successfully implemented. Some of these strategies include integrated multi-trophic aquaculture, use of vegetated drainage ditches and use of land-based recirculation systems (Armitage & Marschke, 2013; Chopin et al., 2013; Flora & Kröger, 2014; Rasheed, Mian, & Aubrey, 2011; Stadmark & Conley, 2011; Verdegem, 2013).

The objective of this research project is to conduct policy analyses of two different national aquaculture policies, one from Canada and one from Norway, and compare their environmental effectiveness, economic efficiency, fairness and simplicity. Both policies are designed to reduce biodiversity loss, a perceived threat, from aquaculture activities. Norway’s production being superior to Canada and having a longer history, it is expected that Norway would have stronger environmental policies, although this might come at the expense of economic efficiency, fairness or simplicity.

This environmental policy analysis will first give an overview of the history of commercial aquaculture for both countries, before detailing the impacts of Atlantic salmon farming. The methodology used for the analyses and the comparison will then be explained and followed by the actual policies, beginning with Canada. The policy analyses will present, in order, the environmental effectiveness, the economic efficiency, the fairness and the simplicity. Finally, the comparison between both policies will be made in the same order.

2. History of aquaculture

2.1. Early years

Aquaculture has been practiced for many centuries as a way to improve accessibility to healthy and nutritious food. Historians have traced the earliest mention of aquaculture to 4000 years ago in China, where practices and methods were described in recovered manuscripts (Rabanal, 1988). It would seem that in the following centuries the practice of fish farming spread to the neighbouring countries mostly through immigration and traveling. Also, throughout these years, the practice evolved. Traditional Chinese pond farming began using new techniques including artificial reservoirs to hold fish and polyculture (i.e., multiple species that complement each other in their need for resources raised in the same basins) (Rabanal, 1988). As for European aquaculture, records suggest that some form of fish farming was already occurring in the 15th century. Fish were being raised in waterways around castles and monasteries in order to provide easy access to a fresh supply (Rabanal, 1988). As the Europeans went on to colonize the world in the subsequent centuries, they began spreading the practice of fish farming throughout the continents (Rabanal, 1988).

Aquaculture provided food and livelihoods to many individuals. However, most fish farms were small-scale and owned and managed by families (Rabanal, 1988). Unlike contemporary fisheries, in the early years of fish farming, the industry was relatively small and did not provide a significant amount of seafood products to the global or local markets (Rabanal, 1988; Young & Matthews, 2010). In recent years, as a result of the collapse of wild caught fish at the end of the 20th century, fish farming has become more popular. Now, aquaculture produces about 50 percent of all seafood consumed internationally (Chopin et al., 2013; Gallardi, 2014; Jones et al., 2014; Marschke & Wilkings, 2014). Although there are still many small-scale fish farms particularly in Asian countries, the last 15 years have seen a significant increase in the amount of large commercial farms owned by multinationals (Armitage & Marschke, 2013; FAO, 2011a; Marschke & Wilkings, 2014). This trend seems especially dominant in Europe and in North America (FAO, 2011b).

2.2. Canadian history

Thousands of years ago, Aboriginal communities were practicing shellfish aquaculture for subsistence purposes on the Canadian Pacific Coast. However, it was not until the 19th century that finfish aquaculture really began (FAO, 2011a; Rabanal, 1988; Young & Matthews, 2010). In the beginning, fish farming was mostly done in lakes for recreational purposes (Rabanal, 1988). It would only be during the two last decades of the 20th century that commercial aquaculture would emerge as an industry (Young & Matthews, 2010). From that point on, Canada's aquaculture industry would keep growing, production rising 50 percent from 1998 to 2008 (FAO, 2011a). About 90 percent of Canadian aquaculture occurs in marine water on the East and West Coasts, while the other 10 percent is produced in freshwater in every province (FAO, 2011a).

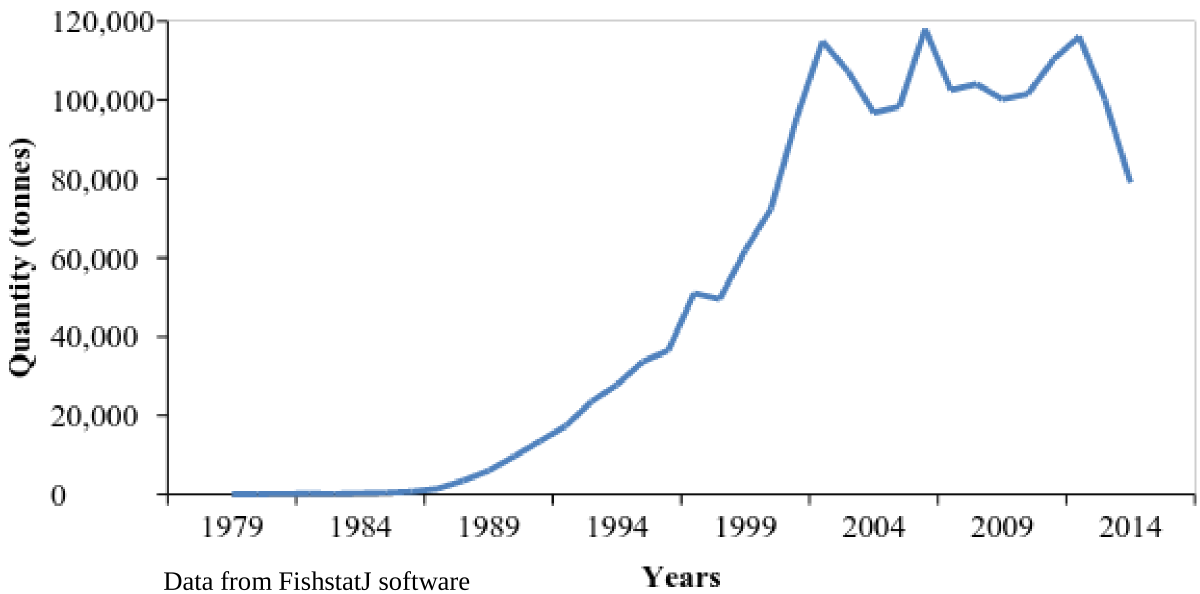
The farming of salmon in Canada began in the early 1970s where farmers with mostly small or medium sized businesses farmed two Pacific species: Coho and Chinook salmon (FAO, 2011a; Young & Matthews, 2010). However, the production soon shifted to Atlantic salmon which grows faster than Pacific species previously farmed and can survive in more crowded conditions, thus making it more profitable (FAO, 2011a). While scientists believed since the late 1960s that Atlantic salmon could be successfully farmed, it took more than a decade for an experimental farm to be allowed to proceed. In 1978-1979, in New Brunswick (NB), scientists from the St Andrews Biological Station were proven correct, as their experimental farm was able to profitably produce Atlantic salmon of market size (FAO, 2011a; Trippel, 1999). British Columbia (BC) adopted the NB methods and started producing Atlantic salmon in the early 1980's. At first, salmon eggs were being imported from the United Kingdom and a few years later, juveniles were received from Washington in the United States. Today, on both coasts, every farm possesses its own hatchery and does not require the importation of eggs or juveniles (FAO, 2011a). Therefore, Canada’s salmon industries are considered integrated because they operate all the steps of the aquaculture value chain: hatchery, growout, processing, and marketing (FAO, 2011a). In other words, each industries is involved in hatching the salmon, raising it to commercial size and transforming it into a marketable product. The industries are also responsible for doing their own marketing.

At the beginning of Atlantic salmon aquaculture, the industry received considerable support from the government and the scientific communities. In 1982-1983, a joint effort by the

Department of Fisheries and Oceans (DFO) and the Atlantic Salmon Federation, created the Salmon Genetics Research Program whose main objective became the breeding of salmon to obtain strains that were specialized for fish farming (Trippel, 1999). Furthermore, as per government recommendations in 1985-1986, the St. Andrews Biological Station established the Atlantic Salmon Demonstration and Development Farm to share aquaculture technologies with the private sector (Trippel, 1999).

As of the 1990's, the production of Atlantic salmon rose steadily on both the Atlantic and Pacific Coasts and peaked in 2002, then again in 2006 and finally in 2012 (Figure 2.1). During the following years annual growth has been constrained by environmental, regulatory and site restrictions in BC and disease outbreaks on both coasts (FAO, 2011a). Public opinions fuelled by media campaigns and divergence in the support from local and Aboriginal communities have also contributed to the reduction in salmon production (Young & Matthews, 2010).

Figure 2.1. Canadian Atlantic salmon aquaculture production from 1979 to 2014. The data used for the design of this graphic was compiled by FAO (2016) and access through their software and database FishstatJ.



Data from FishstatJ software

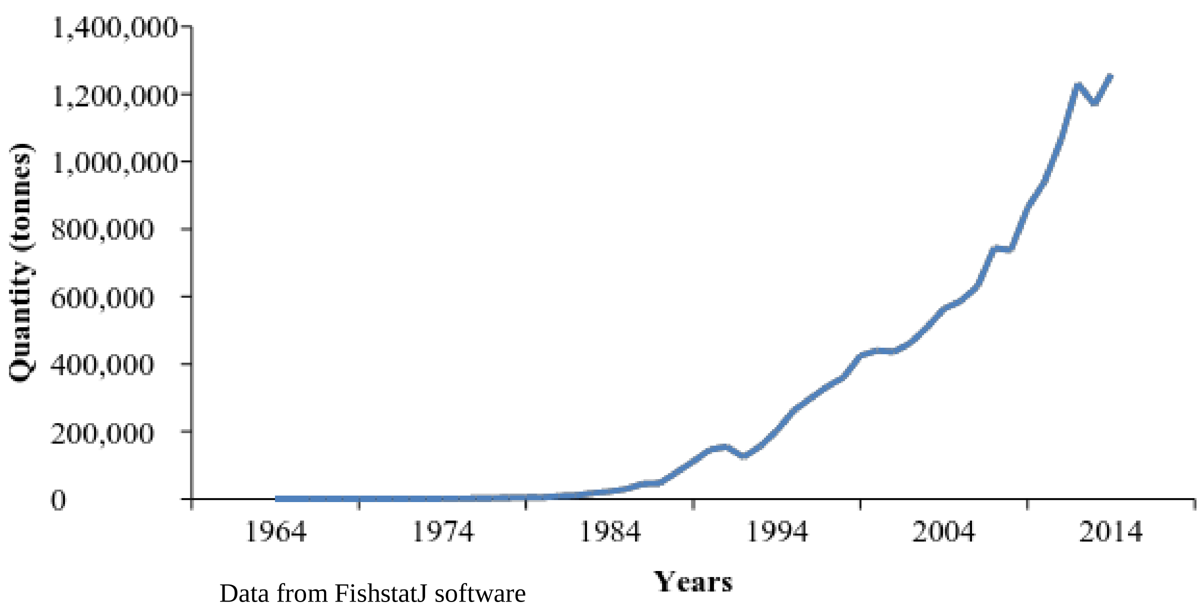
As of 2011, Canada was the fourth largest salmon producing country in the world, with 8 percent of the global market. However, Norway and Chile, the leading producers, are still far ahead with production accounting for 43 percent and 35 percent of the market, respectively (FAO, 2011a). Currently, BC contributes 61 percent of the total Canadian production, while NB is responsible for 33 percent (FAO, 2011a). The last few years have also seen major changes in the Canadian salmon industry. Multiple mergers have left five companies in control of the majority of the production. While BC ownership is mostly in the hands of Norwegian transnational companies, the East Coast is home to more concentrated Canadian-owned and operated industries (FAO, 2011a).

2.3. Norwegian history

Norway possesses large coastlines with a multitude of fjords and islands of various sizes. This particular geography makes it a natural area to practice marine aquaculture. As such, 90 percent of the industry is sea-based (Paisley et al., 2010). Norwegian fish farming began in the 1850's, when hatcheries for rainbow trout and Atlantic salmon were established as an attempt to increase stocks of wild populations. However, commercial aquaculture only began in 1910. Although the industry operated with government support, Norwegian aquaculture, which at that time focused on rainbow trout, did not prove profitable and production levels remained low until the 1950's (Paisley et al., 2010). During those years, fish farming re-emerged as a well-organized industry and it was in the following decade that the production of Atlantic salmon would take off. Now, the farming of this species accounts for 89 percent of the aquaculture production in Norway (Paisley et al., 2010).

Although there are few integrated or combined farms in Norway, the market is now currently composed of smaller specialized companies. As such, the various steps of the aquaculture value chain are divided among different producers (Paisley et al., 2010). Eggs are mostly supplied by two major companies, though there are a few minor actors also present in the market (Paisley et al., 2010). Hatcheries ship juvenile salmons (smolts) throughout the Norwegian Coast. It is speculated that the transportation may have impacts on the salmon, but scientific evidence on the subject is not yet conclusive (Paisley et al., 2010). Furthermore, the shipping of the salmon increases the risk of spreading diseases and infections to the different sites. These risks prompted government officials to establish strict bio-regulations (Paisley et al., 2010). The non-integrated model that defines Norwegian aquaculture has also led to the evolution of an industry built around fish processing. As of 2006, the country had 125 approved processing facilities (Paisley et al., 2010). In the future, there will likely be an increased number of integrated farms in Norway, as they are believed to increase economic efficiency (Figure 2.2) (Paisley et al., 2010).

Figure 2.2. Norwegian Atlantic salmon aquaculture production from 1964 to 2014. The data used for the design of this graphic was compiled by FAO (2016) and access through their software and database FishstatJ.



Data from FishstatJ software

Norway is currently the largest producer of Atlantic salmon worldwide and aquaculture is a significant part of the local economy (FAO, 2011a; Paisley et al., 2010). However, future expansion of Norwegian salmon farming may also be reduced by the limited amount of new sites available and environmental concerns at the existing ones. As such, it is perceived that the progression of the industry will occur through research and the development of new technologies. Already, major investments have been made in this sector and they have led to large reductions in production costs (Paisley et al., 2010; Young & Matthews, 2010).

2.4. Comparison

Canada and Norway are two world producers of farmed Atlantic salmon. However, Norwegian production is much higher than in Canada. Figures 2.1 and 2.2 indicate that the Norwegian aquaculture industry produces about ten times more salmon than the Canadian industry. Although there are some similarities, aquaculture is practiced differently in both countries as it has emerged in different historical contexts. The two countries have mostly marine-based aquaculture industries and both also face similar barriers to further development, namely environmental and health issues caused by fish farming and the public unrest they generate.

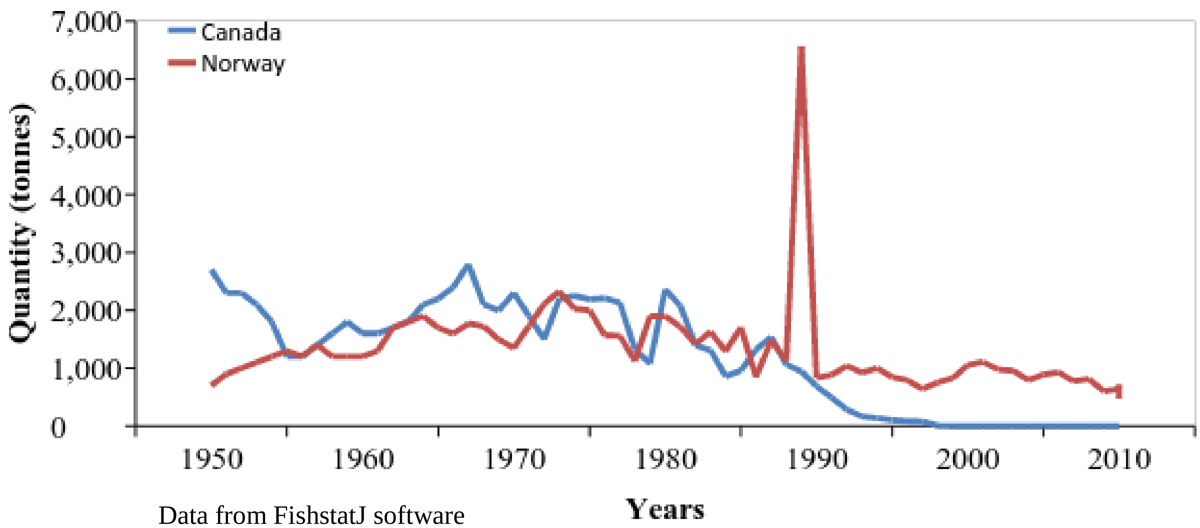
Successful commercial farming of salmon in Norway began about two decades before Canada. Therefore, during those 20 years, Norway was able to refine its process and its technologies. The development of Atlantic salmon farming was also more natural in Norway where it is a native species. Although Atlantic salmon is also native to Canada’s East Coast, it is not native on the West Coast, where current production is at its highest. However, the biggest difference in Canadian and Norwegian aquaculture remains their different business models. Canada's fish farms are mostly large and integrated, while Norway has firms that are specialized for every step of the value chain.

3. Salmonid aquaculture

3.1. Commercial importance

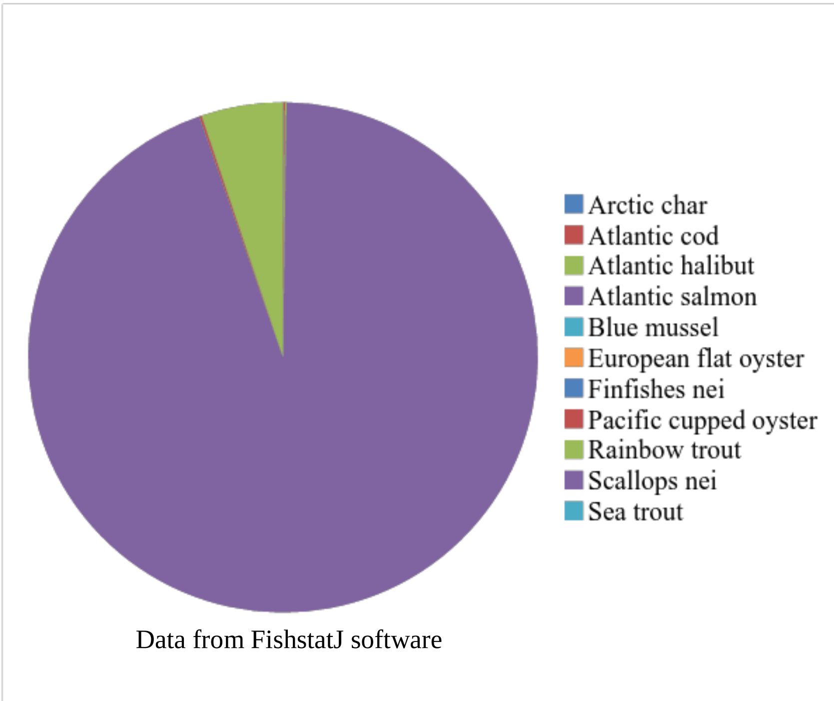
About 70 percent of salmon consumed internationally is provided by aquaculture (Marine Harvest, 2015). Atlantic salmon, particularly, holds a large share of the aquaculture market because of its high demand and the decline of its wild stock in Canada and Norway (Figure 3.1). In both of these countries, Atlantic salmon accounts for the majority of the national aquaculture production (Figures 3.2, 3.3) (FAO, 2011a; Paisley et al., 2010; Váradi et al., 2011). Figure 3.4 shows that global production of salmonid is also dominated by Atlantic salmon. According to Marine Harvest (2015) of Norway, one of the largest seafood companies in the world and the largest Atlantic salmon producer, there is a large difference (approximately 1700 thousand tonnes GWE) between the global production of Atlantic salmon and the small trout (second most farmed fish).

Figure 3.1. Quantity of wild Atlantic salmon captured in Canada and in Norway between 1950 and 2014. The data used for the design of this graphic was compiled by FAO (2016) and access through their software and database FishstatJ.



Data from FishstatJ software

Figure 3.2. Aquaculture production in Norway in 2014[1]. The data used for the design of this chart was compiled by FAO (2016) and access through their software and database FishstatJ.



[1] In figure 3.2 and 3.3 nei means not elsewhere included. This indicates that the data exclude species that would fit into this definition, but are included in another category. For example, in Figure 3.2, Finfishes nei excludes Arctic char, Atlantic cod, Atlantic halibut, Atlantic salmon, Rainbow trout and Sea trout.

Figure 3.3. Aquaculture production in Canada in 2014. The data used for the design of this chart was compiled by FAO (2016) and access through their software and database FishstatJ.

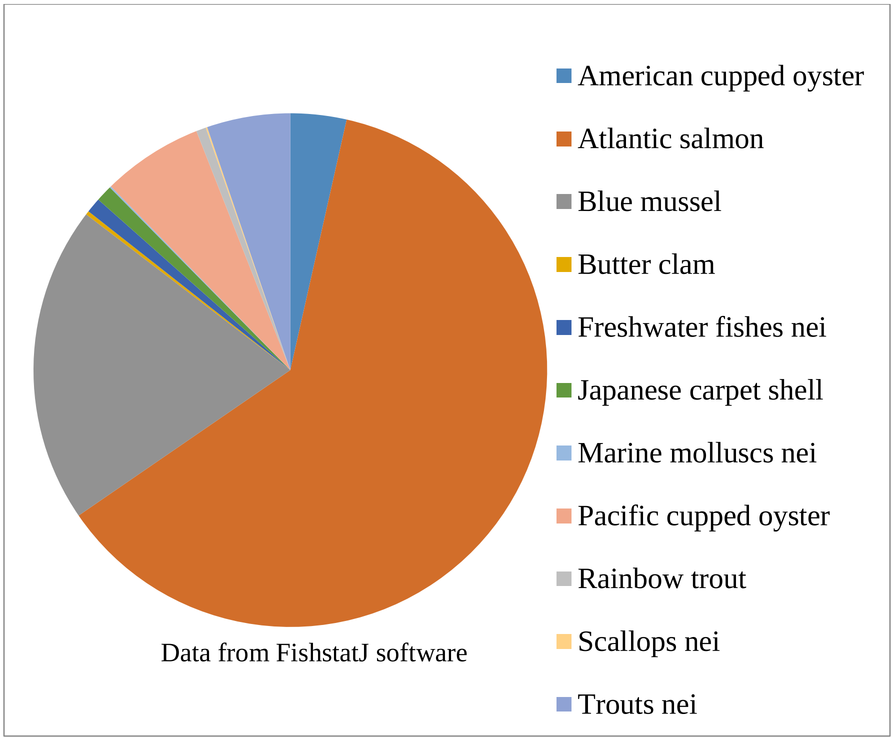
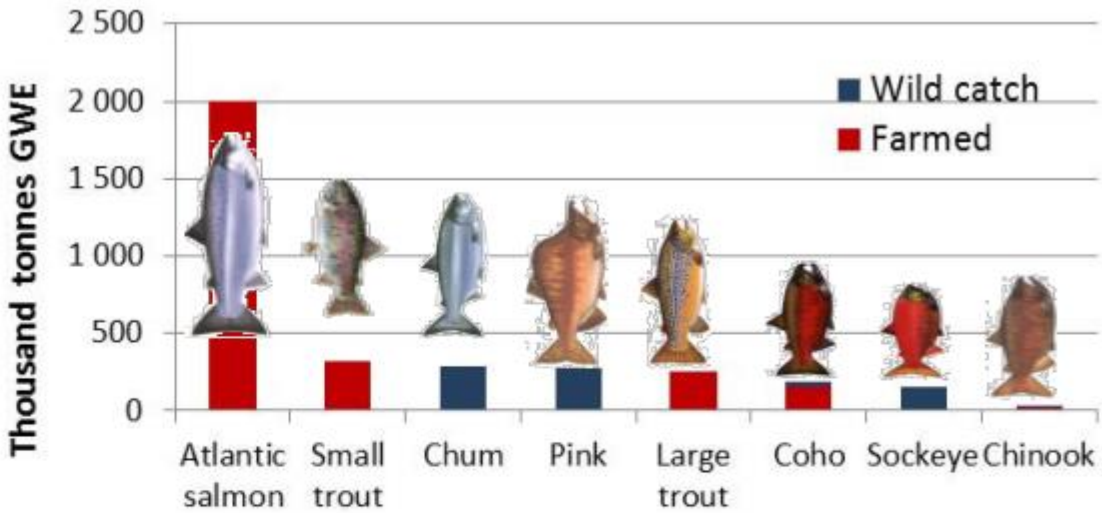


Figure 3.4. Species of Salmonids, Global production



(Marine Harvest, 2015)

Figure 3.5, which was obtained from the OECD (2016) website, represents the worldwide aquaculture production in 2012, all species included, in circles that are proportional to the tonnes of fish farmed by each country. This map indicates the importance of Atlantic salmon in aquaculture, since the two largest aquaculture producers, behind Korea, Norway and Chile, are also the two countries that are dominating the global market for farmed salmon (FAO, 2011a; Marine Harvest, 2015; Young & Matthews, 2010). Salmonoids are exported mostly as a fresh product and therefore, are usually directed at neighbouring countries. For example, salmon produced in Canada will remain and be consumed in North America, primarily in the US, while salmon produced in Norway will be imported by Europe and Russia (Figure 3.6) (Marine Harvest, 2015).

Figure 3.5. Aquaculture production indicator; world map.

(OECD, 2016)

Figure 3.6. Global trade flow of farmed Atlantic salmon

(Marine Harvest, 2015)

3.2. Environmental impacts

There are a significant number of environmental impacts that arise from aquaculture (De Silva & Davy, 2010). Among these environmental impacts, biodiversity loss, habitat destruction, disease, parasites, and pollution discharge have the potential to be the most disruptive (Boyd, 2003; Jones et al., 2014). These issues are also the ones most targeted by the opponents of the industry.

3.2.1. Biodiversity loss

In every marine fish farm there is a risk of fish escaping the facilities and entering into the ocean where they may disturb ecosystems. In Canada, Atlantic salmon have been known to escape into the Pacific Ocean, where the species is not native. For example, in 2008, Marine Harvest reported that over 30,000 Atlantic salmon escaped from its facilities (Marine Harvest, 2008). This event and other similar incidents create concern about the potential impacts on biodiversity, because there have been research suggesting that aquaculture impacts marine food webs (Berkes, 2011; Skaala et al., 2014). Furthermore, there have been many instances of negative interactions between fish farms and predators: seals that approach facilities may be shot by employees, while some animals will get tangled in the cage-net and perish (Cronin, Jessopp, Houle, & Reid, 2014). In both Canada and Norway, opponents of aquaculture and some scientists believe that escapes from fish farms may be altering the genetic material of wild populations through introgression (Skaala et al., 2014; Verspoor et al., 2005; Young & Matthews, 2010). Unlike natural salmon, farmed salmon are bred to have specific genes that are beneficial for aquaculture (e.g., resistance to disease and tolerance of more crowded conditions). Over time, this potential mixing of natural and unnatural salmon from fish farms could lead to reduced genetic variability, thus diminishing the resilience of the wild populations (Paisley et al., 2010; Skaala et al., 2014; Trippel, 1999). Reduction in the resilience of wild populations may impact the survival of wild species, such as Coho or Chum salmon, therefore potentially reducing global biodiversity (Váradi et al., 2011).

3.2.2. Loss of habitats

The creation of farming ponds often results in the loss of habitats through the displacement of native populations. In other parts of the world, farming ponds have replaced mangroves, wetlands, and other coastal features that provide numerous ecological services (Conchedda, Lambin, & Mayaux, 2011). Salmon aquaculture requires very specific sites since these fish must be raised in an area where a moderate current is always present. The ideal sites are coastlines with fiords and islands, such as the ones that can be found in Norway (Marine Harvest, 2015; Paisley et al., 2010). However, an abundance of fish farms, through discharge of organic matters, may render fjords uninhabitable for wild salmons (Skaala et al., 2014). These modifications to the setting may cause pressure on the surrounding ecosystems as well as creating conflict with other users, such as tourism agencies and fishermen (Boyd, 2003; Young & Matthews, 2010).

3.2.3. Diseases, infections and parasites

The crowding and otherwise unnatural growing conditions in which farmed salmon are raised leave the species much more vulnerable to diseases, infection and parasites. These health conditions can spread quickly through the fish farm leading to decline in population size and they can also spread to native organisms (Mckindsey, Landry, O'Beirn, & Davies, 2007; Petton, Pernet, Robert, & Boudry, 2013). Salmonids are susceptible to the many infections, diseases, and parasites including pancreatic necrosis, infectious salmon anaemia and the salmon louse (Váradi et al., 2011). The spreading of infections is particularly an issue in Norway because juveniles are shipped from hatcheries to sites all across the country. The transportation of these fish increases the risk of epidemic outbreaks (Paisley et al., 2010). The treatment of diseases, on its own, can lead to even greater problems as the use of antibiotics and other therapeutic chemicals can lead to unwanted discharges into the environment (Kleter, Groot, Poelman, Kok, & Marvin, 2009; Lan, 2013; Marschke & Wilkings, 2014). However, this last issue is less problematic in both Canada and in Norway where the use of such products is highly controlled (FAO, 2011a; Váradi et al., 2011).

3.2.4. Pollution discharge

Aquaculture is characterized as massing together multiple organisms in a restrained area. This practice results in the creation of pollution as it discharges high concentrations of phosphorus, nitrogen and organic matter into the ecosystem (Skaala et al., 2014; Stadmark & Conley, 2011; Verdegem, 2013). These nutrients and organic waste are quickly utilized by microorganisms, which, in response, proliferate. Some of these microorganisms can cause harmful algal blooms and lead to coastal eutrophication, resulting in a general degradation of water quality (Aníbal et al., 2014; Jones et al., 2014; Rasheed et al., 2011; Whitmarsh et al., 2006). Particularly, Aníbal et al. (2014) and Whitmarsh et al. (2006) have identified a relationship between an increase in the recurrence of harmful algal blooms and intensification of aquaculture activities. This impact on coastal water can limit the capacity of fishermen and providers of recreational activities to safely practice their livelihood. Human health impacts and reduction in property values can also be caused by pollution discharge from aquaculture facilities (Aníbal et al., 2014; Fry et al., 2014; Jones et al., 2014; Rasheed et al., 2011; Whitmarsh et al., 2006).

3.3. Social impacts

The degradation of water quality resulting from fish farming leads to costs to the producers themselves, as it may have negative impacts on their fish, but also to the surrounding communities that depend on coastal waters for subsistence and recreational purposes. Furthermore, aquaculture imposes risks to human health (Schaffner et al., 2009; Whitmarsh et al., 2006). However, there is a discrepancy in how the industry is received by local communities. While some consider the impacts on the environment as limiting their capacity to have a livelihood as a traditional fisherman or as a tourism provider, other communities perceive aquaculture as rejuvenating to local economies that have been suffering since the decline of wild fish stocks (Young & Matthews, 2010). This variation in acceptance is even more prominent in

Aboriginal communities. Certain First Nations see fish farming as a way of preserving their culture, while others consider it a betrayal of their ancestral knowledge (Young & Matthews, 2010). That being said, the conflicting opinions seem to be minimized when local communities are assured that they will retain all of the benefits from the industry (Young & Matthews, 2010). For example, the Kitasoo/Xai'xais First Nation in the community of Klemtu are co-managing an aquaculture operation with Marine Harvest. The community has ownership of the salmon farms and is responsible for environmental monitoring. Marine Harvest provides interested local people with the appropriate training to work in the fish farm with the possibility of more training to achieve management position (Fisheries and Oceans, 2015; Young & Matthews, 2010).

4. Methodology

The methods used for the evaluation of aquaculture related policies in this research project are adapted from the framework proposed in the 2005 Federal Budget: A Framework for Evaluation of Environmental Tax Proposals. This is similar to the framework used by Environment and Climate Change Canada[2] to conduct policy analyses (Audit and Evaluation Branch, 2016; Audit and Evaluation, 2013; Department of Finance Canada, 2005). While Environment and Climate Change Canada uses a combination of literature review, interviews, surveys and cases studies to conduct a policy analysis, this research project will be using only governmental documents and primary literature. Furthermore, this project will use a systematic approach to analyse the scientific evidence supporting policies. With this modified framework, the policies to be studied are examined on the basis of their environmental effectiveness, economic efficiency, fairness, and simplicity. These themes are the same ones examined by Environment and Climate Change Canada (Department of Finance Canada, 2005). The detailed methodology of how the framework will be applied to conduct the policy analyses is explained below and will be illustrated using the British Columbia (BC) carbon tax as an example[3].

[2] The framework was actually used by Environment Canada, before the department changed its name to Environment and Climate Change Canada in 2015.

[3] This example is a simplified representation of the BC carbon tax used only to illustrate how the evidence-based framework will be used. It is not intended to express any opinions about the effectiveness of the policy in CO_2 emissions nor does it strive to examine the complexity of the issue. The values assigned to the SOE, the MOE and the WOE will be entirely made up and do not reflect upon the evidence supporting the policy.

4.1. Environmental effectiveness

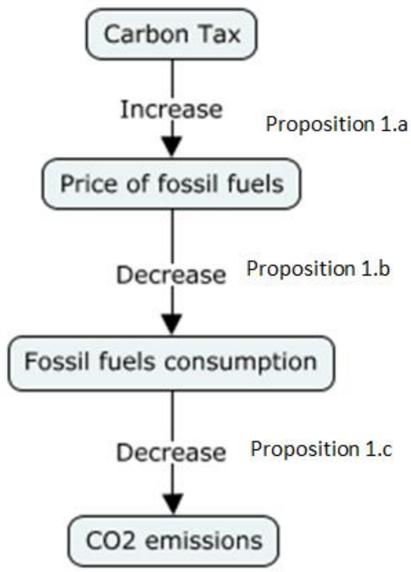
In order to assess the effectiveness of the policy to reduce environmental degradation, an evidence-based approach using primary literature will be used. The environmental effectiveness of policies will be assessed by using the published results of various environmental studies.

4.1.1. Cognitive mapping

First, the relationship between the policy and the expected environmental change will be deconstructed in order to represent the causal linkages between the policy and the intended impact on the environment. The deconstruction of the regulation will be illustrated in the form of a cognitive map, created by the software Cmap (Institute for Human & Machine Cognition, 2015). A cognitive map is a visual representation of the causal relationships between the different propositions which are represented by nodes (vertices). A proposition is a hypothesis that needs to be supported by scientific evidence in order for the policy to have the intended environmental outcome. The nodes are connected directionally through arcs (arrowed lines). The use of cognitive mapping will be essential in determining the key propositions supporting the connexion between the policy and the intended reduction in environmental impact.

The BC carbon tax was introduced in 2008 to reduce CO_2 emissions in the province (Beck, Rivers, Wigle, & Yonezawa, 2015). The policy can thus be deconstructed as shown in Figure 4.1 to indicate the causal relationship between the tax and the desired environmental outcome.

Figure 4.1. Example of cognitive mapping: Deconstruction of the BC carbon tax



4.1.2. Strength of Evidence

Second, each of the propositions identified in the previous step will be assigned a weight of evidence (WOE) score from the strength of evidence (SOE) and the mass of evidence (MOE). The SOE refers to how convincing the scientific evidence supporting the proposition is, based on the results and the design of the associated scientific research (identified as Reference in Table 4.1). The SOE will be applied to environmental studies that either support or refute the propositions that were obtained from the deconstruction of the policies. To evaluate the SOE, each scientific study pertaining to a proposition will be assigned a score between -5 and 5. This score will be attributed according to the strength of the study design, the effect size, the sample size, the potential for bias and the degree of extrapolation. A score of -5 will be given to studies that strongly disagree with the proposition, while a score of 5 will be given to studies that strongly support the proposition. Conversely, a score of 0 indicates that the study did not have significant strength and therefore did not provide convincing evidence to support or refute the proposition. The overall SOE for the proposition will be obtained from the rounded average of all the references examined.

Pursuing with the BC carbon tax, the SOE will be attributed to the three arcs identified with the cognitive map in Table 4.1.

Table 4.1. Example of strength of evidence for the proposition 1.b underligning the BC carbon tax: Higher price of fossil fuel will decrease fossil fuel consumption.

References	SOE
Beck et al., 2015	1
Reference 1	4
Reference 2	3
Reference 3	4
Average	**3.7**

Justification

Beck et al. (2015) created a model with low inferential strength. They only found a small effect size. There was a bias in the choice of variables used to create the model. There was a high degree of extrapolation between the model and the reality.

The following process will then be repeated for each reference from each proposition in order to obtain a solid basis for the SOE of each policy. At the end, a table, like Table 4.2, summarizing the SOE for all the propositions pertaining to the policy will be made.

Table 4.2. Summary of the strength of evidence for each proposition supporting the example of the BC carbon tax.

Proposition	SOE
1.a. Carbon tax increases the price of fossil fuels.	3.7
1.b. Higher price of fossil fuel will decrease fossil fuel consumption.	2
1.c. Reduced fossil fuel consumption will reduce CO_2 emissions.	4.5

4.1.3. Mass of Evidence

The MOE represents how much scientific effort has been put into researching a particular proposition. As it is impossible to gather all the primary literature that will support each proposition, an estimate based on the percent of pertinent references (i.e., all the references that could be used to support or contradict a specific proposition) on all references obtained while researching the specific proposition will be used. These references will be obtained from a search of the primary literature across various databases (ASFA: Aquatic Sciences and Fisheries Abstract, Web of Science and Environmental Impact) with different string phrases. All searches will be systematically recorded regarding the database used, the search string phrase used, the applied filter and the number of pertinent references and the total number of references. This data is available in the Appendix. The MOE will then be attributed as outlined in Table 4.3.

Table 4.3. Value of the mass of evidence based on the percent of pertinent references from the total number of references.

MOE [0,5]	Percent of pertinent references (%)
0	0
1	0-10
2	11-25
3	26-60
4	61-80
5	81-100

This method to attribute the MOE will be illustrated using the same three propositions previously used to demonstrate the SOE in Table 4.2.

Table 4.4. Example of mass of evidence for the propositions underligning the BC carbon tax.

Proposition	Total references	Pertinent references	Percent of pertinent references (%)	MOE
1.a Carbon tax increases the price of fossil fuels.	20	5	25	2
1.b Higher price of fossil fuel will decrease fossil fuel consumption.	30	20	67	4
1.c Reduced fossil fuel consumption will reduce CO_2 emissions.	20	10	50	3

4.1.4. Weight of Evidence

The WOE is a measure of the evidentiary strength for a particular proposition. Thus, this tool will give rationale for the environmental effectiveness of the policy. The WOE for each proposition will range from -25 to 25 and it will be obtained by multiplying the SOE with the mass of evidence MOE, which are each scored out of five. A score of -25 will indicate that there is significant and compelling evidence (i.e., beyond any reasonable doubt) against the proposition, while a score of 25 will indicate that there is significant evidence supporting the proposition. The overall WOE for the policy will then be obtained by taking the average of the WOEs of all the propositions pertaining to the policy.

Table 4.5. Example of weight of evidence for the propositions underligning the BC carbon tax.

Propositions	SOE [-5,5][4]	MOE [0,5]	WOE [-25,25]
1.a Carbon tax increases the price of fossil fuels.	4	2	8
1.b Higher price of fossil fuel will decrease fossil fuel consumption.	2	4	8
1.c Reduced fossil fuel consumption will reduce CO_2 emissions.	5	3	15
Policy WOE[5]	**10**		

4.2. Economic efficiency

Although the emphasis of the analysis and the comparison is being placed on the environmental effectiveness of the regulations, it is also important to examine the economic efficiency, fairness, and simplicity of the policies.

Economic considerations are a significant part of any policy and this is why it has been included in evaluation framework of Environment and Climate Change Canada (Audit and Evaluation Branch, 2016; Audit and Evaluation, 2013). As such, each regulation examined has a review of its cost-effectiveness, its impact on competitiveness, and the adjustment (compliance)

[4] Values rounded from the ones obtained in Table 4.2.
[5] The rounded average from the WOE of each proposition.

costs it requires. Each policy will be examined according to the flexibility afforded to the industry to achieve reduced environmental impact degradation. Furthermore, the impact of the policies on the price of the salmon compare to the global market (competitiveness) will be noted (Department of Finance Canada, 2005). Finally, the compliance costs to the policy will be subjectively evaluated as low, moderate or high (Department of Finance Canada, 2005).

4.3. Fairness

In this section of the analysis, the policies will be critically examined in order to determine if there are higher imposed costs to a particular stakeholder or sector of the industry. An unfair situation would arise if customers, coastal communities, small scales organizations, or large companies would unilaterally bear all the costs associated with the policies. As such, the BC carbon tax can be considered relatively fair, as it is progressive, meaning that the financial burden of the policy is assumed more heavily by wealthy family than by those in difficulty (Beck et al., 2015).

4.4. Simplicity

The simplicity of a policy is a reference to how difficult and how many resources are required from the government for administration and enforcement (Department of Finance Canada, 2005). It also relates to the efficiency of a certain regulation (Audit and Evaluation Branch, 2016; Audit and Evaluation, 2013). In this section, the amount of resources needed for the enforcement of the policy and the ease of compliance will be noted as low, moderate, or high.

As an example, the BC carbon tax, since the tax is added when fuel is purchased, is a simple policy. As such, it does not require many resources to enforce or monitor it, and it is, therefore, considered a “high” simplicity policy.

4.5. Comparison

After the previous analyses are completed, the Canadian and Norwegian policies will be compared based on these same criteria: (1) environmental effectiveness based on the WOE; (2) economic efficiency based on cost-effectiveness, competitiveness and compliance costs; (3) fairness; and (4) simplicity. The policies will be compared for each of these dimensions individually, rather than an overall comparison. This comparison by criteria may highlight some contextual difference that requires further study. As such, perhaps top-down regulations that are not cost-effective may have better environmental outcomes than more flexible approaches. The focus of this research project will be environmental effectiveness, since stronger WOE for Norwegian regulations would suggest that Norway’s aquaculture, perhaps because of its longer history and its higher level of production, is better regulated in terms of reducing the environmental impact of the aquaculture industry.

The following sections present the analysis of the Canadian (section 5) and the Norwegian (section 6) regulations as per the methodology noted here.

5. Prevention of Atlantic salmon escapes in Canada

The environmental and social issues and the financial benefits arising from salmon farming have encouraged the evolution of mitigation strategies. While some of these approaches use research and development of new technologies, governments have involved themselves by heavily regulating the industry. Canada and Norway both possess complex legislation on aquaculture and both apply it through a licensing scheme, as is the norm around the world (Marine Harvest, 2015). This project will compare the respective merits of two policies pertaining to the reduction of biodiversity loss. The Canadian policy is to prevent the escape of farmed Atlantic salmon into the Pacific Ocean. This regulation is defined in the *Pacific Aquaculture Regulation* (2015) section 4 h) act and in the *Finfish Aquaculture Licence under the Pacific Aquaculture Regulation* (2014a). The Norwegian government, on the other hand, has established a policy, under the *Aquaculture Act* (2011) Chapter § 14 *Protection of specific areas*, allowing it to create spaces without aquaculture facilities to protect wild salmon population from the escapes of farmed Atlantic salmon (Norwegian Ministry of Fisheries and Coastal Affairs, 2006). Therefore, both policies reduce the probability of encounters between wild and escaped farmed salmons, which can decrease biodiversity loss from the decline in wild populations.

According to *Pacific Aquaculture Regulation* (2015) section 4 h), when awarding a BC aquaculture license, the Minister may request that the applicant implement measures that will strongly reduce the risk of fish escape. As such, in Canada, in order for a license to be awarded and kept, an aquaculture facility must take "all the reasonable measures to prevent the escape of cultivated fish" and specific standards pertaining to the equipment must be attained. These standards detail the maintenance of the equipment, the quality of the equipment and the quality of the installation. The goal of this policy is to prevent fish escapes, therefore decreasing biodiversity loss attributed to the farming of Atlantic salmon in the Pacific Ocean. In the next section, the policy will be deconstructed into propositions that will then be used in the analysis of the environmental effectiveness.

The Canadian policy pertaining to the prevention of farmed Atlantic salmon escapes in the Pacific Ocean is an extension of the federal government's licensing scheme and is enabled by the *Pacific Aquaculture Regulation* (2015) legislative act and defined by Annex IX of the *Finfish Aquaculture License under the Pacific Aquaculture Regulations* (2014a). According to these regulations, specific standards in respects to the quality, installation and maintenance of the equipment of aquaculture facilities must be met in order to be operational. The objective of this policy is to limit the escape of farmed Atlantic salmon into the Pacific Ocean, which is an environmental interest of the Canadian governments (Fisheries and Oceans, 2014b). Monitoring of salmon spawning rivers near the Pacific Ocean for established population of Atlantic salmon indicates concerns toward the potential risk of having farmed salmon populations interfering with the survival rate of wild salmon populations by competing for resources, such as territory or food, or through genetic introgression (Fisheries and Oceans, 2014b). With food or territory available in a limited amount, a sudden increase in the number of salmon in an area, like in the event of fish escape, could add pressure to existing populations, therefore reducing their survival rates. Furthermore, there is also the possibility that farmed Atlantic salmon reproduce with wild species of Pacific salmon, potentially reducing the genetic variability of wild salmon population. Genetic variability is considered important for species' survival because it allows for more adaptive response in the case of changes in the environment. Therefore, less genetic diversity in wild population of salmon could lead to reduced survival rate. This reduction in survival rate would create a decline in wild populations, which would eventually lead to biodiversity loss.

5.1. Environmental effectiveness

5.1.1. Cognitive mapping

Figure 5.1 Deconstruction of the policy on the prevention of salmon escape in Canada.

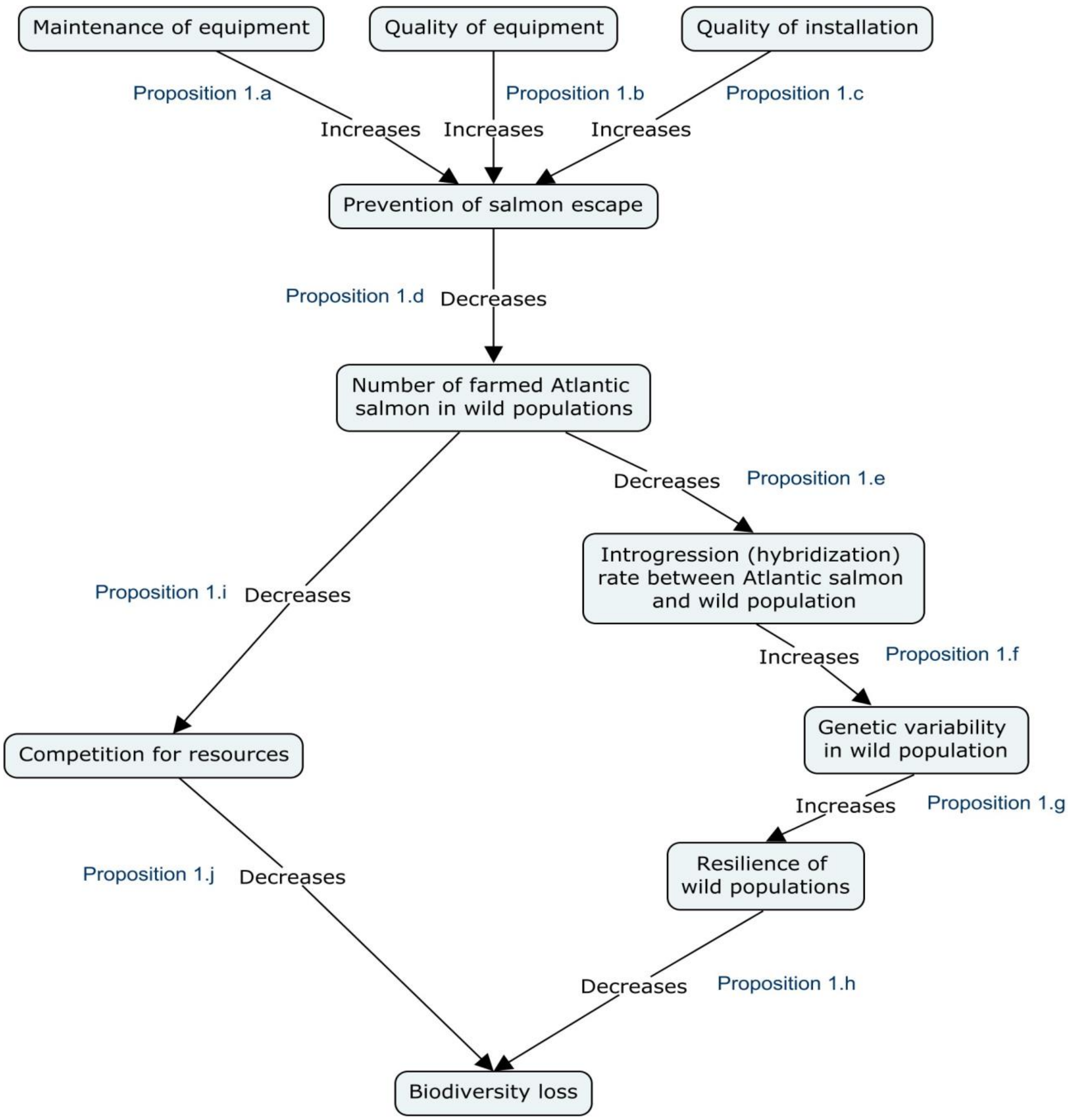


Figure 5.1 is a visual representation of all the different hypothesis (proposition), that must be supported in order for the Canadian policy on the prevention of salmon escape as a way to achieve a reduction in biodiversity loss be evidence-based. Therefore, each propositions will be tested by assessing how well (weight of evidence) it is defended in the scientific literature. The following pages will examine the strength of evidence for each propositions separately by evaluating scientific studies individually.

5.1.2. Strength of evidence

Table 5.2. The strength of evidence of proposition 1.a: Maintenance of the equipment increases the prevention of farmed Atlantic salmon escape.

References	SOE
Thorvaldsen et al., 2015	1
Jensen et al., 2010	3
Average	**2**

Justification:

Thorvaldsen et al. (2015) had a weak study design and there was no effect size because it was a descriptive study without quantitative data. Semi-structured interviews and incident reports were used as data. Bias was moderate since the researchers were careful to survey people from farms of different sizes, different access to technology and geographic distribution, although it was all conducted within Norway. The sample size was small with only 12 respondents participating in the survey. The study weakly supported the proposition.

Jensen et al. (2010) had study design that, although was descriptive, included correlations, a literature review and case studies, thus making it more robust. The effect size was large, with fish escapes dropping to a third of their original number in 8 short years (2001 – 2009). The data were provided by the Norwegian Aquaculture Escape Commission and included detailed reports of all escape events for the time period. Bias was considered moderate due to the selection of references and cases studies. Extrapolation was very large because the correlation analysis does not imply causation; it only has data from Norway and for a short time period. Furthermore, variables other than equipment were not considered. The study moderately supported the proposition.

Table 5.3. The strength of evidence of proposition 1.b: Quality of the equipment increases the prevention of farmed Atlantic salmon escape.

References	SOE
Thorvaldsen et al., 2015	1
Jensen et al., 2010	3
Average	**2**

Justification:

Thorvaldsen et al. (2015) had a weak study design and there was no effect size because it was a descriptive study without quantitative data. Semi-structured interviews and incident reports were used as data. Bias was moderate since the researchers were careful to survey people from farms of different sizes, different access to technology and geographic distribution, although it was all conducted within Norway. The sample size was small with only 12 respondents participating in the survey. The study weakly supported the proposition.

Jensen et al. (2010) had study design that, although was descriptive, included correlations, a literature review and case studies, thus making it more robust. The effect size was large, with fish escapes dropping to a third of their original number in 8 short years (2001 – 2009). The data were provided by the Norwegian Aquaculture Escape Commission and included detailed reports of all escape events for the time period. Bias was considered moderate due to the selection of references and cases studies. Extrapolation was very large because the correlation analysis does not imply causation; it only has data from Norway and for a short time period. Furthermore, variables other than equipment were not considered. The study moderately supported the proposition.

Table 5.4. The strength of evidence of proposition 1.c: Quality of the installation increases the prevention of farmed Atlantic salmon escape.

References	SOE
Thorvaldsen et al., 2015	1
Jensen et al., 2010	3
Average	**2**

Justification:

Thorvaldsen et al. (2015) had a weak study design and there was no effect size because it was a descriptive study without quantitative data. Semi-structured interviews and incident reports were used as data. Bias was moderate since the researchers were careful to survey people from farms of different sizes, different access to technology and geographic distribution, although it was all conducted within Norway. The sample size was small with only 12 respondents participating in the survey. The study weakly supported the proposition.

Jensen et al. (2010) had study design that, although was descriptive, included correlations, a literature review and case studies, thus making it more robust. The effect size was large, with fish escapes dropping to a third of their original number in 8 short years (2001 – 2009). The data were provided by the Norwegian Aquaculture Escape Commission and included detailed reports of all escape events for the time period. Bias was considered moderate due to the selection of references and cases studies. Extrapolation was very large because the correlation analysis does not imply causation; it only has data from Norway and for a short time period. Furthermore, variables other than equipment were not considered. The study moderately supported the proposition.

Table 5.5. The strength of evidence of proposition 1.d: Prevention of salmon escape decreases the number of farmed Atlantic salmon in wild populations of salmon.

References	SOE
Thorvaldsen et al., 2015	2
Jensen et al., 2010	0
Flammang et al., 2014	3
Heino et al., 2014	2
Skilbrei, 2012	4
Uglem et al., 2013	4
Average	**2.5**

Justification

The design used by Thorvaldsen et al. (2015) was weak because it was a descriptive study and it only relied on one incident report describing the escape of farmed fish into the ocean when the physical barrier was removed. The effect size is irrelevant in this context and the sample size is one. The selection of the one incident report could be considered a bias. There is high degree of extrapolation because the event referred to occurred in Norway. There are assumptions that escapes occur every time physical barriers are removed and that salmon behaviour are similar in both countries. In Thorvaldsen et al. (2015), the study did not support or contradict the proposition.

Jensen et al. (2010) used a study design that was weak because it was descriptive and only used one set of data provided by the Norwegian Aquaculture Escape Commission. However, the data were reliable and should include data on all escape cases and there was little possibility for bias. The effect size was quite large: the prevention of the large-scale events (>10 000 individuals) happened only 19 percent of the time, while they accounting for 91 percent of fish escapes. The extrapolation level between the study and the proposition is quite large because data were only collected in Norway. There is the assumption that these data can be applied to the prevention of having Atlantic salmon cultivated in the Pacific Ocean. Jensen et al. (2010) supported weakly the proposition.

Flammang et al. (2014) made a hypothesis-driven experiment and that had a strong study design. The testing had the proper controls. The experiment was randomized and repeated 35 times to reduce biases to a minimum. The sample size was moderate at 28 fish. The effect size was also quite large since 89.3 percent of fish escaped when barriers were absent compared to 0 percent with physical barriers (prevention of escape). However, the level of extrapolation was high. Although the research supported that prevention of escape will reduce the number of fish escapes, this experiment was conducted in order to test the reaction of walleyes to non-physical barriers. The experiment was conducted in the United States, in a freshwater reservoir used for sport-fishing rather than aquaculture. Thus, it must be assumed that fish behaviour is the same regardless of the species. Flammang et al. (2014) moderately supported the proposition.

Heino et al. (2014) used empirical data from another study to model the introgression rate of farmed salmon into wild populations. One of the main variables was the percentage of farmed salmon in the wild population. This variable, which was supported by empirical data, suggested that the absence of an escape prevention strategy has resulted in farmed salmon in the wild population. However, since the researchers did not collect the data themselves, the study design was weak. The sample size was moderate with 20 rivers sampled and the effect size was extremely variable going from about 5 percent to 90 percent. The potential for bias as low. However, the level of extrapolation is quite high, since it must be assumed that the prevention of escape would have resulted in less salmon mixing in the wild population. There is also a large amount of generalization to be made in order to apply the results from this study to the Canadian context, since the experiment was conducted in Norwegian rivers. Heino et al. (2014) somewhat supported the proposition.

Skilbrei (2012) was part of a descriptive study: researchers released tagged, farmed Atlantic salmon and then measured the recapture rates. This experiment was repeated six times. The sample size was very large since 11,915 fish were released. The potential for bias was also minimized. The effect size was small; the recapture rate was only 1 percent. The degree of extrapolation is moderate. The experiment was conducted in a real ecosystem and included rivers, coasts and a large geographic distribution (some salmon were recovered more than 100 km away from the release site), thus reducing the degree of extrapolation. However, to support the proposition, it must be assumed that the released salmon integrated into the wild population and that the results from Norway can be applied directly to the Canadian context. Skilbrei (2012) supported well the proposition that the prevention of farmed salmon escapes decreases the number of farmed Atlantic salmon in wild populations of salmon.

Uglem et al. (2013) released marked, farmed Atlantic salmon from an aquaculture facility and noted their behaviour. It was a descriptive experiment and although it was conducted in real conditions, controls were inserted into the design. The experiment did not include repetitions. Bias was decreased by random sampling of fish. The sample size was 47, which is moderately large. The effect size was significant; only 4 salmon died and most of them left the facility quickly upon release. About half of the fish spread from the shore to the ocean in a day. Since the study was conducted in nature, the degree of extrapolation is low. However, it must be assumed that the released fish integrated into the wild population and that these Norwegian results can be applied to the Canadian context. Uglem et al. (2013) supported the proposition well.

Table 5.6. The strength of evidence of proposition 1.e: Less farmed Atlantic salmon in the Pacific Ocean decreases introgression rate between farmed and wild salmon.

References	SOE
Skjæraasen et al., 2010	3
Castillo et al., 2008	3
Fraser et al., 2010	4
McGinnity et al., 2003	3
Clifford et al., 1998	3
Average	**3.2**

Justification

Skjæraasen et al. (2010) used an experimental design to examine mating between farmed and wild fish. It was a descriptive study with quantitative data. The experimental setting allowed for many controls. The sample size of 64 fish was considered moderate and there was a low possibility of bias. The effect size was significant; about half of the eggs laid by farmed females were sired by wild males. However, the extrapolation level is large because the experiment was conducted on farmed and wild cod in Norway, rather than on salmon in Canada. Furthermore, the extrapolation degree is increased because the study was conducted in an experimental setting. It is quite possible that both farmed and wild fish would have had different behaviour in their natural ecosystem. Skjæraasen et al. (2010) moderately supported the proposition.

Castillo et al. (2008) supported the proposition by examining the interspecific and intraspecific hybridization events that occurred in the wild over the course of three generations when domesticated brown trout and Atlantic salmon were released in rivers. The study was descriptive and it occurred in a natural setting with little or no controls. The experiment was conducted from 1984 to 2004 and took place in rivers in France and in Spain. The potential for bias was small and the sample size was large with over 2000 salmons released. The effect size, on the other hand, was quite small as hybridization only varied from 3.5 percent to 0.7 percent when the release of domesticated fish was halted. The degree of extrapolation is moderate because the experiment was conducted in a natural setting. However, the examined hybridization included Atlantic salmon and brown trout. Perhaps this would not occur with the wild population of the different species of salmon found in the Pacific Ocean. It is also possible that the European results might not be representative of what would happen in Canada. Castillo et al. (2008) supported the proposition.

Fraser et al. (2010) bred, in experimental conditions, wild and farmed strains of Atlantic salmon in order to identify fitness differences. The experimental setting allowed for multiple controls to be included in the design, but the experiment was not repeated. Randomization in the selection of individuals from each strain reduced potential biases. The sample size was quite large; each strain having about 500 eggs. The effect size was enormous; the breeding of the wild and farmed strain yielded well over 3000 eggs, although breeding in between farm fish and in between wild fish yielded more. The degree of extrapolation of the data is moderate. The experiment took place in Canada and the fish species used was Atlantic salmon. However, the unnatural setting of the experiment limits the applicability of the results to natural ecosystems. Furthermore, the experiment was conducted with three strains of Atlantic salmon and did not include Pacific species of salmon. Therefore, it is unknown if similar results would be achieved with Pacific species of salmon. Fraser et al. (2010) supported the proposition with convincing evidence.

McGinnity et al. (2003) bred wild and farmed salmon to study the difference in reproductive success, among others. The part of the study supporting the proposition was conducted in a man-made hatchery, which allowed for significant control. The study was conducted over a large period of time (1993-1998). The potential for bias was limited by randomization of the selection of eggs and the large sample size of 523 eggs. The results showed no significant difference between egg mortality of two wild salmon versus farmed and wild salmon. However, the mating of two hybrids produced higher levels of egg mortality. The effect size is thus large. Extrapolation was moderate because the experiment was conducted with strains of Atlantic salmon only rather than different species of salmon. Furthermore, the research was conducted in Ireland and in an artificial setting. McGinnity et al. (2003) moderately supported the proposition.

Clifford et al. (1998) used an experiment specifically designed to identify the prevalence of hybridization between farmed Atlantic salmon escaped from a fish farm in Ireland and wild fish. Using 8 different sampling sites and an eight-year time period (1987-1995), Clifford et al. (1998) collected fish from four streams surrounding an aquaculture facility and used genetic alteration to identify hybrids. The study design did not have strong controls, such as the measures of the level of hybridization in stream located in areas where aquaculture facilities are prohibited. Potential of bias is minimal, although site selection might have favoured one type of fish over another. The sample size was 27, which is average. The effect size was quite variable; in 1993 it was around 18 percent, while in 1995 it was 2 percent. These results mean that in two years the researcher found that hybridization was 9 times lower. Although the study was conducted in a natural setting, the extrapolation level is still elevated, because the experiment was only conducted in 4 Irish streams and only on Atlantic salmon. The results must be generalized considerably in order to apply to Canada's Western Coast. Clifford et al. (1998) moderately supported the proposition.

Table 5.7. The strength of evidence of proposition 1.f: Less introgression increases genetic diversity[6] in wild population.

References	SOE
Chelenkova et al., 2012	-2
Hutchings and Fraser, 2008	1
Coughlan et al., 2006	2
Bourret et al., 2011	-4
Average	**-0.8**

Justification

Chelenkova et al. (2012) tested whether fish escapes from aquaculture facilities induce a reduction in the genetic diversity of wild population. The results indicated a reduction, although it was not a consequence of introgression, but rather assertive mating in the wild population, probably from the presence of escaped fish. The study was conducted in laboratory using DNA provided by the DNA bank of the National Agency for Fish and Aquaculture. The samples were collected randomly, thus reducing potential biases. 146 DNA samples were analysed and the

[6] In this project, genetic diversity will be measured by allele richness and heterozygosity.

results showed that heterozygosity was 44 percent lower than expected in both wild and farmed fish populations. Therefore, the experiment had both high sample size and high effect size. However, there is a great deal of extrapolation, as there is minimal knowledge on the fishes' environmental conditions prior to the harvesting of their DNA. Furthermore, the study was conducted on populations of brown trout in Bulgaria and not on Canadian salmon population. As such, the result might have been quite different in that context. Chelenkova et al. (2012) did not support the proposition.

Hutchings and Fraser (2008) did a literature review that was not very convincing, as they chose not to include the methodology they used to find their sources. The potential for bias is, therefore, extremely high. Overall, the study cited five studies supporting a reduction in wild fishes' genetic variability as an impact of outbreeding with escaped farmed fish. The extrapolation is very high because the type of fish and the type of experiment used to support the reduction of genetic diversity in wild populations are unknown and might not be applicable. This literature review did not strongly support the proposition.

Coughlan et al. (2006) examined DNA from fish before and during the operation of an aquaculture facility. The DNA was provided by the Marine Institute's archived scale collection for the years 1958, 1980, 1989, 1990 and 1995, which represent years before the fish farm and after the fish farm began. The study was conducted in a laboratory and used correlation. The researchers had little control over other environmental factors that could have yielded changes in gene diversity. The potential for bias was low and the sample size was moderate to high depending on the years. The effect size was moderate; the experiment showed 8.1 percent more heterozygosity than expected between 1958 and 1980. Extrapolation levels are quite high because a correlation study does not imply causation and the study was conducted in a laboratory. Therefore, it cannot be assumed that the escaped fish from the aquaculture facility really caused the decrease in genetic diversity in the wild populations. Furthermore, the study was made on sea trout in Ireland. The results might not be applicable to Atlantic salmon along Canada's West coast. Coughlan et al. (2006) had little strength of evidence supporting the proposition.

Bourret et al. (2011) set out to examine the genetic diversity of a wild population of Atlantic salmon when farmed salmon were also present. Although the study showed that introgression had occurred between both strains of fish, the genetic variability was not different. This experiment occurred in a natural ecosystem and salmon were sampled for about 20 years (1980-2000). The potential for bias was low, although perhaps the adult individuals that were sampled had a predisposition for being caught. The sample size was average; adult wild fish sample sizes were 31, 60 and 34 all of which had their DNA analysed in 1980, 1992 and 2000, respectively. Genetic diversity between all the groups examined was not significantly different, with a p-value of about 0.9. Extrapolation is low. The experiment was conducted in Eastern Canada on Atlantic salmon. However, since the study was only conducted in one population, the results are a bit less robust. Furthermore, the conclusions might not be applicable to the Western

Coast of Canada, because of the different species of salmon present. Bourret et al. (2011) strongly opposed the proposition.

Table 5.8. The strength of evidence of proposition 1.g: Genetic diversity increases wild population resilience[7].

References	SOE
Haak and Williams, 2012	2
Braun et al., 2016	4
Verspoor, 1997	2
Evans et al., 2012	3
Stewart Grant, 2012	3
Average	**2.8**

Justification

Haak and Williams (2012) attempted to defend the hypothesis that genetic variability was, among other variables, responsible for the conservation of fish population (population resilience). However, they used a proxy, genetic purity of the population, to assess genetic diversity. Furthermore, the data for genetic purity was gathered by various organizations across the US; some of them used expert opinions to make the assessment. This increases the potential for bias. The sample size was quite large, involving 306 populations. The effect size was also impressive: 70 percent of the population that had genetic purity was resilient. The extrapolation level was quite high, because the study was conducted on cutthroat trout in the United States. Therefore, the requirements for resilience might be different in salmon populations in Canada. Haak and Williams (2012) did not strongly support the proposition.

[7] Resilience, in the context of this project, is defined as the capacity of an individual or of a population to adapt to diseases and environmental changes.

Braun et al. (2016), in this experiment, linked genetic diversity to diversity in behaviours to population resilience to changing environmental conditions. The experiment was conducted in a natural setting and used correlation analysis to interpret their results. The potential for bias was low. The sample size was quite large; 41 populations were used in the experiment. The effect size was moderate: the study showed a correlation of -0.16 between genetic diversity and changes in behaviours. Furthermore, the extrapolation is low, because the experiment was conducted on Chinook salmon populations in the Fraser River in British Canada. However, the study was only correlative and to assume causation still requires too much generalizing. Braun et al. (2016) have well-supported their hypothesis that genetic diversity increases wild population resilience.

Verspoor (1997) aimed to do a systematic review of the current knowledge on genetic diversity in wild and farmed escaped salmon and its implications, including how genetic diversity increases population survival. However, the potential for bias in this review was quite high, because the author did not include his methodology for the selection of experiments that were used in his study. Normally, systematic reviews have a high value in terms of study design and the extrapolation levels are low. However, in this case, the review was conducted in 1997. As such, scientific evidence might have changed greatly since then. Therefore, in this case, the degree of extrapolation is quite high. Verspoor (1997) supported weakly the proposition.

Evans et al. (2012) conducted a study in order to determine the impact of genetic variability on resilience, defined as reproductive success and offspring's survival over a three-year time period. The experiment was conducted in a controlled environment and the potential for bias was generally low. The sample sizes were quite large; 650, 352 and 177 fish were sampled in 1996, 1997 and 1998 respectively. The results indicated that reproductive success was maximized when the genetic difference between parents was around 20 on a scale of 0 to 35. Furthermore, offspring's survival was maximized with genetic diversity in the parents. This experiment must, however, be extrapolated to support the proposition. The experiment was conducted using Atlantic salmon in Quebec, where the species is native and therefore reproduction with other Atlantic salmon, rather than on species of wild salmon from the Pacific Ocean. Also, the researchers studied intrapopulation resilience rather than the resilience of the population in general. Evans et al. (2012) moderately supported proposition.

Stewart Grant (2012) moderately supported by the positive relationship between genetic diversity and population resilience. The study consists of a systematic review of the current knowledge on the results of the interactions between farmed and wild Alaskan salmon. The author might have been biased during his review because he did not include its methodology related to article selection criteria. Although the review is quite robust and applies to populations of Pacific salmon on the West Coast of North America, the need for extrapolation is still significant because the author specified that reduction in genetic variability may cause reduction in the population's resilience to environmental factors. This statement was only corroborated by three studies, one of them being by Verspoor (1997), which itself is a review. Stewart Grant

(2012) moderately supported by the positive relationship between genetic diversity and population resilience.

Table 5.9. The strength of evidence of proposition 1.h: Population resilience decreases biodiversity loss.

References	SOE
N/A	0
Average	**0**

Justification

In the literature surveyed it was impossible to find scientific evidence that supported or contradicted the proposition. The steps taken to research this proposition can be seen in detail the appendix. These results indicate the likely presence of a gap in the scientific literature. Research has not been conducted to prove or disprove the relationship between population resilience and survival, and subsequent reduction of biodiversity loss. For the Canadian policy currently under examination, this lack of evidence indicates, that an assumption is being made regarding the efficiency of equipment and maintenance regulations as a mean to reduce biodiversity loss.

Table 5.10. The strength of evidence of proposition 1.i: Less farmed Atlantic salmon in the Pacific Ocean decreases the competition with wild populations of salmon for resources.

References	SOE
Naylor et al., 2005	-2
Nash, 2003	-1
Fleming et al., 2016	3
Metcalfe et al., 2003	-3
Einum and Fleming, 1997	2
Average	**-0.2**

Justification

Naylor et al (2005) conducted a risk assessment of the impacts of salmon escapes on wild populations across the world. Although they were able to determine that the aggressive behaviour of farmed and hybrid salmon increased pressure for territory on the native population, they noted that there was not a significant competition for food from Atlantic salmon, because it is not a native species. However, these results might change with increased numbers of farmed fish and fish escaping from them. Furthermore, their assessment of the absence of competition for food was only based on two studies. There is a potential for bias in this risk assessment because the methodology pertaining to the selection of literature reviewed for the project was not mentioned. The degree of extrapolation is low, since they specifically targeted Atlantic salmon that escaped into the Pacific Ocean. Nevertheless, the number of studies supporting this fact is minimal and there is no assessment of the quality of those experiments. Naylor et al (2005) supported a hypothesis that is in contradiction with the proposition.

Nash (2003) examined five literature reviews regarding the impacts of Atlantic salmon on the Pacific Ocean. First, the author did not include any in-text citations. Second, the potential for bias is very high, since the author did not explain the reasons behind the selection of the literature reviewed. Furthermore, the author classified each issue according to its risk level. However, he did not include the criteria used for such characterization. The review indicated that the risk of competition between Atlantic salmon and native species was low to inexistent. The level of extrapolation is relatively low, because the review pertained to the escape of Atlantic salmon in North-western Pacific water, in an area immediately south of the British Columbia Coast. While the study contradicts the proposition, this review is really weak.

Fleming et al. (2016) used a controlled natural setting with tagged fish to identify the impacts of farmed Atlantic salmon on the native population. Risk of bias was high, since, for identification purposes, the biologists selected salmon with certain alleles, which might have impacted the results. The sample size and the effect size were average at 39 and 30 percent respectively. Extrapolation was moderate, since the study was conducted in a Norwegian river, where Atlantic salmon is actually native, as opposed to the Pacific Ocean. Fleming et al. (2016) supported the proposition.

Metcalfe et al. (2003) conducted a study in order to observe territorial competition between wild and farmed Atlantic salmon and was conducted in an experimental setting. The authors concluded that although farmed individuals normally reported more aggressive behaviour, they lose their dominance over wild resident fish, meaning that they would lose a territorial dispute in the wild. The potential for bias in the experiment was minimal. The sample size was between 45 and 195 territorial encounters depending on the experiment. The effect size was large; when a wild fish was given residence over a territory it would win an encounter with a farmed salmon about 7 times out of 10. Unfortunately, the extrapolation level for this experiment is quite high, because it was conducted between Norwegian populations of Atlantic salmon, as opposed to Canadian Atlantic salmon and Pacific salmon species and it occurred in an artificial setting. Metcalfe et al. (2003) disagreed that a competition for resources exist between escaped Atlantic salmon and wild Pacific salmons.

Einum and Fleming (1997) made an experimental study that was conducted in an artificial setting and it was designed to examine territorial competitions between wild and farmed Atlantic salmon, similarly to the previous experiment. However, they did not use the same type of controls to try and recreate conditions that were more likely to occur in the wild. Therefore, their results are opposite to those of Metcalfe et al. (2003). The potential for bias was minimal. The sample size was 30 territorial encounters and the effect size was 61 percent. The extrapolation is similar to that of the previously mentioned study. Norwegian Atlantic salmon were also studied. However, the lack of measures taken to increase the similarities with natural settings increased the degree of extrapolation. Einum and Fleming (1997) did not strongly support the proposition.

Table 5.11. The strength of evidence of proposition 1.j: Less competition from farmed Atlantic salmon for resources decreases biodiversity loss.

References	SOE
Ruggerone et al., 2012	4
Einum et al., 2008	2
Ruggerone and Goetz, 2004	4
Sturdevant et al., 2012	3
Average	**3.3**

Justification

Ruggerone et al. (2012) made a regression analysis indicating a negative correlation between the abundance of farmed Chum salmon and wild Chum salmon in the Northern Pacific Ocean. The data were obtained from the Alaska Department of Fish and Game and a number of variables were included as controls. However, although the choice of variables was comprehensive, they were subjective and could have created a bias in the results. The sample size was enormous; almost 38 million individual values were computed. The effect size is also quite remarkable, as 72 percent of wild salmon declined following the increase in aquaculture facilities. Extrapolation levels are considered low because the regression was completed on salmon species in the Northern Pacific Ocean, not too far from BC. Ruggerone et al. (2012) supported the proposition.

Einum et al. (2008) made a spatial population model not designed to examine the relationship between farmed and wild Atlantic salmon in any way. However, the authors were able to conclude that competition between different populations of Atlantic salmon in the same ecosystem will likely lead to a decrease in the abundance of adult in the populations (biodiversity loss). The potential for bias is low, while extrapolation is still quite high, since this model was not tested in an artificial or a natural setting. Furthermore, it is possible that competition with individuals that have been farmed would have different results. Einum et al. (2008) weakly supported the proposition.

Ruggerone and Goetz (2004) conducted a study using tagged Chinook salmon that were released in the streams near Puget Sound in years contrary to their lifecycle, therefore creating an artificial competition with Pink salmon. For the duration of the experiment (1984-1997) Chinook salmon were also released in the streams throughout their normal lifecycle years. As such, they did not compete with pink salmon and were used as a control group. The potential for bias for this experiment was low and the sample size was extremely large. About 53 million Chinook salmon were released and more than a million were recaptured and analysed. The effect size was impressive; Chinook salmon competing with pink salmon suffered a reduction in population by 59 percent compared to the control group. Extrapolation was pretty low, since the experiment was conducted on species of Pacific salmon in an area adjacent to BC. Ruggerone and Goetz (2004) well-supported the proposition by their experiment.

Sturdevant et al. (2012) examined the correlation between the feeding intensity of farmed chum salmon and the abundance of wild chum salmon. The authors concluded that there was a negative correlation between both, although it is impossible to attribute causality. The potential for bias was minor. The sample size was large: 3123 fish were sampled during a two-year period (2004-2005). The correlation factor between the farmed salmon feeding intensity and wild salmon abundance was only -0.14, which is a small effect size. However, using this number to imply that competition between farmed and wild salmon causes a decrease in the abundance of the latter (biodiversity loss) would require a large extrapolation of the results. Furthermore, the study was conducted in Alaska and only lasted two years. Sturdevant et al. (2012) moderately supported by the study.

Table 5.12. Summary of the strength of evidence for each proposition.

Proposition	SOE
1.a. Maintenance of the equipment increases the prevention of salmon escape.	2
1.b. Quality of the equipment increase the prevention of salmon escape.	2
1.c. Quality of the installation increases the prevention of salmon escape.	2
1.d. Prevention of salmon escape decreases the number of Atlantic salmon in wild populations of salmon.	2.5
1.e. Less Atlantic salmon (farmed) in the Pacific Ocean decreases introgression rate between farmed and wild salmon.	3.2
1.f. Less hybridization increases genetic diversity in wild population.	-0.8
1.g. Genetic diversity increases wild population resilience.	2.8
1.h. Population resilience decreases biodiversity loss.	0
1.i. Less Atlantic salmon in the Pacific Ocean decreases the competition with wild population of salmon for the resources.	-0.2
1.j. Less competition for resources decreases biodiversity loss.	3.3

Table 5.12 presents the strength of evidence of all the previously examined propositions. The negative strength of evidence of propositions 1.f and 1.e indicate that currently scientific research does not support these hypotheses[8]. However, their small values also indicate that scientific evidence is not very compelling. Since there is a low strength of evidence in respect to the impacts of hybridization on genetic diversity, population resilience on biodiversity loss and competition for resources between Atlantic salmon and wild populations, the environmental effectiveness of the policy is not well supported.

[8] Refer to the appendix for the complete methodology regarding how the references were obtained.

5.1.3. Mass of Evidence

Table 5.13. The mass of evidence of the propositions underlying the policy on the prevention of salmon escape in Canada.

Proposition	Total references	Pertinent references	Percent of pertinent references (%)	MOE
1.a. Maintenance of the equipment increases the prevention of salmon escape.	20	2	10	1
1.b. Quality of the equipment increase the prevention of salmon escape.	20	2	10	1
1.c. Quality of the installation increases the prevention of salmon escape.	20	2	10	1
1.d. Prevention of salmon escape decreases the number of Atlantic salmon in wild populations of salmon.	23	6	26	3
1.e. Less Atlantic salmon (farmed) in the Pacific Ocean decreases introgression rate between farmed and wild salmon.	12	5	42	3
1.f. Less hybridization increases genetic diversity in wild population.	23	4	17	2
1.g. Genetic diversity increases wild population resilience.	24	5	21	2
1.h. Population resilience decreases biodiversity loss.	19	0	0	0
1.i. Less Atlantic salmon in the Pacific Ocean decreases the competition with wild populations of salmon for the resources.	17	5	29	3
1.j. Less competition for resources decreases biodiversity loss.	17	4	24	2

5.1.4. Weight of Evidence

Table 5.14. The weight of evidence of the propositions underlying the policy on the prevention of salmon escape in Canada.

Propositions	SOE [-5,5]	MOE [0,5]	WOE [-25,25]
1.a. Maintenance of the equipment increases the prevention of salmon escape.	2	1	2
1.b. Quality of the equipment increase the prevention of salmon escape.	2	1	2
1.c. Quality of the installation increases the prevention of salmon escape.	2	1	2
1.d. Prevention of salmon escape decreases the number of Atlantic salmon in wild populations of salmon.	3	3	9
1.e. Less Atlantic salmon (farmed) in the Pacific Ocean decreases introgression rate farmed and wild salmon (hybridization).	3	3	9
1.f. Less hybridization increases genetic diversity in wild population.	-1	2	-2
1.g. Genetic diversity increases wild population resilience.	3	2	6
1.h. Population resilience decreases biodiversity loss.	0	0	0
1.i. Less Atlantic salmon in the Pacific Ocean decreases the competition with wild population of salmon for the resources.	0	3	0
1.j. Less competition for resources decreases biodiversity loss.	6	2	6
Policy WOE	**3**		

In 2015, the federal government consolidated the *Pacific Aquaculture Regulations* Act, which had a specific section addressing the prevention of fish escapes through the use and maintenance of specific equipment. According to the previous analysis, based on scientific evidence, the environmental effectiveness of such policy can be questioned. The weight of evidence, meaning the evidentiary strength for this regulation, is only 3 out of 25, which is quite weak. There are a few possible explanations for the lack of a strong support pertaining to the prevention of fish escapes through the equipment quality and maintenance. First, it seems that little scientific research has been done on certain propositions, namely the link between equipment and fish escapes. Most people would assume that this relationship is obvious and should not be examined. However, perhaps equipment failure can only account for a small part of fish escapes, while human errors or interactions with predators might be stronger contributors (Jensen et al., 2010; Thorvaldsen et al., 2015). Therefore, although the propositions cannot be identified as wrong, they cannot be considered correct either. Secondly, the scientific literature still contains conflicting ideas about the survival of farmed fish in the wild. While some researchers will infer successful integration (access to food, territory and ability to reproduce) of farmed fish into natural ecosystems, others are positive that most farmed fish have reduced fitness and cannot adapt to the new conditions (Bourret et al., 2011; Metcalfe et al., 2003; Sturdevant et al., 2012). As long as consensus cannot be achieved on the subject, achieving a strong weight of evidence will be difficult. Finally, many conservation theories that are well-known in a terrestrial context have yet to be studied in a marine environment, therefore creating a significant assumption pertaining to their applicability for aquaculture and fishery management (Mcclure et al., 2013).

5.2. Economic efficiency

Nevertheless, the economic impact of a policy is another important criterion in evaluating its performance and it is included in the evaluation framework of Environment and Climate Change Canada (Audit and Evaluation Branch, 2016; Audit and Evaluation, 2013). The Canadian policy on the prevention of fish escapes through equipment quality and maintenance enabled by the *Pacific Aquaculture Act* (2015) and applied through licensing employs a command and control approach to regulation. The legislation prescribes exactly what equipment should be used and when and how maintenance must be conducted (Fisheries and Oceans Canada, 2010). Therefore, it does not leave any flexibility to the industry in the application of the policy and, as such, it does not seem to indicate cost-effectiveness.

The standards pertaining to equipment and maintenance may create an increase in production cost because of higher demand on a limited amount of equipment suppliers and the increased cost of regular maintenance. Canada, although the third largest producer of farmed Atlantic salmon in the world, has only a small share of the global market and cannot influence the price of salmon. Consequently, higher production costs could render the Canadian aquaculture industry less competitive (Young & Matthews, 2010). This potential reduction in competitiveness is even more of a threat in Canada, since the country is competing with Chile, which has lower production costs, for the American market (Marine Harvest, 2015; Young & Matthews, 2010).

Compliance costs can be considered moderate. As mentioned previously, there is a risk of increased production cost from the need to use specific equipment. However, since the requirement for equipment and maintenance have been stipulated in Annexe IX of the *Finfish Aquaculture License* (2010), any industry requesting a license is forewarned of the costs associated with the equipment needed for the facility before it can begin running.

5.3. Fairness

The policy's fairness is another important aspect of its overall evaluation. The command and control approach of this regulation applies the same standards to everyone. However, the potential increase in production price may play out in one of two ways. First, the limited capacity of the industry to increase its prices because of global competition might decrease its overall profit. Thus, the burden of the policy would be assumed by the industry. Second, the industry might reduce its production cost by reducing its number of employees, which would impact coastal communities that depend on aquaculture facilities for their livelihood. The burden of the policy would then be assumed by the local communities. Overall, it is more likely the weight of the regulation is shared by both of these stakeholders. Therefore, the policy is considered slightly unfair.

5.4. Simplicity

The licensing scheme requires each aquaculture facility to be registered in order to operate, according to the *Pacific Aquaculture Act* (2015). The license contains detailed information about the facility, the fish cultivated, the design of the infrastructure, the location, the size of the operation, including the number of fish permitted and more. It also includes information about what reports must be conducted when, such as maintenance reports, and for how long they must be kept. All this information must then be available at the request of the governmental officers responsible for monitoring aquaculture facilities (Fisheries and Oceans Canada, 2014). This documentation facilitates the enforcement of regulations. Any breach of the conditions issued with the license is liable to submit its holder to fines and even imprisonment. However, the process to issue a license and ensure that conditions are met prior to authorizing the facility to be operational increases the administrative burden imposed on the government. Therefore, the policy to prevent Atlantic salmon escapes into the Pacific Ocean through licensing conditions is moderately simple.

6. Creation of protected areas for the protection of wild salmon in Norway

Although Norway similarly possesses policies about the quality and the maintenance of the equipment used in aquaculture facilities, the Norwegian *Aquaculture Act* (2011) also gives the Ministry the right to create protected areas. According to Chapter § 14 *Protection of specific areas* of the previously mentioned act:

> The Ministry may establish a ban, order relocation or place other conditions on aquaculture activities if such actions are necessary to protect areas of special value to aquatic organisms (*Wild salmon protected areas*) (Norwegian Ministry of Fisheries and Coastal Affairs, 2006).

In the last few years, the Norwegian Parliament has granted itself of this right and has established several protected areas, called National Salmon Fjords and National Salmon Rivers, to help preserve wild salmon populations. In these areas, new facilities cannot be established, while current ones were disbanded in 2011 (FAO, 2010). The objective behind this policy was obviously to improve the protection of wild Atlantic salmon in Norway and effectively reduce biodiversity losses caused by aquaculture activities.

The Norwegian *Aquaculture Act* (2011) Chapter § 14 *Protection of specific areas* allows the Ministry to create special protected areas, such as national salmon fjords, to preserve wild Atlantic salmon populations. According to the Norwegian Ministry of Fisheries and Coastal Affairs (2006) these protected areas ban aquaculture facilities in order to protect wild population of salmon from escaped farmed Atlantic salmon. National salmon fjords would increase the protection of wild salmon population and therefore increase the number of fish in each population, as well as the number of population in a geographically defined area. A larger population of wild salmon would then likely have a greater genetic variability which would improve genetic variability, population resilience and therefore increase the survival rate of wild Atlantic salmon populations in Norway. An improved survival rate would then decrease the likelihood of a population decline leading to biodiversity loss.

6.1. Environmental effectiveness

6.1.1. Cognitive mapping

Figure 6.1 Deconstruction of the policy on wild Atlantic salmon protected areas in Norway.

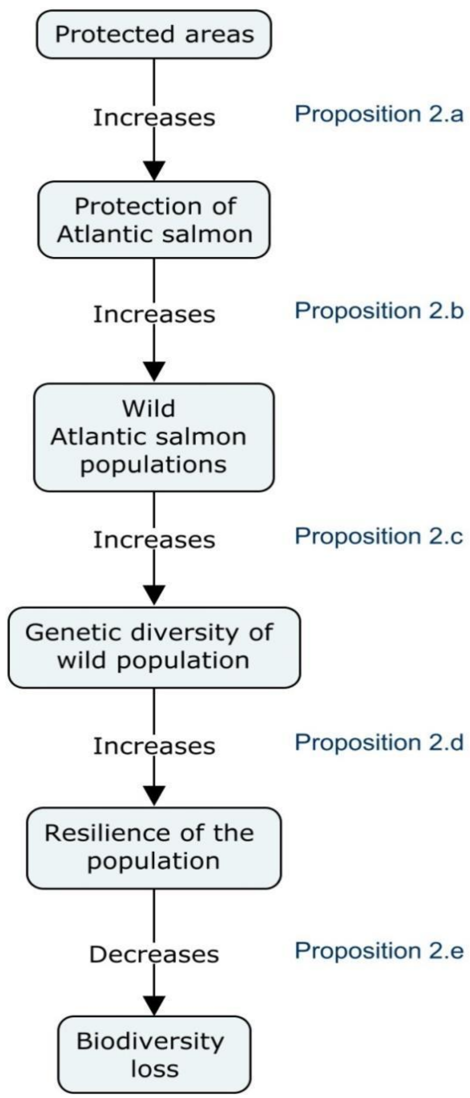


Figure 6.1 is a visual representation of all the different hypothesis (proposition), that must be supported in order for the Norwegian policy on the establishment of national protected areas for wild salmon as a way to achieve a reduction in biodiversity loss be evidence-based. Therefore, each propositions will be tested by assessing how well (weight of evidence) it is defended in the scientific literature. The following pages will examine the strength of evidence for each propositions separately by evaluating scientific studies individually.

6.1.2. Strength of evidence

Table 6.1. The strength of evidence of proposition 2.a: Protected areas increase the protection of wild Atlantic salmon wild populations.

References	SOE
Haberstock et al., 2001	-1
MacInnis et al., 2008	-3
Morton et al., 2005	4
Average	**0**

Justification

Haberstock et al. (2001) suggest that the efficiency of a freshwater protected area depends on the size of its terrestrial buffer zones. Therefore, the conservation of Atlantic salmon in Norway cannot be ensured by the Norwegian *Aquaculture Act* (2011), because it does not give the Ministry the authority to create terrestrial buffer zones around wild salmon habitat. However, this part of the study was only a literature review and therefore, the authors could have been biased since they did not include their research methodology. Furthermore, the number and the nature of papers sampled were not provided. The experiment and the literature review of the study claimed that buffer zones, to be effective, must be between 21m and 91m. The level of extrapolation is quite high, since the results from the literature review may not apply to the reality. However, the results did relate to the protection of Atlantic salmon. Haberstock et al. (2001) weakly opposed the proposition.

According to MacInnis et al. (2008), the protection of wild Atlantic salmon is better served by restoring the banks surrounding the rivers. This experiment was conducted in a natural setting, a river which had its surrounding clear cut by the logging industry. Using 250 digger logs and bank deflectors, the researchers recreated the natural state of the area. Each year, they counted the number of salmon nests that were present. The potential for bias in this study was minimal and they counted every nest, every year, creating a large sample size. The effect size is quite impressive; the number of nest rose from 43 in 1992 to 592 in 1996. The level of extrapolation is moderate, because this experiment was conducted in only one Canadian river. As such, there is a lack of repetition and it might not apply to the Norwegian context, although wild Atlantic salmon were studied. MacInnis et al. (2008) contradicted the proposition.

Morton et al. (2005) examined 4 fish farming sites where Atlantic salmon were removed (fallowing) during the migration of wild Pacific salmon in order to reduce the risk of infection by sea louse. These are similar conditions to the ones created in Norway by the creation of protected areas. The facilities and the farmed Atlantic salmon were removed from areas populated by wild Atlantic salmon. Therefore, protection against sea louse infection was also possible. The experiment had low potential for biases and had a very large sample size. Every year, between

800 and 1200 salmons were sampled. The year Atlantic salmons were temporally removed from their net-cages, there were 8.9 times less sea louse on the migrating fish. Extrapolation is quite high because the study was conducted in Canada on Pacific salmon. It is possible that differences in water quality and in species' behaviour could have an impact on the dispersal of sea louse in Norwegian waters. Morton et al. (2005) strongly supported the proposition.

Table 6.2. The strength of evidence of proposition 2.b: Protection of wild Atlantic salmon populations increases the abundance of wild populations.

References	SOE
N/A	0
Average	**0**

In the literature surveyed it was impossible to find scientific evidence that supported or contradicted the proposition. The steps taken to research this proposition can be seen in detail the appendix. These results indicate the likely presence of a gap in the scientific literature. Research has not been conducted to prove or disprove the relationship between the protection of wild Atlantic salmon and the abundance of wild population in Norwegian water. This lack of evidence indicates, that an assumption is being made regarding the efficiency of protected areas as a mean to reduce biodiversity loss.

Table 6.3. The strength of evidence of proposition 2.c: The abundance of wild populations increases the genetic diversity of wild populations.

References	SOE
Ozerov et al., 2013	2
Consuegra et al., 2005	-4
Fraser et al., 2007	-2
Average	**-1.3**

Justification

Using genetic material samples of 16 anadromous species of wild salmonids, Ozerov et al. (2013) identified a correlation between population size which, was determined by fishing pressure, and genetic diversity. The potential for bias was low. The sample size was small which made it relatively weak, since only 18 samples were compared. On the other hand, the effect size was medium with a correlation coefficient of -0.51. The level of extrapolation is quite high since this hypothesis was only supported by a correlation made with a small sample size. Furthermore, the experiment was conducted in Russian rivers, on different species of salmonids. Ozerov et al. (2013) weakly supported the proposition.

Consuegra et al. (2005) strongly opposed the proposition. Once again, Consuegra et al. (2005) used genetic analysis, in a laboratory setting to compare DNA samples from different populations. In total, 3 large populations of Atlantic salmon in Scotland were sampled as well as 4 small populations of Atlantic salmon in Iberia. They also conducted a historical analysis, going back 50 years, with the DNA of one of the smaller population. The potential for bias was low because two analyses were used to validate the results. However, the definition of a small and a large population is subjective. The sample size is quite large. Over 700 samples were analysed throughout the study. The effect size was impressive, because there were no significant differences in the genetic diversity of the seven populations when measured by both allele richness and heterozygosity. However, these results might not apply directly to Norwegian salmon populations, since the small population of Iberian salmon showed high levels of dispersal and this same level of dispersion might not be shared by their Norwegian counterparts. Consuegra et al. (2005) strongly opposed the proposition.

In this experiment, Fraser et al. (2007) explored genetic theories to explain the failure of Atlantic salmon reintroduction in two inner rivers of the Bay of Fundy, Canada, where it had been extirpated. This study led the team to the conclusion that population size was not responsible for a significant decrease in genetic diversity. The experiment was conducted by using DNA testing on a sample of 32 fish from both streams. The experiment did not have a control population. Therefore, the potential for bias is high and the sample size is small. The effect size is high: allele richness was, on average, 17.4 per locus, while heterozygosity was 0.5. Extrapolation levels are high because the study was conducted in Canada, in only two streams. Furthermore, the populations sampled were from Atlantic salmon brought to the streams for reintroduction purposes and the conclusions might not apply to wild salmon populations. Fraser et al. (2007) contradicted the proposition

Table 6.4. The strength of evidence of proposition 2.d: Genetic variability increases wild population resilience.

References	SOE
Haak and Williams, 2012	2
Braun et al., 2016	3
Verspoor, 1997	2
Evans et al., 2012	3
Stewart Grant, 2012	2
Average	**2.4**

Justification

In this experiment Haak and Williams (2012) proceeded to test the hypothesis that genetic variability was, among other variables, responsible for the conservation of fish populations (population resilience). However, they used a proxy, genetic purity of the population, to assess genetic diversity. Furthermore, the data for genetic purity were gathered by various organizations across the US; some of them using expert opinions to make the assessment. This increases the potential for bias. The sample size was quite large, involving 306 populations. The effect size was also impressive: 70 percent of the population that had genetic purity was resilient. The level of extrapolation was quite high since the study was conducted on cutthroat trout in the United States. Therefore, resiliency might be different in salmon populations in Norway. Haak and Williams (2012) lightly supported the proposition.

In this experiment, Braun et al. (2016) linked genetic diversity to diversity in behaviours to population resilience to changing environmental conditions. The experiment was conducted in a natural setting and used correlation analysis to interpret their results. The potential for bias was low. The sample size was quite large; 41 populations were used in the experiment. The effect size was moderate: the study showed a correlation of -0.16 between genetic diversity and changes in behaviours. Furthermore, the extrapolation is low, because the experiment was conducted on Chinook salmon populations in the Fraser River in British Canada. However, the study was only correlative and to assume causation still requires too much generalizing. Braun et al. (2016) supported well their hypothesis that genetic diversity increases wild population resilience.

Verspoor (1997) aimed to do a systematic review of the current knowledge on genetic diversity in wild and farmed escaped salmon and its implications, including how genetic diversity increases population survival. However, the potential for bias in this review was quite high, because the author did not include his methodology for the selection of experiments that were used in his study. Normally, systematic reviews have a high value in terms of study design and the extrapolation levels are low. However, in this case, the review was conducted in 1997. As such, scientific evidence might have changed greatly since then. Therefore, in this case, the degree of extrapolation is quite high. Verspoor (1997) weakly supported the aforementioned proposition.

Evans et al. (2012) conducted a study to determine the impact of genetic variability on resilience, defined as reproductive success and offspring's survival over a three-year time period. The experiment was conducted in a controlled environment and the potential for bias was generally low. The sample sizes were quite large; 650, 352 and 177 fish were sampled in 1996, 1997 and 1998 respectively. The results indicated that reproductive success was maximized when the genetic difference between parents was around 20 on a scale of 0 to 35. Furthermore, offspring's survival was maximized with genetic diversity in the parents. This experiment must, however, be extrapolated to support the proposition. The experiment was conducted using Atlantic salmon in Quebec, where the species is native and therefore reproduction with other Atlantic salmon, rather than on species of wild salmon from the Pacific Ocean. Also, the researchers studied intrapopulation resilience rather than the resilience of the population in general. Evans et al. (2012) moderately supported proposition.

Stewart Grant (2012) presented a systematic review of the current knowledge on the results of the interactions between farmed and wild Alaskan salmon. The author might have been biased during his review because he did not include its methodology related to article selection criteria. Although the review is quite robust and applies to populations of Pacific salmon on the West Coast of North America, the need for extrapolation is still significant because the author specified that reduction in genetic variability may cause reduction in the population's resilience to environmental factors. This statement was only corroborated by three studies, one of them being by Verspoor (1997), which itself is a review. Stewart Grant (2012) moderately supported by the positive relationship between genetic diversity and population resilience.

Table 6.5. The strength of evidence of proposition 2.e: Population resilience decreases biodiversity loss.

References	SOE
N/A	0
Average	**0**

In the literature surveyed it was impossible to find scientific evidence that supported or contradicted the proposition. The steps taken to research this proposition can be seen in detail the appendix. These results indicate the likely presence of a gap in the scientific literature. Research has not been conducted to prove or disprove the relationship between population resilience and biodiversity loss in Norway. This lack of evidence indicates, that an assumption is being made regarding the efficiency of protected areas as a mean to reduce biodiversity loss.

Table 6.6. Summary of the strength of evidence for each proposition.

Proposition	SOE
2.a. Protected areas increase the protection of wild Atlantic salmon wild populations.	0
2.b. Protection of wild Atlantic salmon wild populations increases the abundance of wild populations.	0
2.c. The abundance of wild populations increases the genetic diversity of wild populations.	-1.3
2.d. Genetic variability increases wild population resilience.	2.4
2.e. Population resilience decreases biodiversity loss.	0

Table 6.6 presents the strength of evidence of all the previously examined propositions. The negative strength of evidence of the proposition 2.c indicates that currently scientific research support the opposite hypothesis: The abundance of wild population does not increase

genetic diversity in wild Atlantic salmon in Norway[9]. However, the small values also indicates a weak strength of scientific evidence. This result suggest that using protected areas to improve biodiversity loss in salmon population may not be effective. Nevertheless, propositions 2.a, 2.b, 2.e have no strength of evidence. These results mean that it is impossible to conclude if the aforementioned propositions are supported or contradicted. Although these results are inconclusive, they suggest that the Norwegian policy is not based on environmental evidence.

6.1.3. Mass of Evidence

Table 6.7. The mass of evidence of the propositions underlying the policy on the creation of wild Atlantic salmon protected areas in Norway.

Proposition	Total references	Pertinent references	Percent of pertinent references (%)	MOE
2.a. Protected areas increase the protection of wild Atlantic salmon wild populations.	20	3	15	2
2.b. Protection of wild Atlantic salmon wild populations increases the abundance of wild populations.	30	0	0	0
2.c. The abundance of wild populations increases the genetic diversity of wild populations.	25	3	12	2
2.d. Genetic variability increases wild population resilience.	24	5	21	2
2.e. Population resilience decreases biodiversity loss.	19	0	0	0

[9] Refer to the appendix for the complete methodology regarding how the references were obtained.

6.1.4. Weight of Evidence

Table 6.8. The weight of evidence of the propositions underlying the policy on the creation of wild Atlantic salmon protected areas in Norway.

Propositions	SOE [-5,5]	MOE [0,5]	WOE [-25,25]
2.a. Protected areas increase the protection of wild Atlantic salmon wild populations.	0	2	0
2.b. Protection of wild Atlantic salmon wild populations increases the abundance of wild populations.	0	0	0
2.c. The abundance of wild populations increases the genetic diversity of wild populations.	-1	3	-3
2.d. Genetic variability increases wild population resilience.	2	2	6
2.e. Population resilience decreases biodiversity loss.	0	0	0
Policy WOE	**1**		

The Norwegian *Aquaculture Act* (2011) has given the Ministry the authority to cease and to prevent farm fishing activities in protected areas in order to preserve wild Atlantic salmon populations (Norwegian Ministry of Fisheries and Coastal Affairs, 2006). Several of these areas have already been created in the fjords and rivers off the coast of Norway (FAO, 2010). It is well recognized that the creation of protected areas is an efficient means of conserving biodiversity, in this case, the wild populations of Atlantic salmon. However, the present analysis found barely any weight of evidence pertaining to the policy, as seen in Table 6.8. Although these results do not imply that the policy is not effective, they demonstrate that there is a lack of convincing scientific research available on the topic. The low score can also be attributed to a significant gap in knowledge. Conservation theories that have been well explored in terrestrial contexts have been neglected in marine environments (Mcclure et al., 2013). Most research pertaining to Atlantic salmon populations have been conducted in freshwater. Therefore, there is a large part of this fish lifecycle that is not well understood by researchers. The weak weight of evidence can be further explained by the fact that some propositions were given a negative strength of evidence, meaning that the results of the experiments opposed the proposition. However, the small weight of evidence may also be attributable to the nature of Atlantic salmon. This is a species that is highly adaptable and has a wide geographical distribution. Different populations and even subpopulations have proven to be extremely diverse in their behaviours (Klemetsen et al., 2003). Therefore, it is possible that solid scientific evidence can only be obtained while examining the populations of wild Atlantic salmon in Norway's protected areas. However, since the deliberate closure of aquaculture facilities in these areas only happened in 2011, time is still needed for new research to be published.

6.2. Economic efficiency

As for the economic efficiency of the policy, the legislation, enabled by the Norwegian *Aquaculture Act* (2011), does not seem to give the industry any flexibility. New aquaculture facilities will not be awarded license for the protected areas and already existing fish farms within its boundaries must be relocated or closed. Therefore, the policy, in general, does not suggest cost-effectiveness. However, industries already located in protected areas have time allowances to close or move their facilities giving them the opportunity to maximize their efficiency (Norwegian Ministry of Fisheries and Coastal Affairs, 2006).

Furthermore, the delay awarded to the industry is likely to indicate a progressive closure of the facilities, while others become active. Therefore, the price of Atlantic salmon would probably not vary. Although, even if the closures of the facilities were not progressive and occurred on a massive enough scale, the changes would not likely impact Norway's competitiveness. Since, Norwegians are the largest producer of Atlantic salmon worldwide and they hold a large share of the global market, if their production was to decrease, while the demand remains stable, the price of Atlantic salmon would probably increase (OECD, 2016; Young & Matthews, 2010). Therefore, the policy, in any case, is unlikely to decrease the global competitiveness of the country on the global market.

On the other hand, regardless of the awarded time allowance, the policy will likely ensure large compliance costs to the industries within the boundaries of the protected areas. First, the industries will have to face the costs associated with decommissioning their aquaculture facilities; including following the recommendation in their license pertaining to the moving of Atlantic salmon. Furthermore, if the farm decides to relocate, it will need to update or request a new license which is somewhat of tedious process (Norwegian Ministry of Fisheries and Coastal Affairs, 2006). If a new license it needed, the firm will have to obtain it through the auction scheme that regulates the distribution of licenses in Norway (Norwegian Ministry of Fisheries and Coastal Affairs, 2006). Therefore, the compliance costs are likely high.

6.3. Fairness

Creating protected areas to preserve the biodiversity of wild Atlantic salmon in waters where aquaculture was previously allowed is a policy that is not fair. The impact of the policy will be felt strongly, but only by a few facilities, which will have to close or move. Furthermore, the closure of the fish farms is likely to cause job losses and an increase in the rate of unemployment in the local communities. Although, this last issue could be mitigated with appropriate governmental support, the policy is unfair.

6.4. Simplicity

Once the legislation for the creation of the protected area is established under the Norwegian *Aquaculture Act* (2011), its enforcement is straightforward. After the delay has expired, no aquaculture facilities must operate within the boundaries of the protected area. However, the process preceding the enactment of the legislation is probably quite long and requiring discussion and collaboration with different stakeholders. Therefore, this policy probably has a strong administrative burden for the Ministry. Furthermore, this burden would carry on after the policy has been implemented, when the dislocated facilities apply for new licenses. Overall, the policy cannot be considered simple.

7. Comparison

In order to prevent biodiversity loss that could be caused by Atlantic salmon escape, Canada adopted a policy on the maintenance and quality of the equipment that must be used prior and during the operation of the fish farms. This policy was enforced by the conditions attached to the licenses that any aquaculture facilities must have. Norway also regulates the equipment and maintenance of its aquaculture installation through similar regulations (Norwegian Ministry of Fisheries and Coastal Affairs, 2006). However, the Norwegian *Aquaculture Act* (2011), in order to preserve biodiversity, also empowers the Ministry to create wild Atlantic salmon protected areas in order to preserve the biodiversity of these populations. This legislation establishes marine areas where fish farming is prohibited and any farm previously operating within its boundaries must be relocated (Norwegian Ministry of Fisheries and Coastal Affairs, 2006).

7.1. Environmental effectiveness

According to the previous analysis, both policies have overall low weight of evidence, 3 out of 25 for Canada and 1 out of 25 for Norway, meaning that there is little scientific evidence supporting their environmental effectiveness. In both situations, there were not many studies supporting the propositions underlying the policies, indicating a gap in the scientific literature. Furthermore, very few of the studies examined for both policies had a strong design that supported each of the attributed propositions of the cognitive maps. Scientific research also showed that both policies are based on propositions that have some contradictory results, since some of the propositions had both positive and negative strength of evidence. This lack of consensus in the scientific community definitely decreases the scientific evidence that would indicate a strong environmental effectiveness.

Overall these results are unexpected when examining the history of commercial aquaculture of Canada and Norway. Norway's history of commercial Atlantic salmon farming begun about twenty years before Canada's and a lot of the Canadian policies are based on Norway's regulatory framework, such as the one on the standards and maintenance of equipment (Young & Matthews, 2010). Therefore it would be expected that there environmental policies would be more efficient than the Canadian ones (Young & Matthews, 2010). However, this analysis suggests that the policy chosen by the Norwegian government to further protect its biodiversity from the impacts of aquaculture was not based on strong scientific evidence. The creation of protected areas to prevent biodiversity loss has less scientific support for its environmental effectiveness than establishing standards and maintenance routines for the equipment.

7.2. Economic efficiency

Overall, both Norway and Canada have similarly weak weight of evidence. As for their respective economic efficiency, the two policies do not seem to offer the industry any flexibility over how to attain the objective. In Canada, conditions imbedded in the license establish what equipment must be used and when maintenance must be conducted (Fisheries and Oceans

Canada, 2010). In Norway, the Ministry has the right to restrain aquaculture activities in an area it deems important for the protection of wild populations of Atlantic salmon. Therefore, both policies do not appear to be cost-effective for the industry.

As for their impact on competitiveness, the Canadian policy may increase production costs and thus reduce its competitiveness on the global market especially since it is competing with the low production costs of Chile for exports to the United States. However, the Norwegian policy is most likely to reduce the supply of Atlantic salmon available. Since Norway is the largest producer worldwide, the policy would likely create an increase in the price of salmon worldwide. Therefore, the creation of protected areas would not decrease the competitiveness of Norway on the global market, while Canada could lose some market share.

On the other hand, the prevention of fish escapes in Canada has lower compliance costs than the creation of marine protected areas in Norway. While increase in production costs may be incurred by the Canadian policy, Norwegian industry that are within the boundaries of a protected areas must be moved and decommissioned insuring high compliance costs. Consequently, both policies are not cost-effective. While Norway will not suffer a loss of competitiveness, it will have much higher compliance costs than Canada. Therefore, it is not clear which policy has a higher economic efficiency.

7.3. Fairness

Interestingly, both policies will impact the same stakeholders: the industry and the coastal communities. However, while the Canadian policy imposes standards on the equipment and mandatory maintenance, which might increase production costs, the financial burden that is felt by the industry and the coastal communities will be mild compared to the burden created by the closure of aquaculture facilities within an area on the Norwegian industries and local communities. Hence, the Canadian policy is fairer than the Norwegian one.

7.4. Simplicity

Regardless of their differential fairness, Canada and Norway have both implemented policies that are straightforward to enforce. However, the Canadian policy requires monitoring of the installation through inspections, while in Norway protected areas prevent aquaculture activities within designated boundaries, thus making its enforcement natural. On the other hand, with respect to the administrative burden, it is more likely that Norway's policy is much more complex to implement, because it requires the legal legitimization of the area that is to be protected (Norwegian Ministry of Fisheries and Coastal Affairs, 2006). Furthermore, administrative actions must be taken for the delocalisation of the aquaculture facilities that are operating within the boundaries of the protected area. Comparatively, the licensing scheme in Canada, although requiring administrative attention, does not have the same burden as Norway's policy.

8. Conclusion

This policy analysis was conducted to evaluate the respective merits of two policies pertaining to the prevention of the risk of biodiversity loss created by the farming of Atlantic salmon in Canada and in Norway. The scientific evidence shows only minimal support of the environmental effectiveness of the prevention of biodiversity loss through reduction in biodiversity loss from equipment standards and maintenance or through the creation of protected areas. Moreover, both policies show similar economic efficiency; the two having no cost-effectiveness and while Canada has a decrease in competitiveness in the global market, it has less compliance cost. On the other hand, Canada's policy is considered fairer and simpler to implement with a less significant administrative burden, although it requires regular monitoring. Overall, this analysis refutes the hypothesis that, at least for the two policies examined, a longer history would create stronger environmental policies because it has a larger production size and a longer history of commercial aquaculture than Canada.

However, this policy analysis was only conducted on two policies and only pertained to the prevention of biodiversity loss. Moreover, decline in population was the only variable considered for measuring biodiversity; future works could also integrate marine species richness in the analysis. Both countries also have a rich and detailed legislation regarding the regulation of the aquaculture industry and enable the mitigation of other environmental impact such as habitat destruction, pollution discharge and the spread of diseases, infections and other parasites. Therefore, future work should analyse and compare more policy in order to obtain a more detailed portrait of Canada and Norway's aquaculture related policies. Furthermore, it would be interesting to examine the role of the industry and non-governmental organizations (NGOs) in the mitigation of environmental impact. For example, certain industries, to improve their image, are adopting voluntary measures, such as best management practices, to reduce their environmental impact (Marine Harvest, 2015; Young & Matthews, 2010). Furthermore, NGOs can initiate changes in aquaculture practices by lobbying governments for new regulations or by creating certification schemes (Marschke & Wilkings, 2014; Young & Matthews, 2010).

The results of the analysis suggests that the policies currently used in both Canada and Norway to reduce biodiversity loss revealed only a weak support for the environmental effectiveness of such policies. Consequently, governmental policies regarding the reduction of the environmental impacts of aquaculture should favour greater flexibility to the industry and promote the use of adaptive management. Adaptive management would allow the government to set environmental objectives that must be achieved to obtain a license. The industry would then have the liberty to choose how to comply with the end goals. This would allow the management to be tailored to the particular conditions experienced by the farm. Such policies would require for the industries to monitor their activities according to biological indicators to evaluate them and to modify them accordingly. This strategy may also improve the social acceptance of Atlantic salmon farming as it would change the position of the industry from defensive to pro-active (Young & Matthews, 2010). Adaptive management would be beneficial for aquaculture activities in both Norway and Canada.

Bibliography

Aníbal, J., Madeira, H. T., Carvalho, L. F., Esteves, E., Veiga-Pires, C., & Rocha, C. (2014). Macroalgae mitigation potential for fish aquaculture effluents: an approach coupling nitrogen uptake and metabolic pathways using Ulva rigida and Enteromorpha clathrata. *Environmental Science and Pollution Research International*, *21*(23), 13324–34. http://doi.org/10.1007/s11356-013-2427-x

Armitage, D., & Marschke, M. (2013). Assessing the future of small-scale fishery systems in coastal Vietnam and the implications for policy. *Environmental Science & Policy*, *27*, 184–194. http://doi.org/10.1016/j.envsci.2012.12.015

Audit and Evaluation. (2013). Evaluation of Biodiversity Policy and Priorities. Retrieved from https://www.ec.gc.ca/ae-ve/default.asp?lang=En&n=E87EDE3D-1#Toc324422767

Audit and Evaluation Branch. (2016). *Evaluation of Canada's Clean Air Regulatory Agenda (CARA)*. Ottawa. Retrieved from https://www.ec.gc.ca/ae-ve/default.asp?lang=En&n=DD5BE1B8-1#sec3.2

Beck, M., Rivers, N., Wigle, R., & Yonezawa, H. (2015). Carbon tax and revenue recycling: Impacts on households in British Columbia. *Resource and Energy Economics*, *41*, 40–69. http://doi.org/10.1016/j.reseneeco.2015.04.005

Berkes, F. (2011). Restoring Unity: The Concept of Marine Social-Ecological Systems. *World Fisheries: A Social-Ecological Analysis*, 9–28. http://doi.org/10.1002/9781444392241.ch2

Bourret, V., O'Reilly, P. T., Carr, J. W., Berg, P. R., & Bernatchez, L. (2011). Temporal change in genetic integrity suggests loss of local adaptation in a wild Atlantic salmon (Salmo salar) population following introgression by farmed escapees. *Heredity*, *106*(3), 500–10. http://doi.org/10.1038/hdy.2010.165

Boyd, C. E. (2003). Guidelines for aquaculture effluent management at the farm-level. *Aquaculture*, *226*(1-4), 101–112. http://doi.org/10.1016/S0044-8486(03)00471-X

Braun, D. C., Moore, J. W., Candy, J., & Bailey, R. E. (2016). Population diversity in salmon: Linkages among response, genetic and life history diversity. *Ecography*, *39*(3), 317–328. http://doi.org/10.1111/ecog.01102

Canada (2015). Pacific Aquaculture Regulations. SOR/2010-270. Current to June 6, 2016. Ottawa, ON: Minister of Justice. Available at: http://laws-lois.justice.gc.ca

Canada (2016). Fisheries Act. R.S.C., 1985, c. F-14. Current to June 6, 2016. Ottawa, ON: Minister of Justice. Available at: http://laws-lois.justice.gc.ca

Castillo, A. G. F., Ayllon, F., Moran, P., Izquierdo, J. I., Martinez, J. L., Beall, E., & Garcia-Vazquez, E. (2008). Interspecific hybridization and introgression are associated with stock transfers in salmonids. *Aquaculture*, *278*(1-4), 31–36.

http://doi.org/10.1016/j.aquaculture.2008.03.029

Chelenkova, P., Petkova, R., Yochev, S., Vasilev, M., Malamov, D., & Chakarov, S. (2012). One fish, two fish, old fish, new fish - is the biodiversity of bulgarian native brown trout (S. trutta fario) populations at risk? *Biotechnology and Biotechnological Equipment*, *26*(2), 2894–2898. http://doi.org/10.5504/bbeq.2012.0023

Chopin, T., MacDonald, B., Robinson, S., Cross, S., Pearce, C., Knowler, D., … Hutchinson, M. (2013). The Canadian Integrated Multi-Trophic Aquaculture Network (CIMTAN)—A network for a new era of ecosystem responsible aquaculture. *Fisheries*, *38*(7), 297–308. http://doi.org/10.1080/03632415.2013.791285

Clifford, S. L., McGinnity, P., & Ferguson, A. (1998). Genetic changes in Atlantic salmon (Salmo salar) populations of Northwest Irish rivers resulting from escapes of adult farm salmon. *Canadian Journal of Fisheries and Aquatic Sciences*, *55*(2), 358–363. http://doi.org/10.1139/f97-229

Conchedda, G., Lambin, E. F., & Mayaux, P. (2011). Between Land and Sea: Livelihoods and Environmental Changes in Mangrove Ecosystems of Senegal. *Annals of the Association of American Geographers*, *101*(6), 1259–1284. http://doi.org/10.1080/00045608.2011.579534

Consuegra, S., Verspoor, E., Knox, D., & García De Leániz, C. (2005). Asymmetric gene flow and the evolutionary maintenance of genetic diversity in small, peripheral Atlantic salmon populations. *Conservation Genetics*, *6*(5), 823–842. http://doi.org/10.1007/s10592-005-9042-4

Coughlan, J., McGinnity, P., O'Farrell, B., Dillane, E., Diserud, O., de Eyto, E., … Cross, T. F. (2006). Temporal variation in an immune response gene (MHC I) in anadromous Salmo trutta in an Irish river before and during aquaculture activities. *ICES Journal of Marine Science*, *63*(7), 1248–1255. http://doi.org/10.1016/j.icesjms.2006.03.025

Cronin, M., Jessopp, M., Houle, J., & Reid, D. (2014). Fishery-seal interactions in Irish waters: Current perspectives and future research priorities. *Marine Policy*, *44*, 120–130. http://doi.org/10.1016/j.marpol.2013.08.015

De Silva, S. S., & Davy, F. B. (Eds.). (2010). *Success Stories in Asian Aquaculture*. Dordrecht: Springer Netherlands. http://doi.org/10.1007/978-90-481-3087-0

Department of Finance Canada. (2005). *The Budget Plan 2005*. Ottawa. Retrieved from http://www.fin.gc.ca/budget05/bp/bptoc-eng.asp

Einum, S., & Fleming, I. a. (1997). Genetic divergence and interactions in the wild among native, farmed and hybrid Atlantic salmon. *Journal of Fish Biology*, *50*(3), 634–651. http://doi.org/10.1006/jfbi.1996.0330

Einum, S., Nislow, K. H., Reynolds, J. D., & Sutherland, W. J. (2008). Predicting population responses to restoration of breeding habitat in Atlantic salmon. *Journal of Applied Ecology*, *45*(3), 930–938. http://doi.org/10.1111/j.1365-2664.2008.01464.x

Evans, M. L., Dionne, M., Miller, K. M., & Bernatchez, L. (2012). Mate choice for major histocompatibility complex genetic divergence as a bet-hedging strategy in the Atlantic salmon (Salmo salar). *Proceedings. Biological Sciences / The Royal Society*, *279*(1727), 379–86. http://doi.org/10.1098/rspb.2011.0909

FAO. (2010). *National Aquaculture Legislation Overview: Norway*. Rome. Retrieved from http://www.fao.org/fishery/legalframework/nalo_norway/en

FAO. (2011a). *Regional Review on Status and Trends in Aquaculture Development in North America : Canada and the United States of America — 2010*. Rome. Retrieved from http://www.fao.org/docrep/014/i2163e/i2163e00.pdf

FAO. (2011b). *World aquaculture 2010. FAO Fisheries and Aquaculture Department. Technical paper*. Rome. Retrieved from http://www.fao.org/docrep/014/ba0132e/ba0132e.pdf

FAO. (2016). FishStatJ. Rome: FAO - Fisheries and Aquaculture department. Retrieved from http://www.fao.org/fishery/statistics/software/fishstatj/en

Fisheries and Oceans Canada. (2010). *Marine Finfish Commercial Aquaculture Licence*. Retrieved from http://s3.amazonaws.com/zanran_storage/www.pac.dfo-mpo.gc.ca/ContentPages/128966256.pdf

Fisheries and Oceans Canada. (2014a). *Finfish Aquaculture Licence under the Pacific Aquaculture Regulations*. Retrieved from http://www.dfo-mpo.gc.ca/index-eng.htm

Fisheries and Oceans. (2014b). Regulating and Monitoring British Columbia's Marine Finfish Aquaculture Facilities. Retrieved from http://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/mar-rep-rap/2011-2014/docs/rapport_aqua_report_2014-eng.pdf

Fisheries and Oceans Canada. (2015). Community Profile: Kitasoo/Xai'xais First Nation, BC (Salmon). Sector snapshot. Retrieved August 10, 2016, from http://www.dfo-mpo.gc.ca/aquaculture/sector-secteur/commun/kitasoo-eng.htm

Flammang, M. K., Weber, M. J., & Thul, M. D. (2014). Laboratory Evaluation of a Bioacoustic Bubble Strobe Light Barrier for Reducing Walleye Escapement. *North American Journal of Fisheries Management*, *34*(5), 1047–1054. http://doi.org/10.1080/02755947.2014.943864

Fleming, I. A., Hindar, K., Mjlnerd, I. B., Jonsson, B., Balstad, T., & Lamberg, A. (2016). Lifetime Success and Interactions of Farm Salmon Invading a Native Population Author (s): Ian A . Fleming , Kjetil Hindar , Ingrid B . Mjolnerod , Bror Jonsson , Torveig Balstad and Anders Lamberg Published by : Royal Society Stable URL : http://www.jst, *267*(1452), 1517–1523.

Flora, C., & Kröger, R. (2014). Use of vegetated drainage ditches and low-grade weirs for aquaculture effluent mitigation: II. Suspended sediment. *Aquacultural Engineering*, *60*, 68–72. http://doi.org/10.1016/j.aquaeng.2014.04.007

Fraser, D. J., Jones, M. W., McParland, T. L., & Hutchings, J. A. (2007). Loss of historical immigration and the unsuccessful rehabilitation of extirpated salmon populations. *Conservation Genetics*, *8*(3), 527–546. http://doi.org/10.1007/s10592-006-9188-8

Fraser, D. J., Minto, C., Calvert, A. M., Eddington, J. D., & Hutchings, J. A. (2010). Potential for domesticated-wild interbreeding to induce maladaptive phenology across multiple populations of wild Atlantic salmon (Salmo salar). *Canadian Journal of Fisheries and Aquatic Sciences*, *67*(11), 1768–1775. http://doi.org/10.1139/F10-094

Fry, J., Love, D., Shukla, A., & Lee, R. (2014). Offshore Finfish Aquaculture in the United States: An Examination of Federal Laws That Could be Used to Address Environmental and Occupational Public Health Risks. *International Journal of Environmental Research and Public Health*, *11*(11), 11964–11985. http://doi.org/10.3390/ijerph111111964

Gallardi, D. (2014). Effects of Bivalve Aquaculture on the Environment and Their Possible Mitigation : A Review. *Fisheries and Aquaculture Journal*, *5*(3), 8. http://doi.org/10.4172/2150-3508.1000105

Haak, A. L., & Williams, J. E. (2012). Spreading the Risk: Native Trout Management in a Warmer and Less-Certain Future. *North American Journal of Fisheries Management*, *32*(2), 387–401. http://doi.org/10.1080/02755947.2012.678963

Haberstock, A. E., Nichols, H. G., Desmeules, M. P., Wright, J., Christensen, J. M., Hudnut, D. H., … Protection, H. (2001). METHOD TO IDENTIFY EFFECTIVE RIPARIAN BUFFER WIDTHS FOR ATLANTIC SALMON HABITAT PROTECTION ' Determine Optimal Riparian Buffer Widths for redds at the downstream end of riffles or at. *Jawra*, *36*(6), 1271–1286.

Heino, M., Svåsand, T., Wennevik, V., & Glover, K. A. (2014). Genetic introgression of farmed salmon in native populations: Quantifying the relative influence of population size and frequency of escapees. *Aquaculture Environment Interactions*, *6*(2), 185–190. http://doi.org/10.3354/aei00126

Hutchings, J. A., & Fraser, D. J. (2008). The nature of fisheries- and farming-induced evolution. *Molecular Ecology*, *17*(1), 294–313. http://doi.org/10.1111/j.1365-294X.2007.03485.x

Institute for Human & Machine Cognition. (2015). CmapTools. Retrieved from http://www.ihmc.us/cmaptools/

Jensen, Dempster, T., Thorstad, E. B., Uglem, I., & Fredheim, A. (2010). Escapes of fishes from Norwegian sea-cage aquaculture: Causes, consequences and prevention. *Aquaculture Environment Interactions*, *1*(1), 71–83. http://doi.org/10.3354/aei00008

Jones, A. C., Mead, A., Kaiser, M. J., Austen, M. C. V, Adrian, A. W., Auchterlonie, N. A., …

Sutherland, W. J. (2014). Prioritization of knowledge needs for sustainable aquaculture: a national and global perspective. *Fish and Fisheries*, n/a–n/a. http://doi.org/10.1111/faf.12086

Klemetsen, a, P-a, A., Jb, D., Jonsson, B., Jonsson, N., O'Connell, M., & Mortensen, E. (2003). Atlantic salmon Salmo salar L ., brown trout Salmo trutta L . and Arctic charr Salvelinus alpinus (L .): a review of aspects of their life histories. *Ecology of Freshwater Fish*, *12*, 1–59. http://doi.org/10.1034/j.1600-0633.2003.00010.x

Kleter, G. a., Groot, M. J., Poelman, M., Kok, E. J., & Marvin, H. J. P. (2009). Timely awareness and prevention of emerging chemical and biochemical risks in foods: Proposal for a strategy based on experience with recent cases. *Food and Chemical Toxicology*, *47*(5), 992–1008. http://doi.org/10.1016/j.fct.2008.08.021

Krause, G., Brugere, C., Diedrich, A., Ebeling, M. W., Ferse, S. C. A., Mikkelsen, E., … Troell, M. (2015). A revolution without people? Closing the people–policy gap in aquaculture development. *Aquaculture*, *447*, 44–55. http://doi.org/10.1016/j.aquaculture.2015.02.009

Lan, N. T. P. (2013). Social and ecological challenges of market-oriented shrimp farming in Vietnam. *SpringerPlus*, *2*, 675. http://doi.org/10.1186/2193-1801-2-675

MacInnis, C., Floyd, T. A., & Taylor, B. R. (2008). Large woody debris structures and their influence on Atlantic salmon spawning in a stream in Nova Scotia, Canada. *North American Journal of Fisheries Management*, *28*(3), 781–791. http://doi.org/10.1577/M07-077.1

Marine Harvest. (2008). News Release: Atlantic Salmon Escape From Campbell River Area Fish Farm. Retrieved August 10, 2016, from http://www.marineharvest.ca/about/news-and-media/container2008/july-2-2008/

Marine Harvest. (2015). *Salmon Farming Industry Handbook 2015 Marine Harvest*. Retrieved from http://www.marineharvest.com/globalassets/investors/handbook/2015-salmon-industry-handbook.pdf

Marschke, M., & Wilkings, A. (2014). Is certification a viable option for small producer fish farmers in the global south? Insights from Vietnam. *Marine Policy*, *50*, 197–206. http://doi.org/10.1016/j.marpol.2014.06.010

Mcclure, M. M., Alexander, M., Borggaard, D., Boughton, D., Crozier, L., Griffis, R., … Van Houtan, K. (2013). Incorporating Climate Science in Applications of the U.S. Endangered Species Act for Aquatic Species. *Conservation Biology*, *27*(6), 1222–1233. http://doi.org/10.1111/cobi.12166

McGinnity, P., Prodöhl, P., Ferguson, A., Hynes, R., Maoiléidigh, N. O., Baker, N., … Cross, T. (2003). Fitness reduction and potential extinction of wild populations of Atlantic salmon, Salmo salar, as a result of interactions with escaped farm salmon. *Proceedings. Biological Sciences / The Royal Society*, *270*(1532), 2443–50. http://doi.org/10.1098/rspb.2003.2520

Mckindsey, C. W., Landry, T., O'Beirn, F. X., & Davies, I. M. (2007). Bivalve Aquaculture and Exotic Species: a Review of Ecological Considerations and Management Issues. *Journal of Shellfish Research*, *26*(2), 281–294. http://doi.org/10.2983/0730-8000(2007)26[281:BAAESA]2.0.CO;2

Metcalfe, N. B., Valdimarsson, S. K., & Morgan, I. J. (2003). The relative roles of domestication, rearing environment, prior residence and body size in deciding territorial contests between hatchery and wild juvenile salmon. *Journal of Applied Ecology*, *40*(3), 535–544. http://doi.org/10.1046/j.1365-2664.2003.00815.x

Morton, A., Routledge, R. D., & Williams, R. (2005). Temporal Patterns of Sea Louse Infestation on Wild Pacific Salmon in Relation to the Fallowing of Atlantic Salmon Farms. *North American Journal of Fisheries Management*, *25*(3), 811–821. http://doi.org/10.1577/M04-149.1

Nash, C. E. (2003). Interactions of Atlantic salmon in the Pacific Northwest. VI. A synopsis of the risk and uncertainty. *Fisheries Research*, *62*(3), 339–347. http://doi.org/10.1016/S0165-7836(03)00068-7

Naylor, R., Hindar, K., Fleming, I. a., Goldburg, R., Williams, S., Volpe, J., … Mangel, M. (2005). Fugitive Salmon: Assessing the Risks of Escaped Fish from Net-Pen Aquaculture. *BioScience*, *55*(5), 427. http://doi.org/10.1641/0006-3568(2005)055[0427:FSATRO]2.0.CO;2

Norway (2011). Aquaculture Act. Act of 17 June 2005 no. 79 relating to aquaculture. FAOLEX – Legislative database of FAO Legal Office. Available at: http://faolex.fao.org/

Norwegian Ministry of Fisheries and Coastal Affairs. (2006). *The Aquaculture Act*. Oslo. Retrieved from fkd.dep.no

OECD. (2016). Aquaculture production (indicator). http://doi.org/10.1787/d00923d8-en

Ozerov, M. Y., Veselov, A. E., Lumme, J., & Primmer, C. R. (2013). Temporal variation of genetic composition in Atlantic salmon populations from the Western White Sea Basin: influence of anthropogenic factors? *BMC Genetics*, *14*(1), 88. http://doi.org/10.1186/1471-2156-14-88

Paisley, L. G., Ariel, E., Lyngstad, T., J??nsson, G., Vennerstr??m, P., Hellstr??m, A., & ??stergaard, P. (2010). An overview of aquaculture in the nordic countries. *Journal of the World Aquaculture Society*, *41*(1), 1–17. http://doi.org/10.1111/j.1749-7345.2009.00309.x

Petton, B., Pernet, F., Robert, R., & Boudry, P. (2013). Temperature influence on pathogen transmission and subsequent mortalities in juvenile pacific oysters Crassostrea gigas. *Aquaculture Environment Interactions*, *3*, 257–273. http://doi.org/10.3354/aei00070

Rabanal, H. R. (1988). *History of Aquaculture*. Manila. Retrieved from ftp://ftp.fao.org/docrep/fao/field/009/ag158e/ag158e00.pdf

Rasheed, M., Mian, S., & Aubrey, D. (2011). Guidelines for EIA of fish and shrimp hatcheries in a semi-enclosed water body. *Ocean & Coastal Management*, *54*(9), 678–686. http://doi.org/10.1016/j.ocecoaman.2011.06.015

Ruggerone, G., & Goetz, F. (2004). Survival of Puget Sound chinook salmon (Oncorhynchus tshawytscha) in response to climate-induced competition with pink salmon (Oncorhynchus gorbuscha). *Canadian Journal of Fisheries …*, *61*, 1756–1770. http://doi.org/10.1139/F04-112

Ruggerone, G. T., Agler, B. A., & Nielsen, J. L. (2012). Evidence for competition at sea between Norton Sound chum salmon and Asian hatchery chum salmon. *Environmental Biology of Fishes*, *94*(1), 149–163. http://doi.org/10.1007/s10641-011-9856-5

Schaffner, M., Bader, H.-P., & Scheidegger, R. (2009). Modeling the contribution of point sources and non-point sources to Thachin River water pollution. *Science of The Total Environment*, *407*(17), 4902–4915. http://doi.org/10.1016/j.scitotenv.2009.05.007

Skaala, O., Johnsen, G. H., Lo, H., Borgstrom, R., Wennevik, V., Hansen, M. M., … Barlaup, B. T. (2014). A conservation plan for Atlantic salmon (Salmo salar) and anadromous brown trout (Salmo trutta) in a region with intensive industrial use of aquatic habitats, the Hardangerfjord, western Norway. *Marine Biology Research*, *10*(3, SI), 308–322. http://doi.org/10.1080/17451000.2013.810758

Skilbrei, O. T. (2012). Adult recaptures of farmed Atlantic salmon post-smolts allowed to escape during summer. *Aquaculture Environment Interactions*, *1*(2), 147–153. http://doi.org/10.3354/aei00017

Skjæraasen, J. E., Meager, J. J., Karlsen, Mayer, I., Dahle, G., Rudolfsen, G., & Fernö, A. (2010). Mating competition between farmed and wild cod Gadus morhua. *Marine Ecology Progress Series*, *412*, 247–258. http://doi.org/10.3354/meps08670

Stadmark, J., & Conley, D. J. (2011). Mussel farming as a nutrient reduction measure in the Baltic Sea: Consideration of nutrient biogeochemical cycles. *Marine Pollution Bulletin*, *62*(7), 1385–1388. http://doi.org/10.1016/j.marpolbul.2011.05.001

Stewart Grant, W. (2012). Understanding the adaptive consequences of hatchery-wild interactions in Alaska salmon. *Environmental Biology of Fishes*, *94*(1), 325–342. http://doi.org/10.1007/s10641-011-9929-5

Sturdevant, M. V., Fergusson, E., Hillgruber, N., Reese, C., Orsi, J., Focht, R., … Smoker, B. (2012). Lack of trophic competition among wild and hatchery juvenile chum salmon during early marine residence in Taku Inlet, Southeast Alaska. *Environmental Biology of Fishes*, *94*(1), 101–116. http://doi.org/10.1007/s10641-011-9899-7

Thorvaldsen, T., Holmen, I. M., & Moe, H. K. (2015). The escape of fish from Norwegian fish farms: Causes, risks and the influence of organisational aspects. *Marine Policy*, *55*, 33–38.

http://doi.org/10.1016/j.marpol.2015.01.008

Ting, K.-H., Lin, K.-L., Jhan, H.-T., Huang, T.-J., Wang, C.-M., & Liu, W.-H. (2015). Application of a Sustainable Fisheries Development Indicator System for Taiwan's Aquaculture Industry. *Aquaculture*, *437*, 398–407. http://doi.org/10.1016/j.aquaculture.2014.12.030

Trippel, E. A. (1999). The first marine biological station in Canada: 100 years of scientific research at St. Andrews. *Canadian Journal of Fisheries and Aquatic Sciences*, *56*(12), 2495–2507. http://doi.org/10.1139/cjfas-56-12-2495

Uglem, I., Økland, F., & Rikardsen, A. H. (2013). Early marine survival and movements of escaped Atlantic salmon Salmo salar L. juveniles from a land-based smolt farm during autumn. *Aquaculture Research*, *44*(12), 1824–1834. http://doi.org/10.1111/j.1365-2109.2012.03187.x

Váradi, L., Lane, A., Harache, Y., Gyalog, G., Békefi, E., & Lengyel., P. (2011). *Regional Review on Status and Trends in Aquaculture Development in Europe*. *FAO Fisheries and Aquaculture department* (Vol. 1). Rome. Retrieved from http://www.fao.org/docrep/014/i2211b/i2211b.pdf

Verdegem, M. C. J. (2013). Nutrient discharge from aquaculture operations in function of system design and production environment. *Reviews in Aquaculture*, *5*, 158–171. http://doi.org/10.1111/raq.12011

Verspoor, E. (1997). Genetic diversity among Atlantic salmon, 965–973.

Verspoor, E., Beardmore, J. A., Consuegra, S., Garcia de Leaniz, C., Hindar, K., Jordan, W. C., … Cross, T. F. (2005). Population structure in the Atlantic salmon: insights from 40 years of research into genetic protein variation. *Journal of Fish Biology*, *67*, 3–54. http://doi.org/10.1111/j.1095-8649.2005.00838.x

Whitmarsh, D. J., Cook, E. J., & Black, K. D. (2006). Searching for sustainability in aquaculture: An investigation into the economic prospects for an integrated salmon–mussel production system. *Marine Policy*, *30*(3), 293–298. http://doi.org/10.1016/j.marpol.2005.01.004

Young, N., & Matthews, R. (2010). *The Aquaculture Controversy in Canada: Activism, Policy, and Contested Science*. Vancouver: UBCPress.

Appendix

Tracking of research strategies for the Canadian policy on the reduction of biodiversity loss through the prevention of Atlantic salmon escapes in the Pacific Ocean (Section 5).

Proposition	Database	String phrase	Filters	Pert refs	Total refs
1.a Maintenance of the equipment increases the prevention of salmon escape.	Web of Science	Fish escape AND equipment	None	2	8
	ASFA: Aquatic Sciences and Fisheries Abstracts	Fish escape AND Aquaculture AND equipment	Scholarly Journals English	0	4
	Environmental Impacts	Fish escape AND Aquaculture AND equipment	None	0	4
	Web of Science	Prevention escape AND Aquaculture	None	0	4
1.b Quality of the equipment increase the prevention of salmon escape.	Web of Science	Fish escape AND equipment	Peer-Reviewed Articles	2	8
	ASFA: Aquatic Sciences and Fisheries Abstracts	Fish escape AND Aquaculture AND equipment	Scholarly Journals English	0	4

	Environmental Impacts	Fish escape AND Aquaculture AND equipment	None	0	4
	Web of Science	Prevention escape AND Aquaculture	None	0	4
1.c Quality of the installation increases the prevention of salmon escape.	Web of Science	Fish escape AND equipment	Peer-Reviewed Articles	2	8
	ASFA: Aquatic Sciences and Fisheries Abstracts	Fish escape AND Aquaculture AND equipment	Scholarly Journals English	0	4
	Environmental Impacts	Fish escape AND Aquaculture AND equipment	None	0	4
	Web of Science	Prevention escape AND Aquaculture	None	0	4
1.d Prevention of salmon escape decreases the number of Atlantic salmon in wild populations of salmon.	Web of Science	Prevention salmon escape	None	2	8
	Web of Science	Physical Barrier* AND salmon escape*	None	1	6
	Web of Science	"Atlantic Salmon" AND "Pacific Ocean" AND Escape	Article	0	1

	ASFA: Aquatic Sciences and Fisheries Abstracts	"Atlantic Salmon" AND "Pacific Ocean" AND Escape	None	0	1
	Environmental Impacts	"Atlantic Salmon" AND "Pacific Ocean" AND Escape	None	0	0
	Environmental Impacts	prevention AND aquaculture AND "Atlantic salmon" AND escape	None	0	0
	Environmental Impacts	"Atlantic salmon" AND survival AND "Pacific Ocean"	None	0	0
	ASFA: Aquatic Sciences and Fisheries Abstracts	Atlantic salmon AND survival AND "Pacific Ocean"	None	0	1
	Environmental Impacts	Farmed fish AND escape AND survival AND salmon	Journal Article	3	6
1.e Less Atlantic salmon (farmed) in the Pacific Ocean decreases introgression rate farmed and wild	Web of Science	(Introgression OR hybridization) AND "fish* escape*" AND salmon	None	1	1

salmon (hybridization).	ASFA: Aquatic Sciences and Fisheries Abstracts	(Introgression OR hybridization) AND fish escape AND Atlantic salmon	Scholarly Journals	4	11
1.f Less hybridization increases genetic variability in wild population.	Web of Science	(Introgression OR hybridization) AND genetic variability AND aquaculture AND salmon	None	3	8
	ASFA: Aquatic Sciences and Fisheries Abstracts	"Genetic diversity" AND population AND "Atlantic salmon" AND aquaculture AND (introgression OR hybridization)	Article	1	5

	Web of Science	"Genetic diversity" AND population AND "Atlantic salmon" AND aquaculture AND (introgression OR hybridization)	None	0	5
	Environmental Impacts	"Genetic diversity" AND population AND "Atlantic salmon" AND aquaculture AND (introgression OR hybridization)	Journal Article	0	1
	ASFA: Aquatic Sciences and Fisheries Abstracts	(Introgression OR hybridization) AND genetic variability AND aquaculture AND salmon	Journal Article	0	4
1.g Genetic variability increases wild population resilience.	ASFA: Aquatic Sciences and Fisheries Abstracts	salmon AND (Genetic diversity AND population resilience)	Journal Article	0	1

	ASFA: Aquatic Sciences and Fisheries Abstracts	salmon AND Genetic diversity AND population resilience	Journal Article	1	3
	Web of Science	salmon AND Genetic diversity AND population resilience	Article	1	8
	Web of Science	aquaculture AND salmon AND population resilience	Article	0	1
	ASFA: Aquatic Sciences and Fisheries Abstracts	aquaculture AND salmon AND genetic diversity AND population survival	Journal Article/ English/ Article	3	11
1.h Population resilience decreases biodiversity loss.	ASFA: Aquatic Sciences and Fisheries Abstracts	resilience AND ((abundance OR health) of population) AND salmon	Journal Article	0	14
	ASFA: Aquatic Sciences and Fisheries Abstracts	resilience AND "abundance of population*"	None	0	1

	ASFA: Aquatic Sciences and Fisheries Abstracts	Aquaculture AND (biodiversity loss AND population resilience)	None	0	2
	Web of Science	Aquaculture AND biodiversity loss AND resilience	None	0	1
	Environmental Impacts	resilience AND ((abundance OR health) of population) AND salmon	None	0	1
1.i Less Atlantic salmon in the Pacific Ocean decreases the competition with wild population of salmon for the resources.	ASFA: Aquatic Sciences and Fisheries Abstracts	(Salmon escape*) AND (resource* competition) AND aquaculture	Scholarly Journal	5	17
1.j Less competition for resources decreases biodiversity loss.	ASFA: Aquatic Sciences and Fisheries Abstracts	(Resource* competition) AND Aquaculture AND wild population abundance AND salmon	Scholarly Journal	1	5

ASFA: Aquatic Sciences and Fisheries Abstracts	Aquaculture AND salmon AND competition AND population abundance	Scholarly Journal	2	9
Web of Science	Aquaculture AND salmon AND competition AND population abundance	None	0	1
Environmental Impacts	Aquaculture AND salmon AND competition AND population abundance	None	1	2

Tracking of research strategies for the Norwegian policy on the reduction of biodiversity loss through the establishment of wild salmon protected areas (Section 6).

Proposition	Database	String phrase	Filters	Pert refs
2.a. Protected areas increase the protection of wild Atlantic salmon wild populations.	ASFA: Aquatic Sciences and Fisheries Abstracts	((Protected OR conservation OR protection) (area* OR zone* OR region* OR strategy*)) AND effective* AND "Atlantic salmon"	Scholarly Journals	3
2.b. Protection of wild Atlantic salmon wild populations increases the abundance of wild populations.	Web of Science	(salmon protection) AND (increasing population abundance)	Article	0
	ASFA: Aquatic Sciences and Fisheries Abstracts	(Atlantic salmon) AND (protection or conservation) AND (wild population abundance)	Scholarly Journals	0

	ASFA: Aquatic Sciences and Fisheries Abstracts	(National salmon fjords) AND Norway	Scholarly Journals /English	0
2.c.. The abundance of wild populations increases the genetic diversity of wild populations.	ASFA: Aquatic Sciences and Fisheries Abstracts	(Abundance population) AND (Genetic (divers* OR varia*)) AND "Atlantic salmon"	Scholarly Journals	3
	Web of Science	"population abundance" AND (Genetic (divers* OR varia*)) AND "Atlantic salmon"	Article	0
	Web of Science	(National salmon (fjords OR rivers)) AND (genetic (diversity OR variability))	Article	0
2.d Genetic variability increases wild population resilience.	ASFA: Aquatic Sciences and Fisheries Abstracts	salmon AND (Genetic diversity AND population resilience)	Journal Article	0

	ASFA: Aquatic Sciences and Fisheries Abstracts	salmon AND Genetic diversity AND population resilience	Journal Article	1
	Web of Science	salmon AND Genetic diversity AND population resilience	Article	1
	Web of Science	aquaculture AND salmon AND population resilience	Article	0
	ASFA: Aquatic Sciences and Fisheries Abstracts	aquaculture AND salmon AND genetic diversity AND population survival	Journal Article/ English/ Article	3
2.e. Population resilience decreases biodiversity loss.	ASFA: Aquatic Sciences and Fisheries Abstracts	resilience AND ((abundance OR health) of population) AND salmon	Journal Article	0
	ASFA: Aquatic Sciences and Fisheries Abstracts	resilience AND "abundance of population*"	None	0

ASFA: Aquatic Sciences and Fisheries Abstracts	Aquaculture AND (biodiversity loss AND population resilience)	None	0
Web of Science	Aquaculture AND biodiversity loss AND resilience	None	0
Environmental Impacts	resilience AND ((abundance OR health) of population) AND salmon	None	0