Ocean Acidification Effects on the Mollusk Industry in Atlantic Canada

A First Look into the Economic Costs of the Ocean's Changing Chemical Balance in Atlantic Canada

By

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Abstract

This thesis examines how ocean acidification will impact the mollusk industry of Atlantic Canada. Analysis of the industry over a fifteen-year period is averaged and then assessed using a net present value approach. Predicted impacts of ocean acidification are then combined with revenues in the mollusk industry. Different environmental scenarios and discount rates are also considered. The information is then combined and equated with a net present value approach to estimate the possible direct economic losses to the industry. At a 3.5% discount rate, results show that the economic losses expected for the mollusk industry in Atlantic Canada range between $600 thousand and $2.5 million 2010 constant Canadian dollars for the year 2060. For 2100, the expected economic loss for Atlantic Canada's mollusk industry ranges between $350 thousand and $1.5 million 2010 constant Canadian dollars. This represents potential decreases of 5-22% in the Atlantic Canada mollusk industry, and implies that mitigation processes on carbon emissions should be introduced as soon as possible.

1 Introduction

Ocean acidification occurs when the ocean has absorbed excessive amounts of carbon dioxide, which then causes chemical changes in water composition. These changes negatively impact calcifying species, namely corals, crustaceans, and bivalves. This study takes a first look at the future economic costs to the mollusk industry in Atlantic Canada due to predicted declines in survival of mussels from ocean acidification.

Losses are calculated using a net present value equation, different Intergovernmental Panel for Climate Change (IPCC) scenarios for environmental conditions in future years, and different discount rates. For 2060, direct economic losses in the mollusk industry range from $781 thousand to $6.7 million 2010 constant Canadian dollars (CND 2010) for a worst-case climate adaptation world, and between $187 thousand and $1.6 million CDN 2010 for a best-case scenario. In the more distant future, year 2100, direct economic losses to the mollusk industry from ocean acidification in a worst-case adaptation scenario lie between $145 thousand and $10.8 million CDN 2010 and in a best-case scenario range from $33 thousand to $2.4 million CDN 2010.

When discussing climate change problems there are two different kinds of concerns that surround the topic. The first concern is providing sufficient evidence of the problem, and the second is discourse about solutions to the problem. This study provides material which address the first concern; the research contributes information that accounts for the potential economic impacts of ocean acidification.

Although the second concern regarding solutions is urgent, it is not touched upon in detail in this study.

2 Ocean Acidification Contextual Background

Since the Industrial Revolution, the rate of emitting carbon dioxide (CO_2) and other greenhouse gasses has increased to levels that the earth and its environment have never experienced. Carbon dioxide emissions from the earth, both anthropogenic and naturally produced, have increased by nearly forty percent since preindustrial times (Doney et al. 2009). The ocean is one of the earth's natural carbon dioxide buffers, absorbing CO_2 when released into the atmosphere from the earth's surface. The ocean is responsible for roughly thirty percent of the CO_2 absorption that the earth discharges (Doney et al. 2009).

Ocean acidification is the term for the chemical change that occurs when excess carbon dioxide is absorbed into the ocean from the atmosphere. This reaction lowers pH in the ocean and reduces the amount of calcium carbonate available in the ocean's composition. It has been termed "the other CO_2 problem" since it, as well as climate change, are the results of the increased carbon dioxide in the earth's atmosphere (Doney et al., 2009).

The pH balance in the ocean has decreased from 8.21 units to 8.09 units since preindustrial times; Doney et al. (2009) state that it is expected to decrease a further 0.3–0.4 units by the end of the century based on the Intergovernmental Panel for Climate Change (IPCC) scenarios. Oceanic carbon dioxide has increased from a preindustrial level of 280 parts per million volume (ppmv) to roughly 384 ppmv in 2007 (Doney et al. 2009).

This increase in carbon dioxide in the waters has caused the natural chemistry of the oceans to change. Carbonic acid is formed once the carbon dioxide has dissolved into the water, creating more hydrogen ions. These excess hydrogen ions cause a reduction in the pH balance, which leads to more acidic waters (Doney et al., 2009). The excess hydrogen ions also combine with carbonate ions to form bicarbonate, which leaves less carbonate ions available for calcifying species to use for the creation of their shells. Due to the properties of a chemical reaction there is no alternative way for species to calcify their shells. Doney et al. (2009) note that the changing chemistry of the ocean has been shown through time series data –taken globally in Hawaii, Bermuda, and Europe – to be the cause of the increased acidity in the waters.

Kroeker et al. (2010) show crustaceans as well as corals use a form of calcium carbonate in their developmental stages to produce and harden their outer shells, in a process known as calcification. Kroeker et al. (2010) demonstrate that aragonite is the more soluble, or softer, form used by corals, pteropods, and bivalves when calcifying their outer layer, while calcite is the lesser soluble form, used by highly mobile organisms such as crustaceans to calcify shells, and by fish in developmental stages. Barton et al. (2012) demonstrate that these forms of calcium carbonate are distinguishable by their crystal structure and by the contributions of contaminating elements.

The study of ocean acidification effects on calcifying species is fairly new with little conclusive data on the more complex creatures, such as crustaceans, due to their more intricate interior workings. Studies have shown, however, that ocean acidification produces negative affects on calcification, development, and reproduction of species that use aragonite when calcifying. Barton et al. (2012) concluded that mussels, oysters and clams all show definitive negative responses in survival rates to increased carbon dioxide in the waters they live in.

These negative effects on shellfish will correspond with negative effects to the shellfish industry. The fishing industry is responsible for over 4,500 jobs in Atlantic Canada, and Canada is home to over 1,500 rural and coastal communities that rely on the fishing industry for sustainability (Fisheries and Oceans Canada, 2009). These areas will be hardest hit by the expected impacts from ocean acidification.

Sustainability is a major concern in the fishing industry due to the threat of decline from climate change; here the mollusk industry is studied in depth. Steinacher et al. (2009) predict that the poles of the earth, due to ice cap melting and an earlier rise in average temperatures, will feel the effects of ocean acidification before parts in the lower latitudes. Their research suggests that the artic waters can expect to have a pH balance of 7.7 units by as early as 2060. This implies that the effects of ocean acidification could be felt sooner than predicted by the IPCC scenarios in countries that lie in the northern and southern latitudes, Canada being included in this region. These facts imply that research into the effects from ocean acidification is essential.

3 Literature Review

The following chapter discusses the significant studies that have been carried out on the effects of decreased calcification on ocean species. The chapter then reviews the economic studies regarding the implications that ocean acidification has on the economy. This chapter defines the context of how significant the research compiled to date is, and why research is needed to fill gaps in the current knowledge about ocean acidification's impact on the economy.

3.1 Scientific Literature

The scientific data on the effects of ocean acidification on calcifying species has only come to light within the past twenty years; thus it is a new study area. As such, the research supporting the consequences of ocean acidification on underwater species has only recently been made aware to the larger scientific community.

Gazeau et al. (2007) studied the effects of carbon dioxide on juvenile and adult mussels and oysters. The species were collected and stored in a tank that was filtered free of carbon dioxide using lime; this was called the equilibrium tank. The study then took a sample of the species into an incubation tank, where the levels of carbon dioxide in the waters were increased to 600–700 ppmv for two-hour periods two to three times a day. The researchers found that the calcifying rates of both mussels and oysters exhibit a strong decline as a function of the increasing carbon dioxide levels, decreasing pH balance, and the decreasing carbonate balance.

The mussels in the study were found to be more sensitive to the effects of increased carbon dioxide than the oysters studied. Gazeau et al. (2007) found that mussels showed a calcification decrease of 25%, while oysters showed a 10% decrease in calcification. They suggest the reason for the difference was the differing shell composition between species; the mussels studied had a shell composed of mainly aragonite, a weaker and more soluble form of calcium carbonate. Comparably, the oysters studied had shells mainly composed of calcite, a stronger form of calcium carbonate.

Comeau et al. (2009) performed a second study on mussels in which a total of 51 juvenile specimens were collected and stored in beakers. The pH levels were altered, 7.78 units for the test sample and 8.09 units for the control sample, which correspond to an IPCC scenario in 2100 labeled A1F1, and the current time frame, respectively. The IPCC's A1F1 scenarios corresponds to a continued reliance on fossil fuels to develop technology, and predicts that the ocean will roughly contain 700 ppmv CO_2 and have a pH balance of 7.9 units by 2100 (IPCC, 2007). At the end of the experiment, Comeau et al. (2009) found only 30% of the specimens were actively swimming in their beakers, and that specimens tested under the experimental conditions exhibited a 28% reduction in calcification of their shells during the experiment time period of 4 to 6 hours.

In a broader study Kroeker et al. (2010) investigated how ocean acidification affects marine species, using meta-analysis to examine the responses across a spectrum of species. The study compiled case studies where the testing method was to manipulate the pH balance to reflect the IPCC's predicted levels of pH and carbon dioxide for a 2100 A1B scenario. Kroeker et al. (2010) chose to measure species rates of survival, growth, calcification, reproduction and photosynthesis as response variables for the impacts from ocean acidification. However, the developmental stage of the species, the location, the duration of the experiment and the method of how the water was manipulated was also recorded. The meta-analysis analyzed the data using both weighted and unweighted analysis and found no differences in the results. A random effects model was used as well, as a way to account for any biological variation in responses.

Kroeker et al. (2010) began the study with some predictions; 1) ocean acidification had a larger effect on calcifying organisms compared to non-calcifying organisms, 2) that highly soluble mineral forms of calcium carbonate would be more effected by ocean acidification than less soluble mineral forms, and 3) early stages of development would be more effected than later developmental stages. The meta-analysis revealed that ocean acidification had negative effects on calcification and survival rates. The effects of ocean acidification also negatively impacted reproduction and growth rates, while photosynthesis showed no significant effects.

Results from Kroeker et al. (2010) show that calcification was the most sensitive process, suggesting that the effects of ocean acidification will be negative for most species that calcify, with the exception of the crustaceans grouping who had a slight positive reaction. Kroeker et al. (2010) also found that the taxonomic groups had differing responses to ocean acidification at different stages of development. The mollusks group showed larger negative effects on larval stages, while for the other taxonomic groups the juvenile echinoderms and adult crustaceans showed the most negative responses to ocean acidification. Kroeker et al. (2010) remind us that ocean acidification will not occur alone, but in tandem with climate change, which could produce exponential negative effects on marine organisms.

A second meta-analysis study uses the manipulations in amounts of carbon dioxide in water as a base requirement when selecting the reports. Hendriks et al. (2010) normalized the studies collected in order to examine the effects of ocean acidification across differing traits. This was done by comparing the treatment to the control response.

Hendriks et al. (2010) found that the effects of acidification fluctuated across the taxonomic groups and across different organism functions. Survival rates overall decreased by an average of 31% due to acidification, while calcification across different species declined from between 9% and 51% depending on the species. The study found that growth showed dual effects. Overall across species growth increased by an average of 34%, while a number of species, including bivalves and gastropods, demonstrated reduced growth. The study also identifies calcification as being the most sensitive in response to ocean acidification, and suggests an expected reduction in calcification rate by 25% by the end of the 21st century.

This meta-analysis identifies possible hindrances and aids in the predictability of the results. Hendriks et al. (2010) suggest that the short time span of the studies does not allow for the species to adapt to the conditions, allowing for a greater time length in the study might allow for species adaptation to the conditions, which might bring about lesser declines in survival rates. On the opposite side of the coin, the study also states that acidification occurs in tandem with other changes in the environment, such things as eutrophication, increasing UV radiation, and global warming, which could aid in damaging the species.

Ocean acidification is a newly discovered problem. As such, the studies have all been completed within the past ten years. One common theme in all of the studies is scientific research points to negative impacts on the calcifying organisms that call the ocean home. These damages translate into negative impacts on industries that rely on the shellfish population for their income. The next section describes economic studies done on the potential impact ocean acidification has on different economies around the world.

3.2 Economic Literature

Due to scientific research being rare, the economic studies compiled on ocean acidification impacts are, as well, recent. Cooley and Doney (2009) take a look at the potential economic effects of ocean acidification by analyzing commercial mollusk fisheries revenues in the United States from 2007. The focus is on mollusks due to the fact that mollusks have low biological control over their calcification process; the species intakes calcium carbonate from the waters and directly deposits calcium ions along their inner shells as a hardener.

Their case study uses predictions taken from the meta-analysis studies mentioned previously to predict potential decreases in calcification of mollusks of 6% to 25% given a 0.1 unit decrease in pH levels in the waters. Cooley and Doney (2009) use a one-to-one ratio of correspondence between reduced calcification and decrease in mollusk harvest. The study assumes no variation in acidification and does not take into account potentially significant changes in weather patterns, nor does it take into account how potential effects on other species will impact the mollusk population. Cooly and Doney (2009) also assume that fishing intensity, and supply and demand for mollusks remain unchanged into the future time period.

The authors calculate potential revenue loss from decreased mollusk harvest in 2060 and adjust to present day values using a range of discount rates integrated over time to provide estimation for net present value. Cooley and Doney (2009) use three different discount rates; 0%, 2% and 4%. The 0% meaning future generations are created as equals relative to the present, 2% and 4% decreasing the value placed on future generations, respectively.

Two scenarios from the Intergovernmental Panel for Climate Change (IPCC) are considered as potential world scenarios for the study, B1 and A1F1. The B1 scenario is a conservative scenario, in which the world stops consuming resources at an unsustainable rate and starts to move toward clean and resource-efficient technologies. The B1 scenario predicts that by 2100 the oceans will consist of 550 ppmv of carbon dioxide and have a pH balance of 8.0 units. The A1F1 scenario describes a future world with consistent economic growth and the introduction of new technologies as well. The A1F1 scenario describes the energy system of the world as fossil intensive, and predicts that by 2100 the waters will consist of 950 ppmv of carbon dioxide and have a pH balance of 7.7 units.

Using the given information, Cooley and Doney (2009) have predicted that by 2060 the US will be faced with potential losses ranging between $1,226 million and $3,063 million 2007USD for a 0% discount rate in an IPCC B1 scenario, and between

$2,058 million and $5,144 million 2007USD for a 0% discount rate in an IPCC A1F1 scenario. (See Appendix of Figures and Tables; Table 5).

Cooley and Doney (2009) also mention that the broader economic effects are harder to quantify, but use a multiplier similar to another ocean condition that has created economic impacts on the New England coast. The multiplier is used to estimate the total consequences of ocean acidification that can be expected in the US economy. The multiplier includes the direct, indirect, and induced impacts on the economy due to the decrease in mollusk industry revenue from ocean acidification. The ocean condition that ocean acidification is similar to is called harmful algae blooms (HABS), a problem that has caused decreases in catch off of New England in recent years. HABS is estimated to have a multiplier between 2 and 3. Cooley and Doney (2009) use an average of this multiplier to estimate how the decrease in calcification would affect the broader economy of the United States; using a 2.5 multiplier they estimate the broader economic losses for the United States would range from $1.5 to $6.4 billion 2007USD with a 2% discount rate for 2060.

On a global scale, Narita et al. (2012) compiled a partial equilibrium analysis in order to gain an economic assessment of the effects of ocean acidification on mollusks. The partial equilibrium framework allows the capture of welfare losses due to decrease in production and consumption as well as welfare effects of price increases under tightening supply. Narita et al. (2012) looked at the economic costs of production loss of mollusks in 2100 under the IPCC A1B scenario. The A1B scenario describes a future with very rapid economic growth and a slow transfer to more efficient technologies. This is predicted to be the most likely scenario that the world will see by 2100. In a 2100 A1B scenario world the oceans will contain 700 ppmv of carbon dioxide and have a pH balance of 7.9 units.

Narita et al. (2012) note that mollusks are harvested in two ways, through wild harvests and bred in aquaculture systems. They theorize that mollusks bred in aquaculture could potentially avoid the affects of ocean acidification if the tanks are sealed from outside air and the water monitored with reduced carbon dioxide levels. However, this is not the practice today, and all aquaculture mollusks spend a period of time in open water and are sometimes brought in from the ocean in the bivalve stage to farm (Narita et al. 2012). This means that whether mollusks are harvested from the wild or bred in aquaculture, each kind of breeding is exposed to the harmful effects of ocean acidification.

Narita et al. (2012) predict that by 2100 the waters will have decreased pH balance by 0.4 units and sets the rate of mollusk harvest lost equal to the predicted decrease in calcification from ocean acidification that is expected at the given pH balance. Narita et al. (2012) assess the economic impacts on 10 regions that have the largest mollusk industries across the globe. These include the USA, the EU, Japan, Australia, Mexico, Turkey, Vietnam, China, South Korea, and a group named the Other Developed Countries, in which Canada is included. They then take mollusk harvest information from the FAO Fisheries and Aquaculture Department and The Sea Around Us Project and base the future average of mollusk harvest off the average harvest between 1997 and 2006 for each country considered.

Per nation basis production data and economic conditions are aggregated using the IMPACT model and based on the GDP conditions that are associated with the IPCC A1B scenario. The IMPACT Model is used to create baseline predictions about how the rippling effect of a particular variable will cascade throughout the economy. The IMPACT model uses a general equilibrium approach to its methodology, but due to the fact that the science behind ocean acidification's affects on sea life is so new, only a partial equilibrium model is used in this study (Narita et al. 2012). The economic costs are assessed as the difference between enhanced levels of production with and without the effects of ocean acidification.

Narita et al. (2012) look at the economic costs through a number of scenarios. The main difference being in the first case they assume constant demand and in the second case they assume the demand rises at a rate due to income rising in the future. In a constant demand scenario losses from ocean acidification globally in 2100 are estimated to be 6 billion USD, while in the second consideration with increased demand, the losses from ocean acidification are estimated to be well over 100 billion USD.

It is noted by Narita et al. (2012) that these estimations would correspond to between 1% and 1.5% of the total damage expected from climate change. The authors mention in the concluding remarks next steps to the research would be to integrate the science into a general equilibrium model in order to explore the effect that ocean acidification would have on employment in the fishing industry.

In a more recent case study, Armstrong et al. (2012) analyzed the effects of ocean acidification, using an ecosystem services approach on Norwegian waters. The ecosystem services approach contains four categories that are then each assigned an economic value based on the impact to human welfare. Armstrong et al.

(2012) mention supporting, regulatory and cultural services in their study, but state that in order to exclude double counting and personal preferences of individuals, only provisioning services can be studied for determining economic costs. Provisioning services are those services that humans obtain from the ecosystem, thus fisheries and aquaculture would be considered under this category.

The study then contrasts best and worst-case scenarios for the cost associated with ocean acidification. The best case situation is associated with conditions that are in line with the IPCC B1 scenario and the worst case situation is in line with the IPCC A1F1 scenario in that the predictions of parts per million volume of carbon dioxide in the waters and the pH balance of the waters are similar. Armstrong et al. (2012) use the predictions in the two meta-analysis studies mentioned previously by Kroeker et al. (2010) and Hendriks et al. (2010) on how ocean acidification will affect the marine life. They report a 32% to 46% reduction in calcification in mollusks, and up to almost 60% reduction in the survival rates (See Appendix of Figures and Tables; Table 6). Inserting these predicted reactions into the best and worst case scenarios, Armstrong et al. (2012) estimate that in a best-case 2110 world mollusks will show a 2.7% increase in survival, and a worst-case where mollusks will show a 59.44% reduction in survival.

Armstrong et al. (2012) then calculated the economic impact of ocean acidification as the difference between the sale profit in 2010 and the sale profit in 2100, also taking into account discount rates. They use a similar scheme to Cooley and Doney (2009) in the US for discounting future generations; 0%, 2% and 4% discount rates are used in the Norway study. The study goes further to predict the present value of economic loss over the 100 year period, based on average prices and catch volumes, which ranges from 38 billion 2010USD at a 4% discount rate in a worst-case scenario and 21.5 billion 2010USD at a 4% discount rate in a best-case scenario, to between 185.9 billion 2010USD in a best-case scenario and 387.8 billion 2010 USD in a worst-case scenario at a 0% discount rate.

Armstrong et al. (2012) noted that the 4% discount rate is most relevant, as it is suggested to be appropriate discounting for the future. They also predict that most of the losses will be felt between now and 2060, and then losses will diminish in quantity from 2060 to 2110. Due to the science being so new the study ends by acknowledging the knowledge gaps that hinder its accuracy, however they provide the most well rounded study of the possible economic consequences that can result from ocean acidification to date.

Finally, Sumaila et al. (2011) take a slightly different interpretation on the economics of climate change. This study simulated a basic 'first look' at what could happen to fisheries globally in the face of impacts due to climate change. The fishing industry worldwide has been estimated to incorporate 520 million people, including post harvest activities; this equates to roughly 8% of the world's population being negatively affected by the adverse effects of climate change just in the ocean alone (Sumaila et al. 2011). The study demonstrates that changes in environmental conditions will have a strong effect on the distribution of fish across the ocean latitudes, and this in turn will effect fishing operations across the globe.

Sumaila et al. (2011) suggest that the results of the research initiatives indicate that using the IPCC world scenarios for the earth's future there will be increased catch of fish in the Arctic and sub Arctic regions but decreased potential catch in the tropics. Results of the research presented demonstrate that the effects of ocean acidification will substantially reduce the potential catch of fisheries due to a reduction in the amount of dissolved oxygen in the waters caused by ocean acidification. The quality and quantity of fish catch and subsequent economic impact will vary with the extent of regional ocean acidification.

Sumaila et al. (2011) suggest that insight can be drawn from the 1997 – 98 El Nino event. They note that during El Nino the Chilean and Peruvian fishery landings decreased by 50%, which is equal to an 8.2 billion USD drop in exports. Similarly, it is noted that in Southeast Asia effects from El Nino were felt in the mackerel fishing industry, where 48% of landings were lost due to the change in sea surface temperature, equaling a 6.2 million USD loss in exports.

It is suggested by Sumaila et al. (2011) that a price increase is possible to offset losses, but more information needs to be known about price elasticity and how substitutes are valued before increasing the price can be certain to offset the losses. Sumaila et al. (2011) mention the uncertainty associated with climate change, which could result in today's generation incorrectly valuing future generations; placing greater value on the short term as opposed to the long term. They conclude by stressing the importance of climate change in playing a leading role in the creation of new laws and regulations.

The studies reviewed demonstrate that ocean acidification could cause substantial losses to a country's economy. Such impacts are something policy makers, economists, and the fishing industries should be aware of. To date there has been no estimation of the Canadian mollusk industry potential economic losses. Such research could identify the potential damages faced in the wake of ocean acidification and initiate programs to mitigate the projected impacts. As such, my contribution to this field of research is an important first step in this process.

4 Methodology

The focus of this thesis is on the economic impacts of ocean acidification on the mollusk industry in Atlantic Canada. For this research Atlantic Canada includes the provinces of Newfoundland Labrador, Prince Edward Island, Nova Scotia, New Brunswick, and Quebec, as each of these provinces have a shoreline on the Atlantic Coast. Using a net present value equation, the potential value of the mollusk catch into the future is calculated, firstly without the predicted detrimental effects of ocean acidification and then, secondly, compared with the value of future mollusk catch with the predicted effects from ocean acidification. The difference in the values equals the potential economic loss for Atlantic Canada's mollusk industry due to ocean acidification.

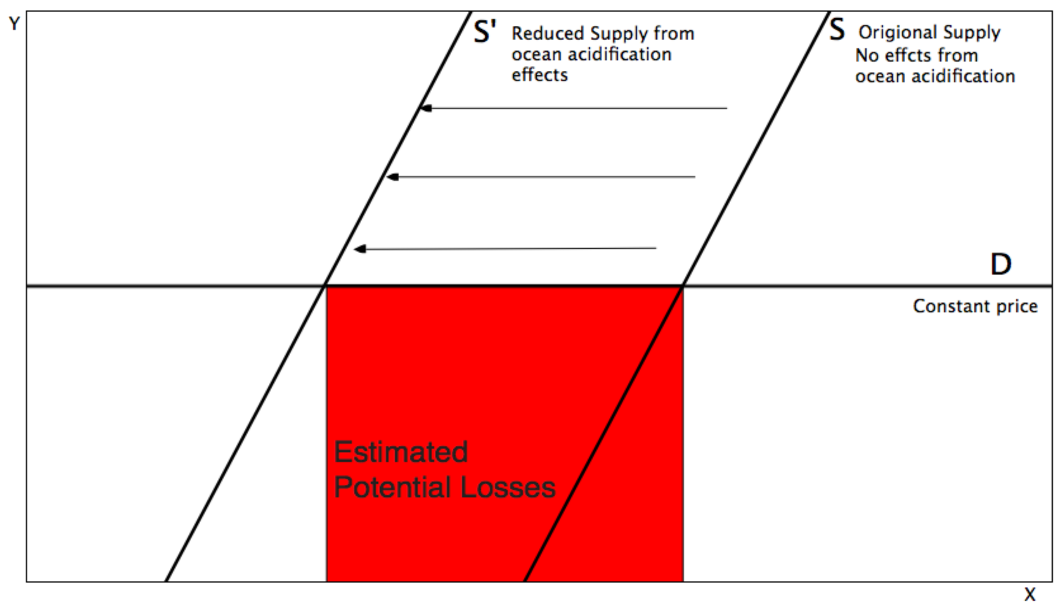
The net present value equation discounts the value of future revenue back to the present. The equation takes into consideration annual revenue, timespan into the future, and a discount rate. Revenue is defined as price of mollusks multiplied by the quantity of mollusks harvested. Two time horizons are considered for this study. The first being 2060, 50 years into the future from the base year 2010, and then 2100, 90 years into the future. The study considers five discount rates, discussed in further detail later in this chapter. (See Appendix for equation; Figure 6)

The price and quantity of mollusks caught data over a fifteen-year period is averaged and used as an estimation of revenue for the future without the impacts of ocean acidification. Nominal prices are converted into 2010 dollars via the GDP deflator. The GDP deflator is used instead of CPI conversion because the CPI reflects the prices of a representative and fixed basket of goods for a certain year. Over a timespan this basket of goods can become unrepresentative of the consumer. Thus to avoid a CPI that could be unreflective of years to come, and in order to take all domestic goods into consideration, the GDP method is used over the fifteen year average.

As stated, revenue is comprised of price multiplied by the quantity sold. Price is a function of demand, and the amount of quantity produced, otherwise known as supply. Hence, supply and demand are crucial in evaluating a net present value. The average price found is held constant for projections into the future. No assumptions are made regarding substitution behavior or possible decline in quantity demanded due to lack of information about consumer behavior. As such, holding price constant parallels the assumption that demand for mollusks is perfectly elastic. This assumption is made in order to obtain the potential estimated economic losses due to a reduction in the mollusk harvest because of ocean acidification.

The supply of mollusks is assumed to have no irregular shocks due to natural events that will effectively increase or decrease the harvested mollusk population. For the purposes of estimating economic loss, the negative impacts from ocean acidification act as the sole variable affecting the supply of mollusk harvest. As in the United States case study compiled by Cooley and Doney (2009), a direct 1:1 ratio between reduced calcification of mollusks and the decline of supply in the mollusk industry is assumed. The constant price assumption, along with the declining mollusk population available for harvest thus produces potential economic losses for the mollusk industry of Atlantic Canada. These losses are summarized in Figure 1.

Figure 1:Assumptions Pertaining to Supply and Demand for Mollusks for Estimating Potential Economic Loss due to Reduction in Harvest from Ocean Acidification[1]



Average revenue data was obtained from the Department of Fisheries and Oceans Canada for each Atlantic province and converted into base year 2010 dollars. The average revenues for each Atlantic province are presented in Table 1. Again, all revenues are to remain constant and be unaffected by other factors for the timespan under consideration, declining only due to the decrease in quantity harvested from the effects of ocean acidification.

Table 1: 2010 Base Year Revenues in Aquaculture for Atlantic Provinces Based on 15 Year Average ($000) [2]

NL	PEI	NS	NB	QC
$1,186.26	$23,377.07	$1,376.43	$593.81	$646.34

[1] Source: Author's Creation.

[2] Source: (1) Data from Fisheries and Oceans Canada. 2013. Aquaculture: Production Quantities and Values. *Retrieved from* http://www.dfo-mpo.gc.ca/stats/aqua/aqua-prod-eng.htm. (Accessed January 6, 2013).
(2) Calculations: Author's own.

Three different IPCC scenarios are considered, each corresponding to a change in water chemistry, which leads to a different rate of reduction in calcification. Rates of reduction in calcification are determined from Gazeau et al. (2007) and Cooley and Doney (2009) , which show a decrease in the harvest of between 6% and 25% for a 0.1 unit decrease in pH balance in waters. Table 2 presents the IPCC scenarios, along with the predicted decrease in mollusk harvest that correspond to such water conditions.

Table 2: IPCC Scenario and the projected water chemistry associated with each at the studied time intervals along with the predicted decrease in mollusk harvest. [3]

	2060			**2100**		
	PPMV	pH UNITS	Decrease Harvest	PPMV	pH UNITS	Decrease Harvest
B1	500	8	6%	550	7.95	9%
A1B	550	7.9	12%	700	7.85	25%
A1F1	700	7.85	25%	950	7.7	40%

In each IPCC scenario the ocean is predicted to contain different amounts of carbon dioxide and different levels of pH balance. The IPCC B1 scenario suggests that in 2060 the world will have 500 ppmv of carbon dioxide and an 8-unit pH balance; by 2100 these levels will change to 550 ppmv and 7.95-units. The IPCC A1B scenario is a mid- range scenario, which predicts carbon dioxide levels at 550 ppmv and a 7.9-unit pH balance by 2060, and in 2100 the levels are supposed to be 700

[3] Source: (1) Data from Comeau, S., G. Gorsky, R. Jeffree, J.-L. Teyssié, and J.-P. Gattuso. 2009. Impact of ocean acidification on a key Arctic pelagic mollusk (*Limancian helicina*). *Biogeosciences* 6: 1877-1882.
(1) Data from Intergovernmental Panel on Climate Change. 2007. Climate Change 2007: Working Group I: The Physical Science Basis. *Retrieved from* http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch10s10-4-2.html (Accessed October 23, 2012).
(2) Compilation of information is Author's creation.

ppmv of carbon dioxide and 7.85-units pH balance. The third scenario considered is the A1F1 IPCC scenario. A1F1 is a worst-case scenario where the world does not change to cleaner energy sources. Levels of carbon dioxide and pH balance associated with this scenario are 700 ppmv carbon dioxide and 7.85-units pH balance in 2060 and 950 ppmv with 7.7-units by 2100.

Yet to be mentioned is the discount rate. When taking into consideration net present value from an environmental perspective, the discount rate considers what value to place on future generations. A discount rate assumes that future generations have the same preferences as their existing cohorts. That is they will place the same value on goods as the current generation. The lower the discount rate, the more weight and consideration are put on future generations and their time preferences. As such, a zero percent (0%) discount rate makes the argument that future generations should be considered as equals to the present, thus it is otherwise known as a perfect generational equality rate. As the discount rate increases, less value is placed on the needs and preferences of future generations in the present time frame.

Five discount rates are considered; 1) the perfect generational equality rate of 0%, 2) a 2% discount rate, which is a liberal IPCC discount rate, 3) 3.5% which argued is Boardman et al. (2010) and taken up by Canadian Public Policy to be the Canadian Government accepted discount rate, 4) 4.7% the yearly growth rate of mollusks, and lastly 5) 7% which is a conservative IPCC discount rate. These discount rates, along with the predicted decrease in harvest levels, present a range of inputs used to estimate the possible economic losses generated via the net present value equation.

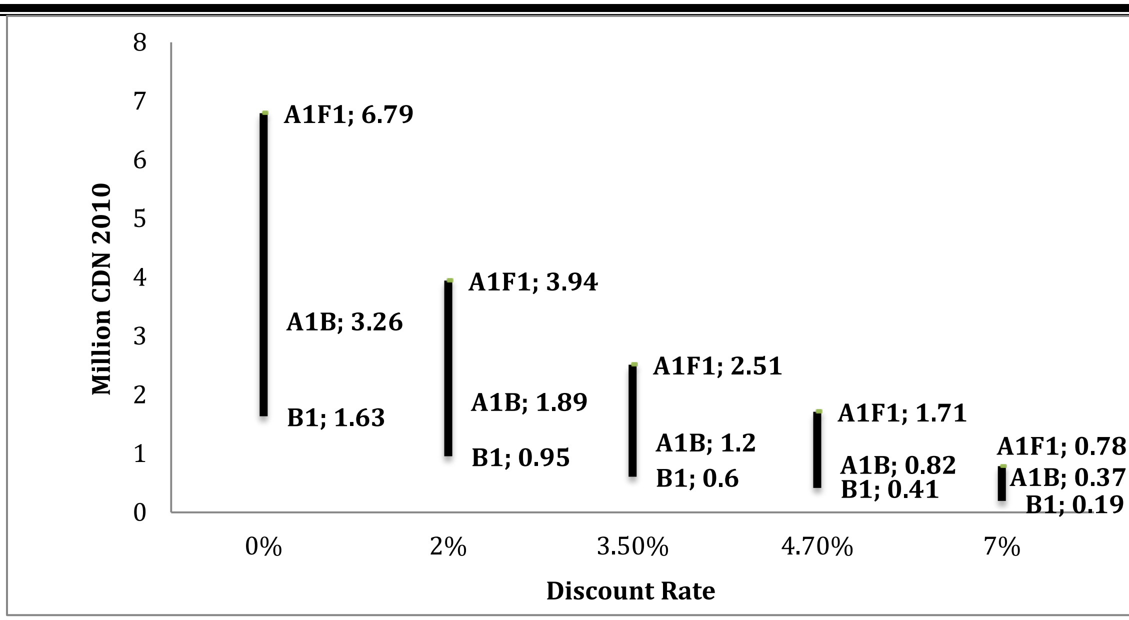
Table 3: Discount Rates Considered for Valuing Future Generations[4]	
Perfect Generational Equality	0%
Liberal IPCC	2%
Canadian Acceptable Consideration	3.5%
Sustainable Growth Rate of Mollusks	4.7%
Conservative IPCC	7%

[4] Source: (1) Data from Boardman, Anthoney E., Mark A. Moore, and Aidan R. Vining. 2010. The Social Discount Rate for Canada Based on Future Growth in Consumption. *Canadian Public Policy* XXXVI (3): 325-343.
(1) Data from Intergovernmental Panel on Climate Change. 2007. Climate Change 2007: Working Group III: Mitigation of Climate Change. *Retrieved from* http://www.ipcc.ch/publications_and_data/ar4/wg3/en/ch2s2-4-2-1.html. (Accessed October 23, 2012).
(1) Data from Fabry, Victoria J. 1990. Shell growth rates of pteropod and heteropod molluscs and aragonite production in the open ocean: Implications for the marine carbonate system. *Journal of Marine Research* 48: 209-222.
(2) Compilation of information is Author's creation.

5 Results

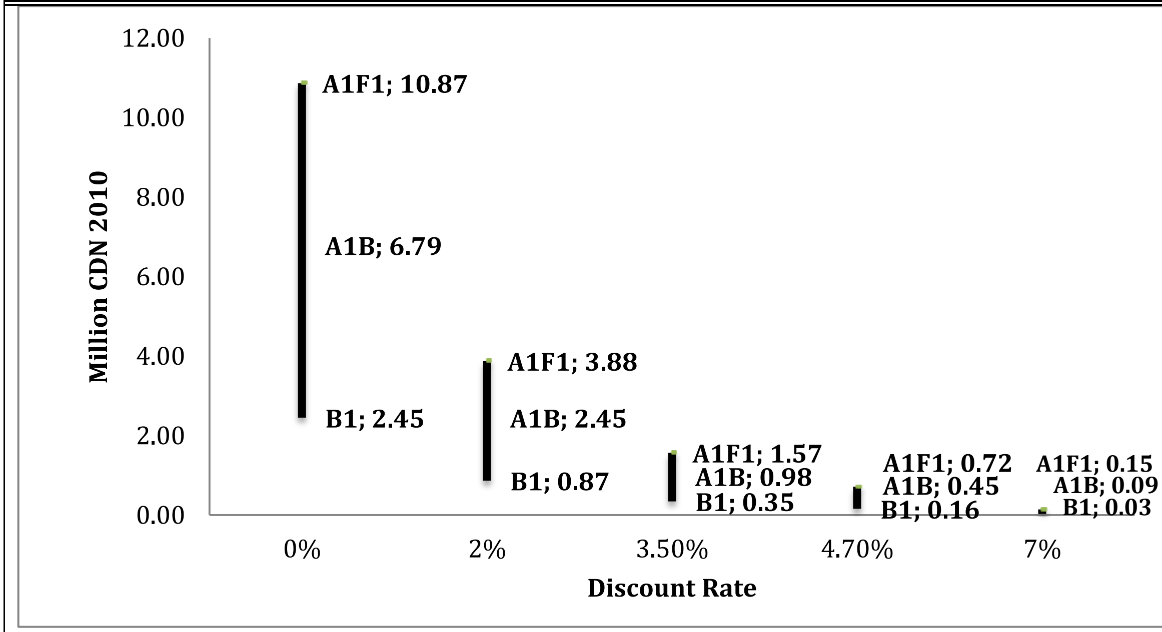
Using the net present value concept, and the inputs mentioned in the methodology chapter, Atlantic Canada mollusk aquaculture industry economic losses for the three IPCC scenarios are calculated and shown in Figure 2 and Figure 3. The losses for the year 2060 range from $187 thousand to $6.8 million CDN 2010. In 2100, estimated economic losses for Atlantic Canada lie between $33 thousand to $10.9 million CDN 2010. Different decreases in harvests lead to different economic losses for the mollusk industry. A higher decrease in harvest will lead to a larger economic loss, and a lower discount rate will value these losses greater in their present value.

Figure 2: 2060 Atlantic Canada Mollusk Aquaculture Industry Economic Losses in Millions of CDN (2010 Base Year)[5]



[5] Source: (1) Data from Fisheries and Oceans Canada. 2013. Aquaculture: Production Quantities and Values. *Retrieved from* http://www.dfo-mpo.gc.ca/stats/aqua/aqua-prod-eng.htm. (Accessed January 6, 2013).
(2) Calculations: Author's own.

Figure 3: 2100 Atlantic Canada Mollusk Aquaculture Industry Economic Losses in Millions of CDN (2010 Base Year)[6]



Looking at these losses graphically is helpful in assessing the implications of choosing at which rate future generations are valued. Choosing the Perfect Generational Equality Rate means estimated economic losses for the mollusk industry ranging in the millions of dollars for each IPCC scenario. Contrastingly, discounting the future at a rate of 7% leads to estimating losses only in the thousands of dollars. This is not to say that the severity of impacts from ocean acidification decreases depending on the discount rate, it only implies that the impacts are valued less in the present because the future generations' losses are discounted at a higher rate.

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[6] Source: (1) Data from Fisheries and Oceans Canada. 2013. Aquaculture: Production Quantities and Values. *Retrieved from* http://www.dfo-mpo.gc.ca/stats/aqua/aqua-prod-eng.htm. (Accessed January 6, 2013).
(2) Calculations: Author's own.

Choosing at what rate to value the future is an issue that has been highly debated for some time. It is argued in Boardman et al. (2010) that Canada should regard the future with a 3.5% discount rate. This implies that the middle column in Figure 2 and Figure 3 are of the most importance to Atlantic Canada mollusk industries when evaluating these potential economic losses. Thus in a worst-case A1F1 IPCC scenario, losses for 2060 would be $2.5 million CDN and for 2100 would be $1.5 million CDN.

A point to be noted is that data for the average revenue was obtained from the Department of Fisheries and Oceans Canada for each Atlantic province and converted into base year 2010 Canadian dollars using the GDP Deflator. Due to data availability, only aquaculture statistics for the selected provinces could be evaluated. This however does not alter the overall hypothesis of this study. As mentioned in Narita et al. (2012), all mollusks in aquaculture spend significant time in tanks with unregulated carbon dioxide levels. Thus aquaculture mollusks are exposed to the same risks from ocean acidification as wild mollusks, and will suffer the same detriments in their developmental processes. Hence aquaculture mollusks can be assumed to be as equally effected by ocean acidification as mollusks harvested from the open ocean. The data presented then only provides potential economic losses for the aquaculture industry; similar decreases will impact the wild harvesting of mollusks, however, due to restrictions of information, these decreases cannot be captured in this study.

Attention should also be drawn to the fact that there is a decreased rate of economic losses from 2060 – 2100, the second time frame segment, than from the first time frame segment under review, 2010 – 2060. This is in line with the IPCC scenario suggestion that detrimental climate change conditions will peak in 2060 due to effects of technological advancement and greener energy being slow to reveal full impacts on reducing greenhouse gas emissions. The damages will decline after 2060 because effects of the greener and more efficient technology will begin to be felt. As such, after 2060 the rate of damage from climate change problems, one being ocean acidification, will decline. It should then be expected that the potential economic losses from ocean acidification would decline in 2100 from their 2060 levels, which can be seen when comparing Figure 2 with Figure 3.

A tabled breakdown of the potential economic losses to the Canadian Atlantic Mollusk Aquaculture Industry is presented in Table 4.

Table 4: Atlantic Canada Mollusk Industry Economic Losses for each Discount Rate[7]

IPCC B1 Scenario, in thousands of CDN					
6% Decrease in Harvest by 2060, and 9% Decrease in Harvest by 2100					
	0%	2%	3.5%	4.7%	7%
2060	$1,630.7946	$945.1582	$601.4016	$409.4879	$187.4537
2100	$2,446.1919	$873.2941	$352.6369	$160.9529	$32.7260
IPCC A1B Scenario, in thousands of CDN:					
12% Decrease in Harvest by 2060, and 25% Decrease in Harvest by 2100					
	0%	2%	3.5%	4.7%	7%
2060	$3,261.5892	$1,890.3163	$1,202.8031	$818.9758	$374.9074
2100	$6,794.9775	$2,425,8171	$979.5469	$447.0914	$90.9056
IPCC A1F1 Scenario, in thousands of CDN:					
25% Decrease in Harvest by 2060, and 40% Decrease in Harvest by 2100					
	0%	2%	3.5%	4.7%	7%
2060	$6794.9775	$3,938.1590	$2,505.8389	$1,706.1996	$781.0571
2100	$10,871.9640	$3,881.3073	$1,567.2750	$715.3462	$145.4489

[7] Source: (1) Data from Fisheries and Oceans Canada. 2013. Aquaculture: Production Quantities and Values. *Retrieved from* http://www.dfo-mpo.gc.ca/stats/aqua/aqua-prod-eng.htm. (Accessed January 6, 2013).
(2) Calculations: Author's own.

6 Discussion

Based on the results it is clear that ocean acidification has the potential to generate between hundreds of thousands and millions of dollars in economic losses for the mollusk (mussel) industry in Atlantic Canada. What has not yet been discussed is the significance of the mollusk industry in Atlantic Canada's economy, as it relates to GDP and unemployment.

The most recent aquaculture production in Canada is summarized by Figures from Fisheries and Oceans Canada in their 2009 Aquaculture Canada: Facts and Figures publication. According to this document, mussels make up 15% of the aquaculture industry in Canada, and the provinces defined in this study as 'Atlantic Canada' comprise 44.8% of the total production of aquaculture in Canada, worth a total $823.6 million CDN 2010. When solely considering shellfish aquaculture, the production of mussels accounts for 68% of total shellfish production in Canada, an estimated market value of $33 million CDN 2010, with PEI producing 77% of the total output. In 2009, Canada exported 10,500 tonnes of mussels worth $30.9 million CDN 2010.

In terms of employment in 2009 in the aquaculture industry, Fisheries and Oceans Canada data shows that the production of aquaculture provided Atlantic Canada provinces with 2,565 direct full-time jobs. Combined with indirect and induced jobs, Fisheries and Oceans Canada estimates that the industry provides 4,820 full-time job equivalents in the Atlantic Provinces. The aquaculture industry in total creates $154 million CDN 2010 in income for the Atlantic Provinces. Overall

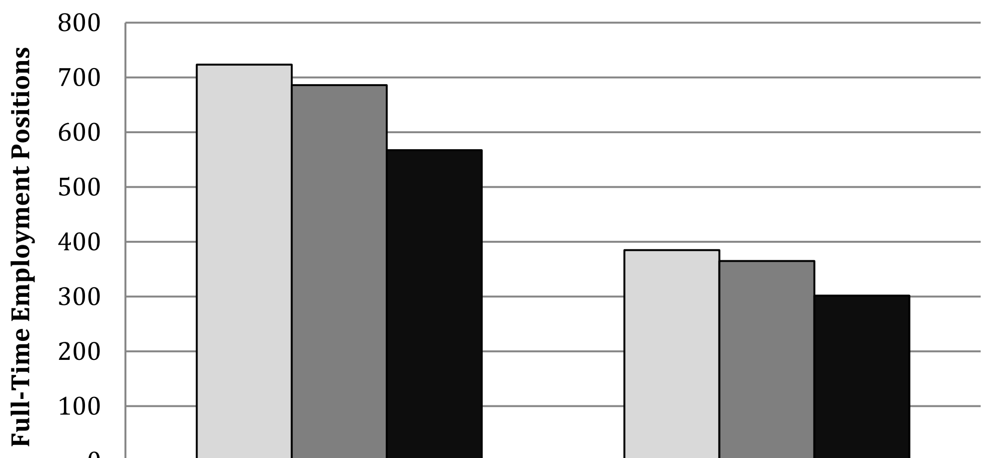
Atlantic Canada's total aquaculture industry accounts for 30% of the Canadian aquaculture industry's contribution to GDP, providing a total value of $305.7 million CDN 2010 to the economy.

As mentioned, the mussel aquaculture industry makes up 15% of the total aquaculture industry in Canada. Applying this percentage to the total figures for full time employment, income generated, and GDP contribution, allows for an estimate of the significance of the mollusk industry. Fifteen percent of the statistics mentioned for the aquaculture industry would correspond to 385 direct full-time jobs and a total (direct/indirect/induced) of 723 full-time employment positions to the economy from the mollusk industry specifically. The income provided by the mussel industry in Atlantic Canada would bring in $11.6 million CDN 2010 in direct income, and in $23.3 million CDN 2010 in total income to the economy, the impact of the mussel industry would contribute 4.5% to GDP, $45.9 million CDN 2010 to the Canadian economy.

Ocean acidification will bring detrimental effects to the mollusk industry. The IPCC scenarios used in this research correspond to predicted decreases in mollusk harvest between 6-40%, with direct economic losses estimated to be between $600 thousand and $2.5 million CDN 2010 for the year 2060 at a 3.5% discount rate. Fisheries and Oceans Canada state that the Atlantic Canada shellfish industry is comprised of mostly small family owned and operated farms, with the exception of PEI. The composition of the industry, having little technological innovation, implies an industry relying heavily on labour for market production.

For estimation of economic losses, suppose that the employment and income levels remain constant into 2060. Losses dispersed solely throughout the labour sector of the mussel industry would then correspond to a decline in direct income of between $9.1 million and $11 million, reducing the direct income from the industry in Atlantic Canada by 5-22%. Assuming that labour is the sole production input affected, a 5-22% drop in full-time employment means that between 20 and 82 direct full-time employment positions will be lost in the mussel industry.

Figure 4: Declines by 2060 of Full-Time Employment if Losses from Ocean Acidification are felt Directly on Labour in Mollusk Industry of Atlantic Canada.[8]



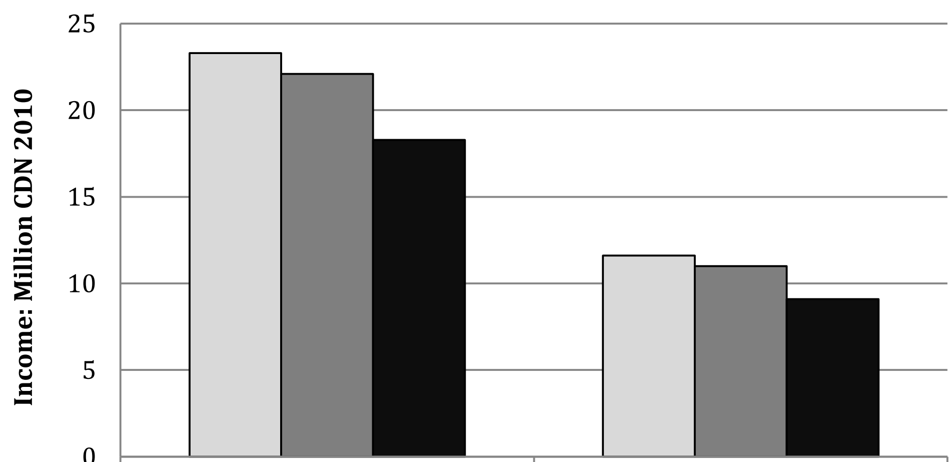
	Total Employement	Direct Employment
2060 Projection	723	384.75
Decline (5%)	685.6	364.85
Decline (22%)	567.18	301.83

If a 5% decline linearly affects the overall mollusk industry, thereby bringing the indirect and induced employment and income down by 5%, it will lead to the

[8] Source: (1) Data from Fisheries and Oceans Canada. 2009. Aquaculture Canada: Facts and Figures. *Retrieved from* http://www.dfo-mpo.gc.ca/aquaculture/ref/stats/aqua-ff-fc-2009-eng.htm. (Accessed February 6, 2013).
(2) Calculations: Author's own.

estimated loss of 37 full-time employment positions and a reduction of total income by $1.17 million CDN 2010 for the Atlantic Canada mollusk industry. Comparatively, a 22% decline of the mollusk industry, will lead to an estimated loss of 155 full-time employment positions and reduced total income of $5.02 million CDN 2010. While these numbers seem relatively small compared to Canada's broader economy, it is important to remember that it is the rural communities in Atlantic Canada who rely heavily on aquaculture that will be impacted the most by these damaging effects.

Figure 5: Declines by 2060 in Income if Losses from Ocean Acidification are felt Directly on Labour in Mollusk Industry of Atlantic Canada[9]



	Total Income	Direct Income
2060 Projections	23.3	11.6
Decline (5%)	22.1	11
Decline (22%)	18.28	9.1

These results only represent the Atlantic mollusk industry in Canada. Yet ocean acidification is a worldwide phenomena, thus the Canadian Pacific mollusk

[9] Source: (1) Data from Fisheries and Oceans Canada. 2009. Aquaculture Canada: Facts and Figures. *Retrieved from* http://www.dfo-mpo.gc.ca/aquaculture/ref/stats/aqua-ff-fc-2009-eng.htm. (Accessed February 6, 2013).
(2) Calculations: Author's own.

industry, as well as industries in other countries, should be aware of the potential damaging effects this carbon dioxide problem can and will impose on the industry. It should be noted that the thesis results are only a first look at the impacts. There are no assumptions about substitution effects, increases in demand or supply, and inflation and growth are also not taken into account. While these assumptions may provide less accurate results, they allow a starting point for the conversation about the impacts expected due to ocean acidification.

The results allow for discussion about mitigating climate change effects on the mollusk industry. For Canada, the results of this study should add urgency to the implementation of climate change mitigation policies. Policies not yet enacted under Bill C-30 should be given greater relevance and more stringent deadlines. A reduction of an industry by 22% in 2060 is a significant reduction that will be felt economically. This illustrates that mitigation processes should be introduced as soon as possible.

Appendix of Figures and Tables

Table 5: Table 3 of Cooley and Doney (2009): Time integrated net present values (NPV) by 2060 of economic losses, assuming declining mollusk catches associated with IPCC B1 or A1F1 emissions scenarios, and the time-integrated NPV of UF and regional fisheries by 2060, assuming no catch decreases. NPVs are in millions (US 2007 dollars). [10]

Emission Scenario	Low IPCC (B1)			High IPCC (A1F1)		
Net Discount Rate	4%	2%	0%	4%	2%	0%
US	324-809	610-1523	1226-3060	543-1358	1023-2557	2058-5144
New England	116-290	218-546	439-1097	195-486	366-916	737-1843
Pacific	38-94	71-177	143-357	63-158	119-298	240-599

Table 6: Table 2 of Armstrong et al.(2012): Selected and Aggregated Results of the meta-analysis of (1) Hendriks, et al. (2010) and (2) Kroeker, et al. (2010).[11]

Organisms:	Contribute to:
Bivalves/Mollusks	**Provisioning Services**
Survival	59.44% reduction – 2.7% increase (2)
Growth	39.49% reduction – 18.79% increase (2)
Calcification	32-46% reduction (1) 66.38% reduction – 3.67% increase (2)

Figure 6: Net Present Value Equation

$$NPV = \sum_{t=1}^{100} \frac{R_t}{(1+r)^t}$$

[10] Source: (1) Reprinted from Cooley, Sarah R., and Scott C. Doney. 2009. Anticipating ocean acidification's economic consequences for commercial fisheries. *Enviornmental Research Letters* 4: 5.

[11] Source: (1) Reprinted from Armstrong, Claire W., Silje Holen, Ståle Navrud, and Isabel Seifert. 2012. The Economics of Ocean Acidification – a scoping study. University of Tromsø, Norway. NIVA, Oslo, Norway. University of Life Sciences, Ås, Norway. Photocopied: 39.

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