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The Effect of Climate Change on the Productivity and Profitability of Cod in the Barents Sea.

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Abstract

Climate change has an inevitable natural impact on fisheries. Continually, several models made of both biological and economic factors are used to measure the effects of climate change on fish stocks. This study has as its objective to identify how climate change effect through carrying capacity affects the productivity and profitability of the cod stock in the Barents Sea. Two scenarios one with climate change effect and the other without climate change effect are compared to explore the climate change effect. This thesis uses a simple bioeconomic model based on a surplus production model to conduct the analysis over 50 years. Two different vessels are considered, coastal fishing vessels and ocean going vessels. The results suggest the positive effect of climate change on total biomass, harvests and discounted profit for both vessel groups. The results also suggest a bigger effect on the coastal vessels than on the ocean ongoing vessels. Sensitivity analysis suggests noticeable impacts with increase in price and intrinsic growth rate. Although this exercise is rather simple, the findings can be used to improve management measures so as to sustainably exploit fish resources if climate change takes places as anticipated.

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Chapter 1: Introduction

The stock productivity of a fishery is one of the crucial factors that determine its profits. Climate change is one of the environmental plagues that affect fisheries all over the world direct or indirect through disaster events like floods or droughts, warmer temperatures, ocean acidification, global warming as well anthropogenic pressures to name a few (FAO, 2018). This is evident with the 2015 Paris Climate Agreement that acknowledged the threat of climate change and the necessity to efficiently and continuously retaliate to this critical threat, by using alleviation and medication procedures (ibid).

Research over the years indicates inevitable effects of climate change on marine fisheries, inland fisheries, and aquaculture (ibid). This explains why over the past years, researchers have been continuously studying to find tools and solutions, which can help, manage, and adapt to the changes caused by climate. Also, researchers find ways to reduce the human impact (anthropogenic pressures) that contributes to the depleting of fish stocks. Climate effects can affect fisheries economically through changes in the ocean temperature influences which might isolate small and large fish leading to certain locations being valuable to exploit due to the state of the ocean altering over time (Haynie & Pfeiffer, 2012). In addition, there are research that focus more on the effects of climate variations on the biological aspects of fisheries than on the economic aspects specifically in terms of those exploiting the fish resource (ibid). Therefore, it is important to observe how productivity and profitability of a fishery can be affected by changes in climate, especially in temperature variations over time while taking into consideration spatial distribution.

The North-East Arctic cod (*Gadus morhua*), one of the Atlantic cod stocks, is considered one of the most valuable cod stocks in the world (Helgesen et al, 2018) and therefore very important commercially to the two nations (Norway and Russia) that share this stock. This study focuses on the Norwegian share of the stock located in the Barents Sea. The North Atlantic cod has however over the years experienced the effects of climate change directly through changes in temperature, warmer waters, and ocean acidification and indirectly through extensive sea and atmosphere mix, availability of food supply and the distribution of eggs and larvae in the sea (Crépin et al. 2017). This has further affected the productivity of the stock and therefore, the profits as well.

Therefore, this study aims to identify the effects of the climate change on the productivity and profitability of NEA cod fishery over fifty years. A bio-economic model is employed here to compare two scenarios, one with climate change effect and the other with no effect. The climate effect is explored through the carrying capacity parameter. To achieve the above objective, the following questions would be addressed:

1) Does climate change affect the productivity of cod fisheries over time?

2) Does climate change affect the profitability of the cod fishery over time?

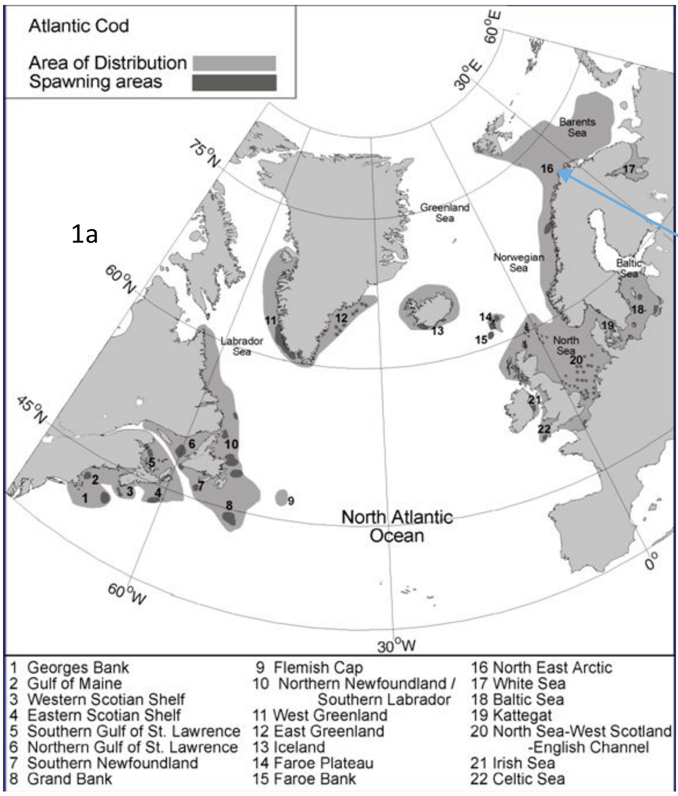
The results of this analysis can provide some useful information for how to exploit fisheries resources if the effect of climate change is plausible.

The rest of the study is structured as follows. Chapter 2 introduces NEA cod fisheries and climate effect on fish stocks and fisheries. Chapter 3 outlines the mathematical model used for the analysis. In Chapter 4, the data and estimated values are presented. The results and sensitivity analysis are presented in Chapter 5, and discussions, conclusions, limitations and recommendations about further studies are presented in Chapter 6.

Chapter 2: Northeast Atlantic Cod Stocks and Fisheries

2.1: North-East Atlantic (NEA) Cod

The Atlantic cod stocks occupy most banks in the North Atlantic with their distribution in the different areas being determined by salinity and temperature of the water (Svasand et al., 2007). The distribution and spawning areas of major Atlantic cod stocks are illustrated in figure 1a below. There are 22 major cod stocks, and North-East Arctic cod is one of these stocks and is numbered 16 in figure 1a below. Figure 1b further shows the distribution of the North-East Arctic cod in the Barents Sea.



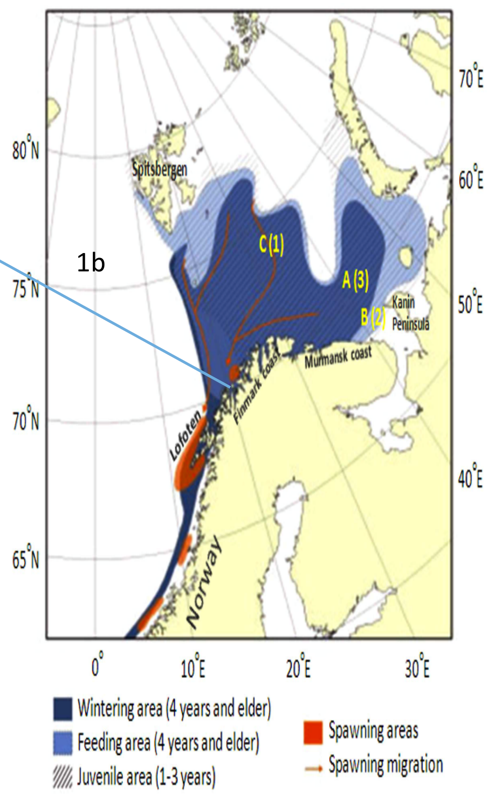


Figure 1a: Distribution and spawning areas for major cod stocks (Source: www.imr.no)

Figure 1b 1: Distribution of NEA cod in the Barents Sea (Source: [Krisna Rungruangsak-Torrissen, 2012)](#)

The Northeast Atlantic cod is highly migratory and spends most of their life in the Barents Sea and spawns along the Norwegian Coast between March and April (Bogstad et al., 2013). Their spawning occurs in the coastal areas of Norway between 62N and 70'8N but mostly concentrated at around 68'8N, which is the Lofoten area (ibid). This makes the Lofoten area the most productive area for then NEA cod. According to Nakken & Raknes (1987), the temperature in the Barents Sea drops from the west to the east. This, therefore, leaves the cod in the younger age groups situated in the east at lower temperatures than the adult cod situated farther to the west.

The North-East Arctic cod stock is considered one of the richest of the Atlantic stocks and also the largest and most lucrative fish stock in the world (Link & Tol, 2006). This stock is harvested by Norway and Russia, with Norway having about 45% of the stock (Helgesen et al., 2018). This cod stock has been intensively and extensively researched over the years and as such, considered one of the well-documented fishery in the world (Eide, 2017). With the existence of environmental fluctuations, this cod stock is believed to be resilient because there has been continuous export of dry cod from this fishery for over a thousand years now (ibid). In addition to the fact that this cod stock is built to adapt to its fluctuating environment, it has been observed to practice variations of independent survival strategies like cannibalism, spawning and feeding traveling methods, adult dynamics and feeding methods based on the opportunity (Kjesbu et al., 2014). However, given the complexity of marine systems and the difficulty of predicting environmental changes, there is still the need to continuously observe and research the effect of climate change on such a valuable resource.

The total catch of these cod stocks have gradually declined over the years due to fishing pressure as well as changing environmental conditions (Marteinsdottir et al., 2005). This was evident from 1970 when the north Atlantic total catch was about 3.5 million tonnes but drop to less than a million by 2003 (Svasand et al., 2007). This has resulted in some of the 22 stocks fishery to be closed or collapse. The North-East Arctic cod stock like several other cod stocks has fluctuated over the years (illustrated in figure 2 below)

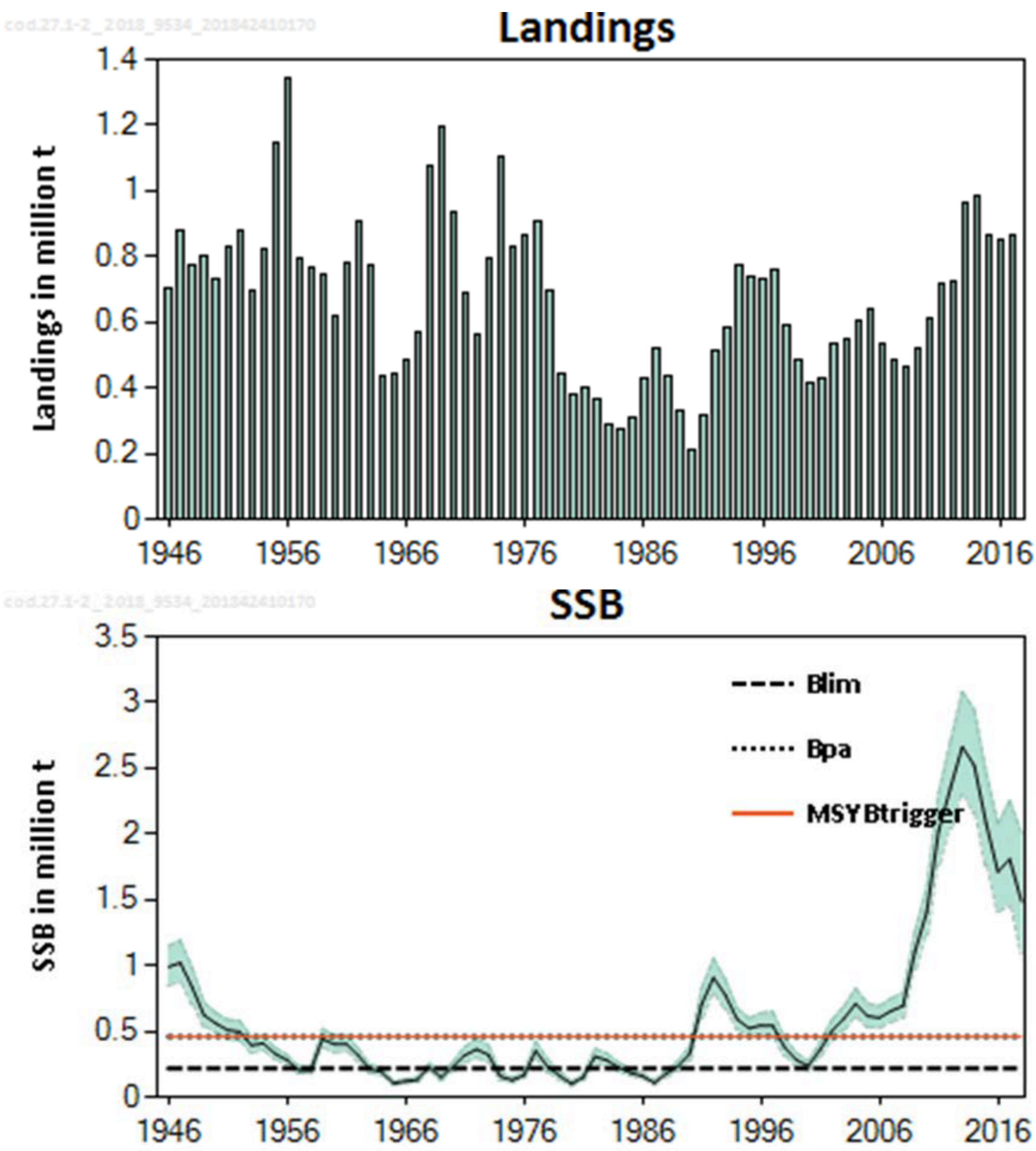


Figure 2: ICES Standard plots for Northeast Atlantic cod (subareas 1 and 2) Source: ICES 2018.

As illustrated in figure 2 above the total catch was on an unvarying decline from about 900,000 tonnes in the 1970s to about 300, 000 tonnes between 1983 to 1985, but increased to about 500,000 tonnes in 1987 before another decline to 212,000 tonnes in 1990 which was the lowest recorded catch (ICES, 2018). However, there was a rapid increase from 1991 but another noticeable decrease in the year 2000. Since 2011, the NEA cod catches have been over the stable average, and as of 2017, the catch was reported to be at 868 276 tonnes (ICES, 2018).

Due to its stock size estimates at 4.2 million tonnes in 2015, NEA cod is considered one of the largest in the world (Helgesen et al., 2018). The stock is considered well managed jointly by Norway and Russia (Eide et al., 2013). The NEA cod is harvested with two different fleets, the coastal fleet, and the ocean-going trawlers; this fleet diversity is influenced by the spatial distribution of this stock (Eide, 2017). According to Eide (2017), NEA cod fishery is considered as the most important fishery in the Barents Sea that employs several varying coping strategies to adapt to the underlying declining marine environment including spawning and feeding migratory patterns, maturation, and cannibalism. In 2015, Norway received 894,000 tonnes, which was 45% of the total allowable catch (TAC) of 4.2 million tonnes. The Norwegian fleet harvested and sold cod worth more than 500 million Norwegian Krone (NOK) in 2015. NEA harvest for cod accounts about half of total Norway produce in a demersal fishing vessel with an estimated profit of about 11 million Norwegian krone (NOK).

2.2: Climate Effects on North-East Atlantic Cod Stock and Fisheries

Globally, climate has increased in temperature remarkably throughout the rear 1300 years (Mieszkowska et al., 2010) According to the 2007 IPCC report, human activity is considered to be the foremost cause of environmental changes. However, recent model projections suggest that globally, the average surface temperature rise by an additional 1.1-2.9C (low emissions B1 scenario) or 2.4 - 6.4C (high emissions A1F1 scenario) (IPCC, 2007). In the Arctic, there has been an event of considerable and prompt alterations in recent years. The most important of these was the event of the minimum Arctic sea-ice area in summer 2007 (Crépin et al., 2017). These alterations are believed to be as a result of both natural changes of the high-latitude climate structure, human activities in emitting stability and following atmospheric and oceanic convections as well as reactions in the atmosphere and ocean systems combined (ibid).

Climate change has been seen to affect fish stocks indirectly through changing breeding times or areas, or directly by natural deaths, maturation, or the availability of food (Skjæraasen et al., 2014). Atlantic cod in the Barents Sea has emerged in enormous amounts on Bear Island Bank as a result of the sea warming up in the early 20th century which led to the re-construction of a cod fishery after it being non-existent for nearly 40 years (Drinkwater, 2005). Furthermore, the codfish also infiltrated Novaya Zemlya significantly from the east and the West Svalbard from the north around the 1920s (ibid). Also, in the 1990s during the warmer periods in the Barents sea, aged three cod was mainly moving eastwards (Ottersen, Michalsen, & Nakken, 1998). These changes, which do not necessarily match the above history of the NEA cod fluctuating over time, still, explain that some changes in this cod stock are due to the changing climate.

Several global studies have been conducted on the impact of climate change on fisheries. As a result of global warming, the growth rate of fish stocks in the Barents sea are affected positively or negatively depending on different environmental scenarios (Eide & Heen, 2002). Due to ocean acidification, studies disclose that there is decrease in growth, survival and calcification on marine organisms (Kroeker et al., 2013; Narita & Rehdanz, 2017). Variations in temperatures are revealed to cause low recruitment at low temperatures but varied recruitment at medium to high temperatures (Bogstad et al., 2013). In addition, natural disaster events cause fish stocks to be vulnerable to climate change effects and therefore affects livelihoods depending on this resource (Iwasaki et al., 2009). These may be partially or fully resulted from anthropogenic pressures like pollution and overfishing (Brander, 2013). Most of these studies have focused on how climate change affects the biological part of the fish stock like recruitment, growth, and age of the stock, food availability, and mortality. These effects could either be positive or negative. The negative effects include declining fish stocks especially overexploited stocks by reducing the rates of recruitment which are already low as a result of decreased SSB as evidence suggests (Mieszkowska et al., 2010). Distribution of aquatic species widely depends on the environment, such as temperature. Their psychological performance changes continuously based on the optimum level of temperature that is within their thermal tolerance limits (Bogstad et al., 2013). For instance, in the Celtic sea, North sea and Irish sea, poor recruitment of stock has been linked with temperatures warming up whereas these same temperatures in the Barents Sea and Labrador coast of Canada relate to good recruitment (FAO, 2018).

Furthermore, they also seek to see how the above aspects of the fish stock affect the availability of the stock for harvesting, its productivity, how these reflect on the fishery's profits and measures employed by the management to adapt to these changes caused by climate changes. Eide (2008) estimated the economic effects of climate change on the cod fisheries in the Barents Sea, and concluded that the economic impact of management regimes was more significant than that of climate change. Another study (Lorentzen & Hannesson, 2005) found out that global warming would increase the cod stock as well as the value of Norwegian fishing fleets depending on the price sensitivity of cod. Also, Olsen et al. (2011) investigated how to better observe the effect of climate change on the relationship between spawning stock and recruitment. Furthermore, one of the most recent studies focused on improving fisheries management to help reduce negative effects of climate change (Gaines et al., 2018) and revealed that better management measures can avoid declining stock and thus increasing revenue.

Chapter 3: Methodology

3.1: Literature Review

The model used in measuring the effects of climate change is an important factor to consider. This is because there is a need to employ a model, including all necessary variables to produce efficient results that have an impact or can influence management decisions. However, given the almost unpredictable nature of natural resources and climate change, this makes the fishery system very complex and difficult to model. This explains the use of different models by different researchers to find the most efficient one that fits their research goal and provides answers to research questions they are seeking to solve.

The most popular of such models used in fisheries research are bio-economic models because they incorporate the important factors in a fishery, including fish biology, the economics of fisheries, and even social factors. There are age-structured or staged-structured models and lump surplus production models that have been used. An example of a study employing the use of a bio-economic model to explore the climate change effects is that of (Nieminen et al., 2012). The research utilizes a simple predation surplus production model to assess fisheries in the Baltic Sea under varying environmental conditions. It follows the procedure of comparing fishing policy status quo to an optimal policy that undoes two varying salinity conditions due to climate change (Nieminen et al., 2012).

Another example of using an age-structured model can be seen in the study by Olsen et al. (2011). The authors study optimal and managed fisheries utilization and open access based on the age-structured model of one fishing fleet. Clark et al. (2003) examine the possible effects of climate change on fish stocks, which is essential to determine the output from large-scale climate approaches utilized in fisheries simulations. The stage-structured model estimates the likely impacts of climate change on the cod population in the North Sea (Clark et al., 2003).

Also, surplus production models (Rose, 2004) are utilized to examine climate change and overfishing on the depleted stocks of cod through reconstructing the cod catches in the region to describe biomass dynamics of cod fisheries. The assumptions made are random fishery-only influences inferring constant or dispensatory parameters that are fared poorly to ensure it does not copy history.

Some researchers combine economic (harvest, cost, revenue, profit) and fish biology (age/stage structured models, logistic growth) to make their studies more detailed and inclusive. For example, Thøgersen et al. (2015) with the use of an age-structured bio-economic model measure the economic effects of cod, herring and sprat stocks management with changing climate. These models could be used either for single species or for multispecies models.

Several different models have been used to discern, manage, and predict the effects of climate change on the Atlantic cod fisheries. This study, however, will be using the surplus production model to measure the climate effect on the productivity and profitability of Atlantic cod over 50 years. The production from a fish stock that surpasses what is needed to restore depletion as a result of natural deaths is known as surplus production (Haddon, 2011, pg.280). The production here refers to the total of current recruits plus the growth of already existing recruits minus harvests (ibid). There are two categories of models which are holistic and analytical as examined by Sparre and Venema (1998). They discuss analytical models where an age structure is a necessity to assess the stock, for instance, age structured models like the Beverton and Holt's Yield per Recruit model. Furthermore, they explain holistic models as those, which do not take into consideration the age or size of the fish (assume comparable biomass) for example surplus production models and production models in general. Therefore, it offers a possibility to observe how the stock reacts to changing climate through carrying capacity and growth rate, the former information helps in assessing the productivity of the stock (Haddon, 2011, p.279) and therefore profitability can be determined as well.

Although this model ignores age group, size, and other differences, they are less complicated and include the time variability which can be used to compare different scenarios and can also be used for predictions since they are dynamic (Musick & Bonfil, 2005). There is a question of what is the best model to study the effect of climate change on a stock? There is no one answer since the climate effects differ among locations and stocks.

The variations in the stock biomass are due to natural deaths, fishing, or environmental fluctuations like climate change. The stock biomass can be affected by the temperature at different stages (growth rate) that could be the larvae stage or first year (Olsen et al., 2011). Also, Skjæraasen et al. (2014) indicate that changes in temperature through recruitment and growth can affect the abundance of cod in the Barents sea. Moreover, random occurrences like temperature changes, wind and currents play an important role in the success of fish recruitment through age composition and generative efforts (Mieszkowska et al., 2010). A comparative study on the effects of climate change, fishing aptitude and fisheries management on spatial distribution of cod in the Barents Sea using two scenarios (one with climate change effects and the other with no effects) showed that at low levels of harvesting and average aptitude, the highest profits were obtained (Eide, 2017).

In addition, with the use of both the ecosystem model and the fleet model Eide (2007) studies the effect global warming has on the economic and biology of fish in the Barents sea. While taking into consideration different management regimes, Eide (2014) uses a cellular model to observe how fleets behave when founded on accessible management rules, economic capacity and information about the resource. He assumes open access setting with small and large vessels located in four separate homeports to observe fleet performance. Furthermore, Eide (2016) employs a simulation model of the NEA cod fishery to examine how fleet diversity is constructed and conserved with the assumptions that economic performance is rational under changing compound limitations, and how the capability of vessels to locate fish impacts profitability, the diversity of the fleet, periodic outlines and stock growth of the fishery.

3.2: The Bio-economic Model

This study aims at analyzing the effects of climate change on productivity and profitability of NEA cod fishery in the Barents Sea. Setting up a model with mathematical equations and using numerical data and computer software to measure the relationship between climate changes in biological and economic factors that affect the fishery will do this. Therefore, the methodology used in this research is quantitative approach using existing data and information from literature.

The surplus production model that is a common stock assessment model considers the fish population as a whole without considering the differences in age and size. The surplus production model has the bases of the Gordon Schaefer model, which includes the carrying capacity and intrinsic growth rate parameters and the stock biomass as well. Biomass is used to measure fish stock, and its main interest is the ability for reproducing, recruitment of new individuals, the growth rate, the natural mortality rate, and rate of fishing mortality.

Therefore, the stock of fish will rise if there is the recruitment of new cod and growth of the existing cods will provide an addition to the cod compared to the removal by fishing and natural morality. The intrinsic growth rate represents a combination of growth rate, the mortality rate, and spawning (Musick & Bonfil, 2005). The logistic growth equation, includes the ideal Schaefer (1991) form, the improved Fox (2004) form, and the improved Pella and Tomlinson (1969) form. The differences in these forms depend on the assumption formulated regarding the answer to production as a biomass function (Schaefer, 1991).

The assessment of fish stocks aims at determining the harvesting rate of stocks and predicting the future state of the stocks, sustainability levels and the profits of the catch concerning what levels the fishing effort is at the time (Sparre & Venema, 1998). This can be done with the use of simulated stock production model.

The surplus production model is employed in this study as it fits the objective of the study. The variables used in the model include climate change, biological and economic factors, which will be further discussed below. The important variables that will be included in this model can be divided into biological and economic variables. The biological variables are the cod stock, which includes its stock biomass, intrinsic growth rate, and carrying capacity.

3.2.1: Biological Model

Logistic Growth Model

Schaefer's production function known as the logistic growth model is used and presented as follows;

$$g(B_t) = rB_t\left(1 - \frac{B_t}{K}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where $g(B_t)$ represents growth production as a function of biomass, B_t, at year *t*, *r* is the intrinsic growth rate which is assumed to be fixed in this study while *K* is the environmental carrying capacity which could be constant or varying. B_t is stock biomass at year *t*. The logistic growth function is a S-shaped curve representing the population growth rate increases faster at the low stock, then decreases when population size approaches the carrying capacity.

The environmental carrying capacity factor is a very important limiting factor representing an environment can sustain or carry a population. It varies dependent upon the stock, size and the productivity of the stock in the habitat while the intrinsic growth rate focuses mainly on the real specie in study. Climate has effects on the carrying capacity as illustrated in Eide (2016). In this study, we assume that *K* is unchanged over time, consider it as without climate effect while with climate effect, *K* will vary over time.

If the fish stock is subject to harvest, then the change of stock per unit of time can be defined as:

$$\frac{dB}{dt} = g(B_t) - H_t \quad \text{(2)}$$

Where H_t is the biomass harvested during the year *t*.

Surplus Production Model

Taking into account growth and harvest, the surplus production can be presented as follows;

$$B_{t+1} = B_t + g(B_t) - H_t \quad \text{(3)}$$

Where B_{t+1} is stock biomass at year *t+1*. Equation 3 can be referred to as the biomass dynamic model, which takes into account the growth of fish stock (a function of carrying capacity, intrinsic growth rate and fish biomass) and harvest (a function of fishing mortality and biomass).

3.2.2: Economic Model

Harvest Function

Harvest takes place due to the deliberative actions of participants in the fishery. Therefore, the harvest function is represented as follows,

$$H_t = f_t \, . \, B_t \quad \text{(4)}$$

Where f_t is the fishing mortality, which indicates how much fish are taken by fishers. In this study, we assume two types of fishing vessels to harvest the same cod stock. The two types of fishing vessels are coastal and ocean going vessels. The coastal vessels that are small vessels operating along the coast while the ocean going vessels that is large vessels operating in the high seas.

Revenue and Cost Functions

Revenue function is the function of price multiplied by harvest per unit of time. This can be illustrated as follows:

$$R_t = H_t \, . P \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5)}$$

Where H_t is the harvest while P is the price of cod. As indicated the harvest also consist of two: coastal and ocean vessels.

The cost function is expressed as a function of fishing effort employed by each fishing type of fishing vessels. And expressed as follows,

$$C_t = c.E_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(6)}$$

Where c is the unit cost of fishing effort, assume to be constant, but differ for coastal and ocean vessels, and E_t is the number of fishing vessels and also varies for coastal and ocean vessels respectively.

Profit Function

The profits (π) is obtained from revenue and cost and expressed as in equation 7 below.

$$\pi_t = R_t - C_t = H_t \, . P - c.E_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ldots. \text{(7)}$$

Where π_t , R_t , C_t represents profit, revenue and cost, respectively.

The discounted profit is expressed as:

$$\Pi = \textstyle\sum_{t=1}^{T} \rho_t \, . \pi_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(8)}$$

Where ρ_t is the discount factor and defined as $\rho_t = \frac{1}{(1+\gamma)^t}$, where γ is discount rate. Profits generated from each fleet are reflected by the differences in sales of landing and total cost of fleet operation.

Chapter 4: Data and Values

4.1 Data and Parameters

Chapter 4 presents the data and their sources used by this study to produce results for climate change and no climate change scenarios. Table 1 shows the data used for bio economic model and their respective sources.

Table 1: Parameters used and their respective values.

Parameters	Description	Value	Unit	Source
r	Intrinsic growth rate	0,36		Fishbase-(www.fishbase.org)
K	Carrying capacity	7,500,000	tonnes	Assumed based on ICES data
Bpa	Minimum spawning biomass	460,000	tonnes	ICES, 2017
Fmsy	Fishing mortality at MSY	0,4		ICES, 2017
E_1	Number of coastal fishing vessels	506[1]		Fiskeridirectorate – profitability analysis
E_2	Number of ocean fishing vessels (trawlers)	35[2]		Fiskeridirectorate – profitability analysis
c_1	The unit cost of coastal fishing vessels	508,174[3]	Kr	Fiskeridirectorate – profitability analysis
c_2	The unit cost of ocean fishing vessels	2,018,306[4]	Kr	Fiskeridirectorate – profitability analysis
γ	Discount rate	7%		Assumed
P_1	Fish price for coastal vessels	13,000	Kr/ton	Eide, 2017
P_2	Fish price for ocean trawlers	13,000	Kr/ton	Eide, 2017

[1] Standardized Based on weighted average catch distribution of coastal conventional gears of
[2] Average number of cod trawlers from 2007 – 2017.
[3] Weighted average costs of conventional coastal gears of 001 -004 from 2007 -2017.

[4] Weighted average costs of cod trawlers from 2007 -2017.

4.1: Carrying Capacity

Figure 3: Carrying capacity development. Source: (Eide, 2017)

The carrying capacity of a fish stock represents the maximum population mass of the stocks that the environment can support and carry, taking into account the availability of water, habitation, food and other essentials accessible in the habitat. This study measures the climate effect through the carrying capacity parameter. It assumes a constant carrying capacity for the scenario without climate change effect and the scenario with climate change effect, the carrying capacity changes over time. The carrying capacity is estimated based on a bio-physical model that simulates the changes in the physical and biological environment where cod stock lives, for instance SinMod model (Eide 2014). Figure 3 shows the annual average carrying capacity index relative to 2012 over 50 years based on the A1B climate model (Eide 2014&2016). However, the carrying capacity varies greatly from month to month. The upper part of figure 4 shows monthly totals of standardized carrying capacities for NEA cod constructed using SinMod A1B simulations (Eide, 2014). In addition, the irregularities demonstrate the proportional difference from the relative month in 2012 (Eide, 2016). The lower part of figure 4 shows the monthly variations with respect to the total carrying capacities of all units measured in million tonnes of cod biomass (ibid). The red lines in the figure indicate the monthly changes while the blue line shows the moving average for 12 months. Thus, it defines rich areas that allow cod to expand and poor areas in which biomasses are at a lower level. Without climate effect, we assume the carrying capacity is about 7,5 million tonnes (estimate from Eide, unpublished) and constant over next 50 years.

With climate effect this study will use the carrying capacity index shown in figure 3 and basic value of 7,5 million tonnes to estimate the carrying capacity for next 50 years (Figure 7).

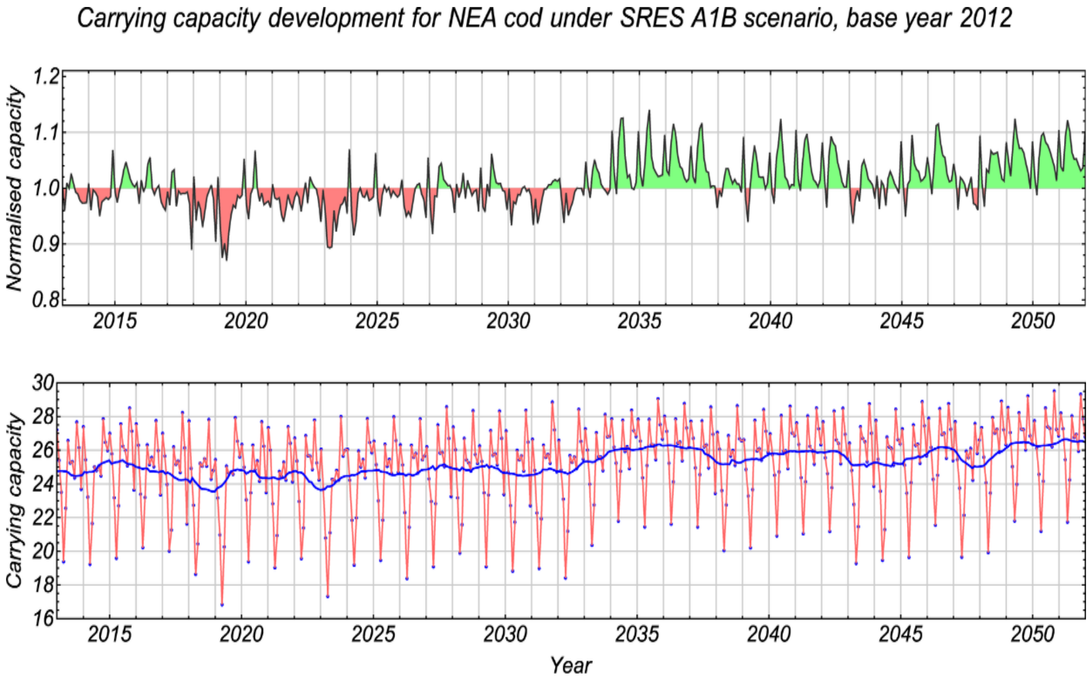


Figure 4: Carrying capacity development for NEA cod under SRES A1. (Source: Eide, 2017a).

4.2: Minimum Spawning Biomass (Bpa)

The minimum spawning stock biomass denoted by Bpa is the reference point set up to ensure stock recruitment. Spawning stock biomass (SSB) represents the total weight of all individuals who can reproduce in a fish stock. To compute the spawning stock biomass, the following variables are needed: an estimation of the amount of fish according to age group, an estimation of the mean weight of the fish per age group and an estimation of the number of matured fish in each age group. The most important factor is the fecundity of each age group. The spawning stock biomass indicates the stock's capacity to reproduce and also the status of the stock, thus the need for reference points (Bpa) about the spawning stock biomass to make sure the stock has enough recruits for growth and harvest. This study employs the above minimum spawning stock biomass as indicated in Table 1 based on the ICES advice, as illustrated in figure 5 below but currently on a decline since 2013 (ICES, 2017).

The total stock biomass at the beginning is given, and assumed to be 5 million tonnes. Thus, the cod stock starts at a healthy situation.

4.3: Fishing Effort

The fishing vessels include both coastal vessels, and ocean-going vessels used to fish at the coastal areas and the high seas, respectively. Coastal vessels are composed of small fishing vessels that generally fish along the coast while ocean vessels operate in the high seas (Eide, 2016). These vessels consist of different kinds of fishing gears, but this study considers the conventional gears for coastal vessels and cod trawlers for ocean vessels. Harvesters have extensive knowledge of potential costs and benefits for their decision on where, how, and when to go fishing. The main aim of commercial fisheries is to maximize profit, which is attributed to aspects such as quality, quantity, and species of the expected catch. However, we assume that fishing effort in term of number of fishing vessels are unchanged over time. The data used for these two types of vessels in the model are the weighted average numbers based on the Fisheries Profitability Survey between the years 2007 - 2017 (www. fiskeridirectorate.no). Here are 506 vessels for coastal fisheries and 35 cod trawlers for ocean fisheries.

4.4: Fishing Mortality

The fishing mortality is a variable and determined by stock situation assessed (ICES, 2017) and fishing effort employed. The precautionary reference points for cod biomass (B_{PA}) and fishing mortality (F_{PA}) are determined based on stock assessment by the ICES. In the ICES 2017 report, the reference point of fishing mortality (F_{PA}) is 0.4 when a precautionary management plan is used. The stock assessment is based on a long-term harvest and other biological data to determine the stock size and corresponding harvest rate each year (ICES 2017). A harvest control rule (HCR) based on stock situation is advised to apply when harvesting cod stock. However, this study does not use this complex HCR but rather applies a simple one. Figure 5 illustrates the changes in f_{lim} (fishing mortality limit to harvest sustainably) and f_{pa} (fishing mortality at precautionary approach) and F_{msy} (fishing mortality at MSY).

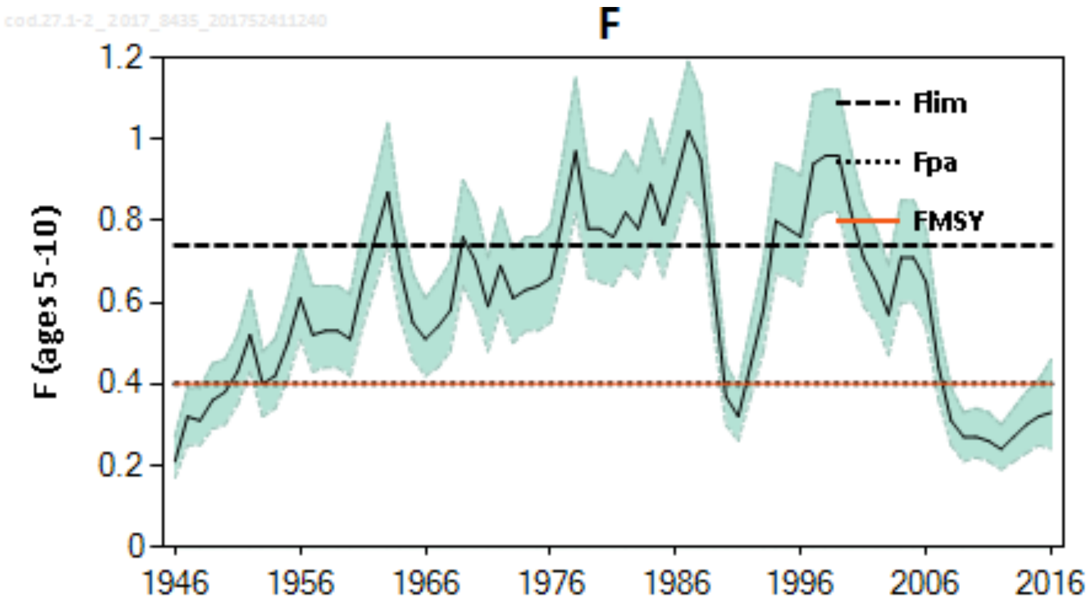


Figure 5: Fishing mortality in Cod in subareas 1 and 2 (Northeast Arctic). Source:(ICES, 2017)

4.4: Fishing Cost and Price

The unit costs of the coastal and ocean fishing vessels are also estimated to be weighted average of the costs of these two gears based on the Fisheries Profitability Survey between the years 2007 - 2017 from the Fiskeridirectorate. Unit cost of fishing vessel is only operational cost, excludes fixed costs.

In this analysis, the prices of fish are assumed to be the same irrespective of the type of vessels used in harvesting and fish size. The price can be affected by the size of the fleet as the products having varying prices. These price values are taken from (Eide, 2017) where he assumes that the fishing fleets are price takers. Therefore, the price per unit harvest is fixed over the 50 years.

4.5: Discount Rate

Discounting refers to considering a prospective worth and deducing what it is valued today. The discount rate is assumed to be 7% in this study. Due to the high risks and uncertainty fisheries faces, it could either result from fisheries management shortcomings, change in technology or environmental fluctuations like changing the climate, there is the need to employ a discount rate factor when determining needs or the behavior of future generations (Harte et al., 2001). In assessing the economic impact of regulating fish stocks, the discount rate can influence the rate at which fish stocks should be harvested, the rate which they can be rebuilt, or what extent they can be conserved (ibid).

Chapter 5: Results

5.1: Overall stock biomass with and without climate and their difference

In this study, the Norwegian share of the cod stock is assumed to be divided between the coastal and ocean vessels with 60% and 40% of the total allowable quota respectively. The Joint Norwegian–Russian Fishery Commission states that fishing mortality is permitted to be at F_{pa} if SSB is greater than B_{pa} (Eikeset et al., 2013). Therefore, implying it is possible to fish at levels of SSB that are greater than B_{pa}. In addition, the HCR limits how TAC can vary in a year (ibid). Here, the harvest control rate applied in this study like this: if the total stock biomass is higher than B_{pa}, then we will harvest with reference fishing mortality, $F_{MSY} = 0{,}4$; if the total stock biomass is lower than B_{pa}, then we only harvest a small proportion of the total biomass, that is the proportion of current stock and B_{pa} multiplying fishing mortality 0,4 (F_{MSY}), which is lower than 0,4.

The study utilizes excel software to carry out data analysis, visualization and numerical computation. This software will assist in modeling and simulation in analyzing data, building models, and running deployed models showing the effects of climate change on productivity and profitability of the cod's fisheries over time. The simulation runs 50 years.

Stock Biomass

The cod biomass data as shown in figure 6 below for the past 50 years illustrates that, the total biomass for both scenarios are almost the same but the scenario with climate change effect is a little higher as total biomass for both scenarios fall until the stock reaches to a stable level after several years. This difference between two scenarios are attributed to the positive climate effect on carrying capacity. For instance, the rise in temperature levels could give the cod stocks a large habitat area and increases their access to food.

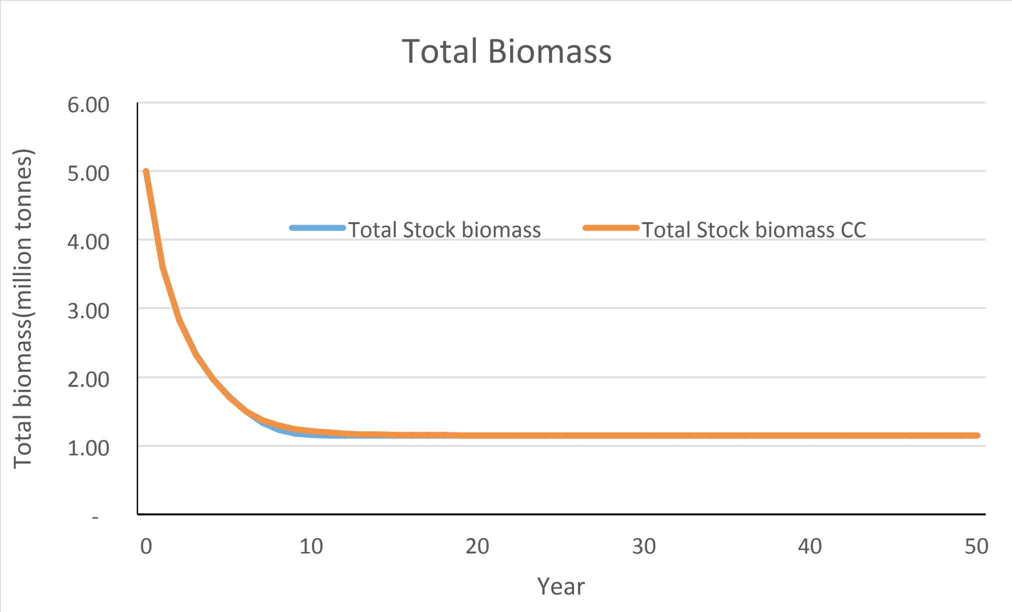


Figure 6: Total biomass for both scenarios.

Based on the assumptions made, the study investigates the total biomass for the past 50 years, through simulating the total harvest in the two scenarios. During the last 50 years, NEA cods biomass has varied between 1 - 5 million tonnes (it is assumed that the starting biomass is 5 million tonnes). In the model simulation, the interval of intrinsic growth has been at a constant value of 0.36. The study shows that the sustainable level of biomass is dependent on the current harvest level in the region. The ICES estimates the minimum spawning biomass Bpa that indicates the stock capacity available to reproduce at 460,000 tonnes. The results indicate that the average of the total biomass for the scenario with climate change effect is 1,376 million tonnes compared to the scenario without the climate change effect that is estimated at 1,370 million tonnes. This shows a difference of 0, 44% that can be attributed to increase carrying capacity. Therefore, the study shows that climate change has a slight positive impact on total biomass in the scenario with climate effect as shown by the changes in carrying capacity of the cod stock in the region.

Carrying Capacity

Figure 7 below shows carrying capacity with and without climate change effect. It is estimated based on carrying capacity index (Figure 3) and assumed carrying capacity at the beginning (7,5 million tonnes). It implies how climate change causes the carrying capacity to vary over time as such explains the increase in total biomass. As seen in figure 7 below, carrying capacity fluctuates a lot, decreases at the first 20 years so, and then increases.

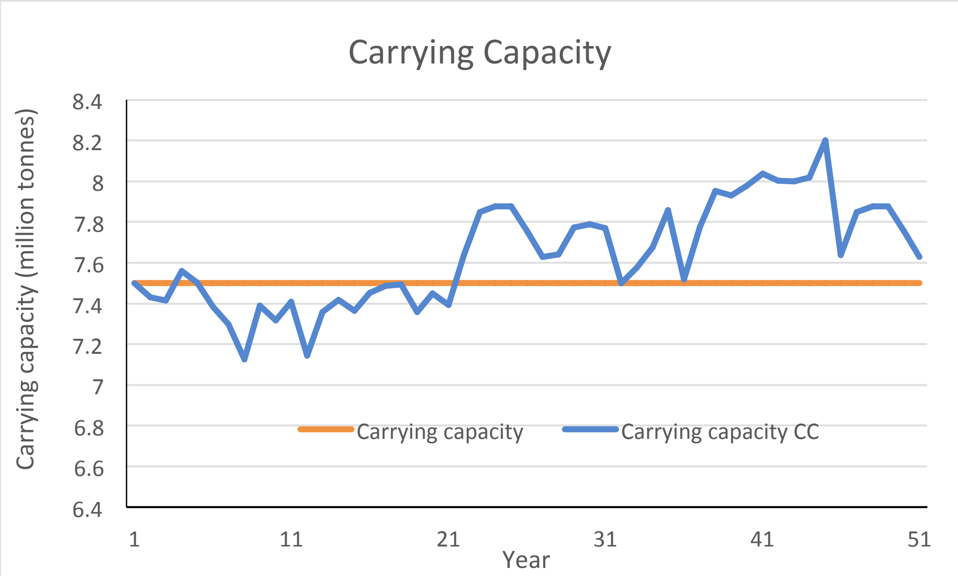


Figure 7: Carrying Capacity for both scenarios

5.2: Harvests

Total Harvest

The average of the total harvest for the scenario with climate change effect equals 458 689 tonnes while that of the scenario without climate change equals 456 114 tonnes. Thus the average harvest of scenario with climate change is higher than that without climate change at a difference of 2 575 tonnes (about 0, 57%) which indicates a positive effect of climate change on the stock.

Coastal Vessels

As illustrated in Figure 8 below, the harvest for the scenario with climate change, is slightly bigger than the scenario without climate change. The average of harvest with coastal vessels with the climate change effect equals 275 214 tonnes while that without climate change effect averages at 273 669 tonnes. Giving a difference of 1 545 tonnes. Since we assume that the quota for coastal and ocean fishing vessels are constant over 50 years.

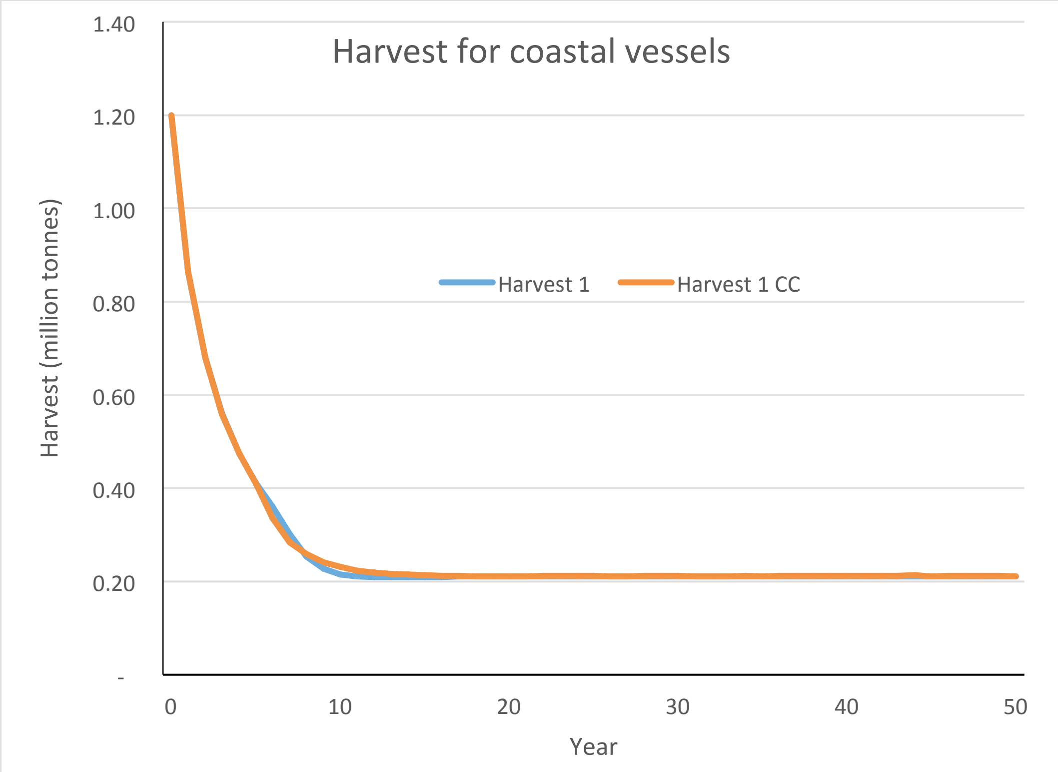


Figure 8: Harvest for coastal vessels for both scenarios.

Ocean Vessels

Based on table 1 above, there are 35 ocean vessels in NEA fisheries; the unit cost of Ocean vessels is 1, 95 million NOK. Therefore, large fleets have a technological advantage in comparison to the coastal fleet that is shown by the huge difference in the unit cost of vessels. Thus, because ocean fishing vessels have a wider range of profitability highlights the availability of significant diversity at the huge rates of exploitation. Figure 9 below shows the cod stocks are impacted by changes that can be observed from the differences in total harvest in both scenarios. The results show that, the average harvest for the scenario with climate change (183 476 tonnes) effect is bigger than that without climate change (182 446 tonnes) effect over the 50 years. This shows a positive difference of 1 030 tonnes. This was the same for the case with small vessels. However, the difference in the average harvest with coastal vessels is greater than that with the ocean vessels.

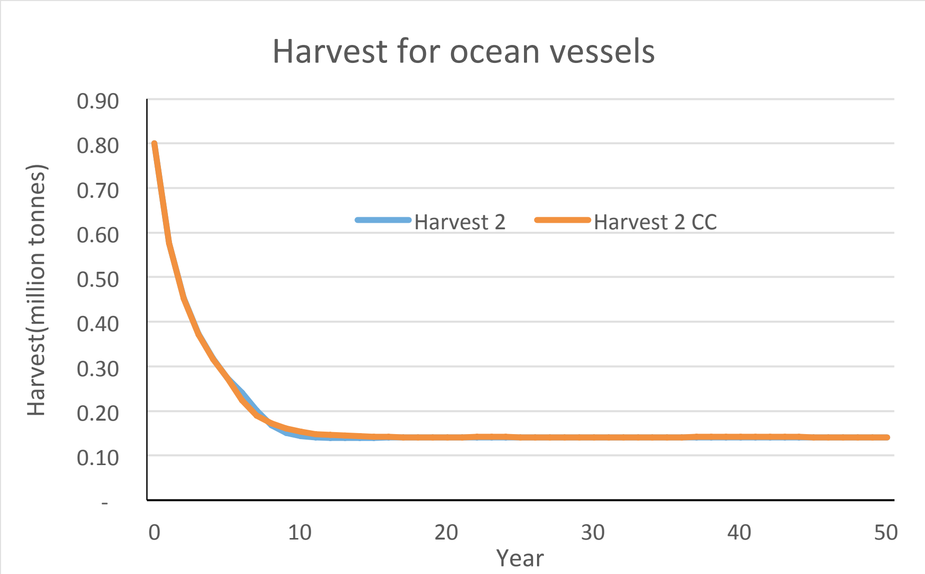


Figure 9: Harvest for ocean vessels in both scenarios

5.3: Profit with and without climate and their difference

Total Discounted Profit

The simulations conducted on the study uses a discount rate of 7% to determine the impact of the discount rate on profits. The total discounted profit over 50 years for both scenarios with and without climate change for the two different vessels shows that the scenario with climate change has a higher profit than the scenario without climate change.

Table 2: Discounted profits under two scenarios for coastal and ocean vessels.

	Without Climate Change (million NOK)	With Climate Change (million NOK)	Differences (%)
Coastal vessels	73 500	73 644	0,2
Ocean Vessels	50 492	50 587	0,12
Total	123 992	124 231	0,19

Coastal Vessels

The total sum of discounted profit for coastal vessels with climate change is estimated at 73 644 million NOK while the option without climate change it is estimated at 73 500 million NOK, which shows a difference of 143 million NOK which is approximately a 0, 2% difference as shown in Table 2 above. The difference between the two scenarios highlight that climate change might result in a slight increase in profits generated by small vessels overtime. Figure 10 below illustrates the both scenarios though not clearly visible, the climate change scenario surpasses the non-climate change scenario.

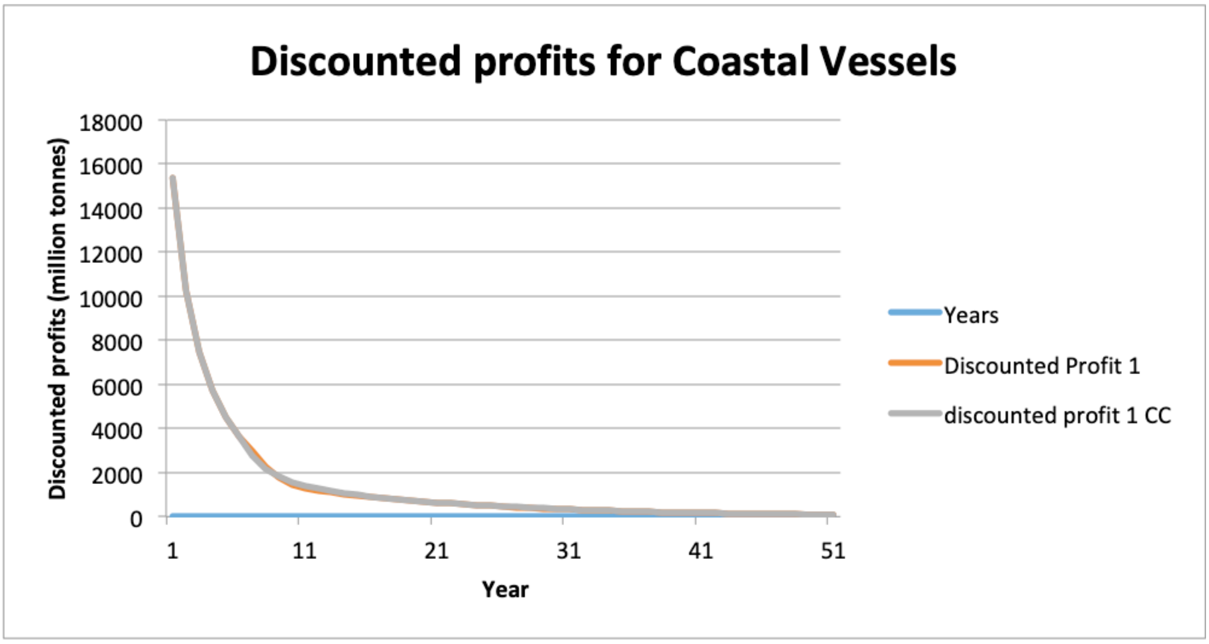


Figure 10: *Discounted profits for coastal vessels for both scenarios.*

Ocean Vessels

Discounted profit will be utilized to investigate the impact of climate change on the profitability of cod in the Barents Sea generated by ocean vessels fishing in the high sea. For the climate change scenario, total discounted profits for ocean vessels over 50 years are estimated at 50 587 million NOK while for the scenario without climate change total discounted profit is estimated at 50 492 million NOK. which shows a difference of 96 million NOK (a 0,12% difference as seen on table 2) and can attributed to changes in climate over the given period of 50 years that affect the carrying capacity of cod fisheries resulting to an increase in total harvestable biomass. Figure 11 below illustrates both scenarios over the 50 years. As observed with average harvest, discounted profits for coastal vessels is greater than that of ocean vessels.

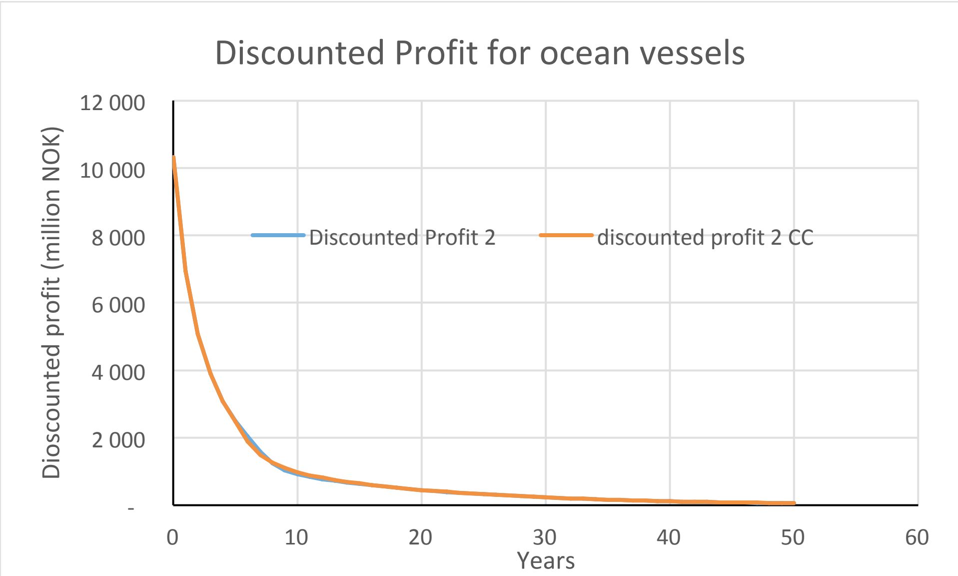


Figure 11: Discounted profits for ocean vessels for both scenarios.

Sensitivity Analysis

In this study, we made some assumptions about the model and parameter values. Some parameters and their values may have more effects than others on the results. Thus, we test the robustness of some parameters in the results. Table 3 below illustrates results from altering the intrinsic growth rate, price, costs and quota parameters one at a time while keeping other parameters constant to see how this affect both scenarios as compared to the original values used.

The intrinsic growth rate parameter change was applied only on the scenario with varying carrying capacity (climate change scenario) while keeping the other scenario constant. The change was both positive (0,36*(1+0,2%)) and negative (0,36*(1-0,2%)). The price parameter change was applied to both scenarios. The price for coastal vessels was increased to 14 000 NOK/ton while that for ocean vessels was increased to 16 000 NOK/ton. The costs parameter was also applied to both scenarios, with costs for both vessels being increased by 2% each. For the quota parameter, we change both vessels to 50/50 quota share each, and the second change 40/60 for coastal and ocean vessels respectively. We assumed constant 60/40 distribution for coastal and ocean going vessels, this may not be true. If the cods stocks move towards to the ocean-wide, the coastal fishing vessels may lose some fishing ground, resulting low harvest.

Table 3: Growth rate change, Price, Costs and Quota change.

	Without Climate Change (million NOK)	With Climate Change (million NOK)	Differences (%)
Coastal vessels	73500[5], 73500[6], 85393[7], 73424[8], 70900[9], 68300[10]	73531[5], 73755[6], 85558[7], 73567[8], 71043[9], 68443[10]	0,04[5], 0,34[6], 0,2[7], 0,2[8] , 0,2[9], 0,2[10]
Ocean Vessels	50491[5], 50491[6], 58420[7], 50470[8], 53091[9], 55691[10]	50512[5], 50662[6], 58530[7], 50566[8], 53187[9], 55787[10]	0,04[5], 0,33[6], 0,2[7], 0,2[8], 0,02[9], 0,2[10]
Total	123991[5], 123991[6], 143813[7], 123894[8], 123991[9], 123991[10]	124043[5], 124417[6], 144088[7], 124133[8], 124230[9], 124230[10]	0,04[5], 0,335[6], 0,2[7], 0,2[8], 0,11[9], 0,2[10].

Table 3 above presents the results for each parameter change as explained above. The different results are marked by the different footnotes 5, 6, 7, 8, 9 and 10 for intrinsic growth rate (negative), intrinsic growth rate (positive), price, costs, 50/50 quota share and 40/60 quota share respectively.

The results from changing intrinsic growth rate parameter shows that the positive change has more effect on both vessels (0, 67%) than the negative change (0, 08%). This might due to the fact that increased carrying capacity as well as positive growth rate will lead to more harvest as such increased discounted profit over time. The change in the climate

[5] Results from change in intrinsic growth rate by (1-0, 2%).
[6] Results from change in intrinsic growth rate by (1+0, 2%).
[7] Results from increasing price for coastal vessels to 14000 and for ocean vessels to 16000.
[8] Results from change in costs by 2% increase for both vessels.
[9] Results from changing quota share to 50/50 for each vessel.
[10] Results from changing quota share to 40/60 for coastal and ocean vessels respectively.

change scenario is greater than that without climate change. However the coastal vessels have higher profit for both scenarios.

The price parameter is an important factor that affects profits. Change in price to 14 000 NOK/ton and 16 000 NOK/ton for both coastal and ocean vessels respectively indicate a general increase in total discounted profit for both vessels as compared to all other changes. Discounted profits for coastal vessels in both scenarios are higher than that for ocean vessels. The change for the climate change scenario is higher than that for the non-climate change scenario. However the percentage difference indicates total difference of 0, 2%.

While keeping other parameters constant, the results from increasing costs for both vessels by 2% indicate a little change of 0,2% for both scenarios. Just like the other parameters there is a greater effect on the climate change scenarios and for the coastal vessels.

Results from changing quota share to 50/50 for both vessels shows a very little total change of 0, 22% for both scenarios and vessels. However, changing the quota share to 40/60 for coastal and ocean vessels respectively gives a total percentage difference of 0, 2% for both scenarios and vessels. For both quota changes, discounted profit for coastal vessels is still greater than that of ocean vessels. This is because the cost of ocean going vessels is much higher than the coastal vessels while the price for both is the same. And the scenario with climate change effect has a greater change as compare to the no climate change scenario.

Table 4: Discounted profits under two scenarios combining changes in Intrinsic growth rate, Price, Cost and Quota. Bracket shows the original value (Table 2)

	Without Climate Change (million NOK)	With Climate Change (million NOK)	Differences (%)
Coastal vessels	76 694 (73 500)	76 846 (73 644)	0,2 (0,2)
Ocean Vessels	65 658 (50 492)	65 774 (50 587)	0,2 (0,12)
Total	142 352 (123 992)	142 620 (124 231)	0,2 (0,19)

Combining the above separate changes in intrinsic growth rate, price, and cost and quota sensitivity all in one, the results on Table 4 above were obtained. The results on Table 4 show that the combined factors increase the discounted profits for both vessel types. The ocean vessels achieve a higher discounted profits than coastal vessels in both scenarios. The scenario with climate change as observed with all the single change in parameters above, has higher profits than that without climate change. This change can be greatly accounted for by, varying capacity, change in price and the positive change in intrinsic growth rate. Another reason could be the increase in the quota share as well. The decrease in discounted profits for coastal vessels can be attributed to loss of fishing ground as its quota decreased by 10% and no change in price. However these changes are still not greatly significant. Overall, global warming can increase cod stock and have an impact on the value of Norwegian coastal and ocean fishing vessels.

Overall price has the most impacts on the discounted profit, followed by quota changes and positive intrinsic growth rate. The changes in costs are of little significance and the scenario with climate change still carries the greater change.

Chapter 6: Discussions and Conclusions

The main objective of the study was to identify the climate effects through the carrying capacity on the productivity and profitability of NEA cod fishery over fifty years. Therefore, a simplified bio-economic model that is based on the Schaefer surplus production model was used to investigate the objective. The analysis has conducted under two scenarios: one with a climate change effect and the other without climate change effect. The difference between these two scenarios is based on the climate variations measured by the carrying capacity parameter. In climate scenario, the time series carrying capacity is adjusted by using the carrying capacity index generated based on A1B climate scenario from Eide (2017) study.

This biological part of the bio-economic model used a logistic growth function while thee economic part of the model calculates profit from total revenue (function of price) and total cost (function of effort). Several assumptions are considered while setting up this model. The carrying capacity, which measures the climate change effect, is assumed to be constant for the non-climate change scenario but varying for the climate change scenario. The price of both coastal and ocean going vessels are assumed to be the same and constant over 50 years. The intrinsic growth rate is constant at 0,36%, the minimum spawning stock biomass is assumed to be at a precautionary level of 460,000 tonnes. Fishing mortality F_{msy} is assumed to currently set at 0.4%. Based on ICES requirements, the NEA cod stocks can be considered to have a good reproductive capacity due to the size of its stock biomass that has been a significant contributor of the region.

Results revealed that climate change has a positive impact on the carrying capacity, which results in increase in harvestable biomass, which therefore increases profitability of cod fishery. The results further show that the coastal vessels have a higher discounted profit as compared to ocean going vessels in both scenarios, this is due to our assumption that coastal vessel has 60% of the total quota while ocean going vessels has 40% of it. Discounted profits from the climate change scenario are also higher than that of the non- climate scenario.

Fisheries conduct their operations under fluctuating environmental conditions that target fish stock appearing in varying densities in different regions. Therefore, climate change will have an impact on productivity and profitability of NEA cod fishery over the years. For the climate scenario, a change (either decrease or increase) in carrying capacity will result in cod stocks changing their migration and breeding grounds that will affect the patterns followed by fishing vessels. Carrying capacity is a critical parameter to have effects on the total stock biomass that can be carried by the environment. The results as shown in figure 7 above revealed that the carrying capacity for the NEA cod fluctuates for the first 20 years and then increases for the rest of the 30 years. This therefore explains the increase in stock biomass, harvest and the profits.

There is always an expectation that climate change is going to affect the temporal and spatial distribution of fish stocks. According to (Skjæraasen et al., 2014), climate change has been observed to have an impact on the fish stock, which can occur indirectly by changing breeding areas or time and directly by causing fishing mortality. The migratory patterns due to climate changes might affect the ability of coastal vessels that use conventional gears in coastal areas. When targeting the most productive fishing grounds that will influence fleet diversity. This depends mainly on the overall exploitation level (type of vessel) and available harvestable biomass, which is impacted by the carrying capacity in this study. In this study, the reference points for B_{pa} and F_{pa} are based on the stock assessment given by the ICES (ICES, 2017). This uses a B_{pa} of 460,000 tonnes so as to maintain stock biomass. Limit reference point (B_{LIM}) represents the limit which total biomass stock cannot go below while ensuring sustainable harvest of the stock. Fishing mortality represents what has been harvested and differs for each vessel group.

The sensitivity analysis indicates a noticeable change especially with an increase in intrinsic growth rate and price. The intrinsic growth rate is directly related to the stock level as such an increase in the growth rate will increase the stock biomass especially at a higher carrying capacity as depicted by the sensitivity analysis. Price being an important factor when considering profits is bound to have significant changes when increased or decreased.

NEA cod stock is shared equally between Russia and Norway. Harvestable biomass for Norway is assumed to entail high sea catches as a result of the distribution of cod biomasses in regions available for Russian vessels. According to (Eide, 2014), the author suggests that management of fisheries has massive effect compared to climate change on economic performance and biological development available in Arctic fisheries. Which explains why major fishing regions around the world, has experienced widespread depletion of marine fisheries that are exploited commercially, which is considered as the failure of management. However, based on our assumptions made in this study, climate change has a positive effect on the cod productivity and profitability although the effect is not significant. Climate changes are diverse, and their impact on fisheries can lead to changes in stock productivity that will affect potential yields and profitability of cod stocks in the Barents Sea. Also, it can result in changes in the distribution of stock that will impact possible fishing grounds.

Although this study is based on several assumptions, the results show that it is worthy to take into consideration how climate change might alter a stock's productivity and profitability.

This paper used a simple bio-economic model to explore the climate effect on cod fisheries through only the carrying capacity. The recommendation made for the study is to include more variables like age, size and other climate change parameters to determine how climate change affects the stock at different life stages and other factors such as growth rate, mortality, etc. Furthermore, a management scenario and climate change scenario could be compared to see which has the most effect on cod productivity and profitability.

Limitations: As a result of a short time frame of six months to write this thesis, the choice of a simple bio-economic model limits this studying depth. Although there is rich literature about this cod fishery and stock, the main limitation was the time constraint to develop a more detailed model that includes important variables like age, size, or length. Also, my knowledge of models is limited so using a complex model was proven difficult, if not possible. This therefore, led to this study using a more simplified model that omits the age and size structure but still generate results that can be used to understand how this fish stock will be affected under a changing climate and therefore suggest possible management measures. Also, the simulation in the study ignores other aspects such as the human impact on the fishery sector that leads to reorganization of the surrounding ecosystem.

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