The ecological and fisheries management implications of changing environmental conditions on the Flemish Cap, Northwest Atlantic

By

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ABSTRACT

Fisheries resources are managed to promote food security and economic benefits for current and future generations. Production rates of commercial resources exist as a function of biological, ecological, anthropogenic and environmental factors, and fluctuate in different contexts. On the Flemish Cap, Northwest Atlantic (Northwest Atlantic Fisheries Organization [NAFO] Div. 3M), production declines and altered system dynamics have occurred at the species and ecosystem levels, and have been linked to changing environmental conditions. Internationally-coordinated, global-scale climate models forecast that significant fluctuations will occur to variables driving fisheries production during the 21st century. Changing productivity has not been managed effectively by NAFO in previous eras, although important policy shifts have been made following previous resource collapses. This discourse reviews NAFO policy, landings and environmental context as they pertain to the Flemish Cap, concluding that: (1) fisheries management strategies would be strengthened by incorporating environmental context, (2) that NAFO's capacity to respond to upcoming climate-driven shifts in production is limited by current policy, and (3) that NAFO's institutional characteristics and historical behaviour suggest the likelihood that policies will be redesigned to integrate environmental context is substantial and increasing.

Acknowledgements

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°C	degrees Celsius
CIL	cold intermediate layer
CO_2	carbon dioxide
CPR	Continuous Plankton Recorder
CPRS	Conservation Plans and Rebuilding Strategies
EEZ	Exclusive Economic Zone
H_2CO_3	carbonic acid
H_2O	water
ICNAF	International Commission for the Northwest Atlantic Fisheries
km	kilometre
m	metre
MSE	Management Strategy Evaluation
N	nitrogen
NAC	North Atlantic Current
NAO	North Atlantic Oscillation
NAFO	Northwest Atlantic Fisheries Organization
NO_3^-	nitrate
P	phosphorus
PSU	Practical Salinity Unit
RFMO	Regional Fisheries Management Organization
$Si(OH)_4$	silicate
STAA	Statistical Catch At Age
Sv	Sverdrups
t	tonne
TAC	Total Allowable Catch
UNCLOS	United Nations Convention on the Law of the Sea
VME	Vulnerable Marine Ecosystem
WGESA	Working Group on Ecosystem Science and Assessment
XSA	Extended Survivors Analysis

INTRODUCTION

Whether exploited sustainably or not, the biomass of commercially-valuable animals in the marine environment available to capture fisheries is a product of the environmental and biological contexts of the target area. While many forms of science strive to uncover large-scale patterns with wide-ranging applicability, variability in the marine environment on local to regional spatial-scales precludes a single formulaic approach to fisheries research and management.

Production of biomass, or productivity, is the accumulation of organisms that occurs as the components of an ecosystem carry out their life histories. Production can exist as growth in individual mass or population abundance. Production rates are heavily influenced by ecosystem health (MEA, 2005), an index which can be measured and impacted in numerous ways. Environmental conditions are an important factor determining production levels at the species and system levels- a fact that is of particular importance given recent long-term climate forecasts (IPCC, 2013).

Ecological connectedness in marine systems is exemplified through production dependence between adjacent trophic levels. In marine systems, primary production occurs through photosynthesis conducted by phytoplankton. The ability of this functional group to synthesize sunlight into energy results in an energy source for the complex ecosystem it supports. Zooplankton rely on phytoplankton as their major food stock, and in turn supply higher trophic levels with a critical energy source.

Abiotic variables provide the setting for production throughout marine ecosystems. Nutrient availability in the photic zone dictates production of phytoplankton, zooplankton, and the finfish that require these food sources. High plankton availability releases finfish from bottom-up regulation, allowing for population growth. Capture fisheries benefit from high primary and secondary production, and the biomass these energy sources promote.

Fisheries research targets biologically- or managerially-defined areas with the fundamental goal of informing resource management by providing key information in the form of science, economic, and/or sociological information for the development, implementation, and review of policy frameworks aimed at maximizing resource stability and economic returns.

Ocean conditions play a pivotal role in the size and structure of biological communities. Physical and chemical qualities either enable or restrict biological growth, but act in concert to create distinctive ecotypes even in the open ocean. Stratification of the water column often occurs from the influence of salinity, temperature, and current patterns, with currents, wind and topographically-driven vertical forcing responsible for variations in local nutrient availability. Depth, temperature and water movement exemplify important physical components that influence system productivity, while salinity, pH and elemental presence are important chemical parameters that can define local environments.

The combination of these influences has resulted in a highly-productive biological community in the Flemish Cap region of the Northwest Atlantic (Figure 1).

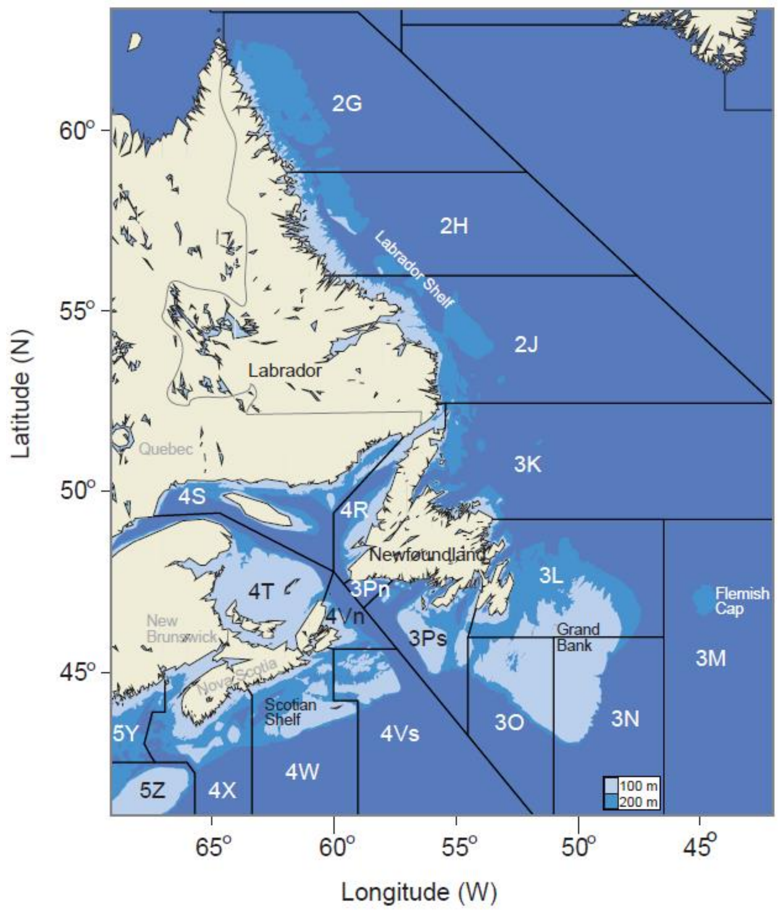


Figure 1 The Northwest Atlantic Ocean, with the Flemish Cap seamount and NAFO statistical divisions depicted.

The area contains six major commercial fisheries targets: Atlantic cod (*Gadus morhua*), redfish (*Sebastes marinus*, *S. mentella* and *S. fasciatus*), Northern shrimp (*Pandalus borealis*), American plaice (*Hippoglossoides platessoides*), Greenland halibut (*Reinhardtius hippoglossoides*) and Northern shortfin squid (*Illex illecebrosus*). Their abundances and values, although varying in availability through time, have attracted fishing fleets from many nations since technological advancements enabled extended excursions to offshore areas of the sea.

Conditions in the Cap region, much like the global marine environment, fluctuate continually. Environmental processes and resulting oceanographic fluctuations have been linked to variations in the recruitment and spatial distribution of many important

Northwest Atlantic stocks, including Atlantic cod, haddock (*Melanogrammus aeglefinus*), squid and capelin (*Mallotus villosus*) (Mann & Drinkwater, 1994). As oceanographic characteristics fluctuate, the biological community fluctuates, not just in biomass, but also size, structure and composition, as realised consequences of both the interaction between environmental drivers and ecological interactions that govern and shape marine ecosystems (Perez-Rodriguez et al., 2012).

Environmental regulation of the biological community is not only a contemporary phenomenon. Historical communities have always existed as a function of their surroundings, but have been exposed to increasing anthropogenic influences over the last 250 years, particularly so since the early 1950s. The colonial days of North American society were powered by the cod stocks of the Grand Banks and Flemish Cap, and while environmental factors altered production (Rose, 2004), increasing effort ultimately drove stock biomass down, eventually leading to stock collapses and arrested groundfish productivity. System productivity had always been regulated by biotic and abiotic components, but it is now clear that anthropogenic influences have become a critical third driver.

The regulatory context of the waters covering and surrounding the Flemish Cap is a product of legal instruments designed by the international community. Currently, in accordance with the United Nations Convention of the Law of the Sea (UNCLOS), the Cap lies beyond any country's Exclusive Economic Zone (EEZ; which extends 200 nautical miles from the coast), and is therefore located in international waters, accessible to vessels from any nation. Currently, and after much management evolution, the Cap's biological resources are managed by the Northwest Atlantic Fisheries Organization (NAFO), via the Convention on Future Multilateral Cooperation in the Northwest Atlantic Fisheries. This Regional Fisheries Management Organization (RFMO) is a collection of countries with an interest in the exploitation and collective management of the Northwest Atlantic's fish resources. Membership has varied throughout the organization's existence; founding and current member states are listed in Table 5 (p. 78).

Environmental conditions on the Cap and across the world's oceans are expected to change in the coming decades (IPCC, 2013). Therefore, investigating how environmental trends have influenced fisheries yield in the recent past may offer insights into expected yields in this region under hypothesized future environmental conditions. Policy designed with environmental context in mind may result in ameliorated socioeconomic standing for fishery participants and industry by increasing resource stability and quota appropriateness- fundamental goals of fishery management.

In this report, I examine how shifting productivity levels impact the biological community of the Flemish Cap, and how this influences the fisheries of the area and the policies that govern fishing activities. To achieve this overall goal, many factors must be considered due to the biological, environmental and political complexity of understanding and managing open ocean ecosystems located in international waters.

First, I review the ocean characteristics important for determining primary production and fisheries yields; I then present a general summary of the oceanographic and biological conditions specific to the Flemish Cap.

Following this oceanographic overview, I present a quantitative review of the oceanographic conditions of the Cap that covers the period of the 1950s through to the year 2000. These environmental data are compared with the fisheries history for the same timeframe, and precede a summary of the important management decisions within that period.

The report then shifts to provide a summary of contemporary oceanographic conditions (2000-2012), which are also presented with a summary of the biological trends of the era and the policies (and rationale) implemented in this timeframe. Comparing the environmental and biological dynamics on the Flemish Cap over different timescales will show that the system's biotic and abiotic characteristics fluctuate together, and that management strategies should consider all influencing components rather than being exclusionary in their design.

After historical and contemporary contexts are reviewed, these findings will be applied to assess NAFO's capacity to respond to changing fisheries production. Timely and effective management response to shifting production is critical for maintaining resource stability; this will become increasingly important as climate influences marine ecotypes in coming decades. Identifying capacity strengths and weaknesses serves to solidify NAFO management, and other jurisdictions with similar portfolios.

This investigation into the environmental, biological, and managerial histories of the Flemish Cap will demonstrate that shifting conditions result in altered communities, a transition expected to lead to production trade-offs requiring altered policy. For policy to be effective, it must be quickly responsive and adaptive, if not proactive. Establishing the link between the drivers of policy and response will facilitate the design of policies responsive to changing environmental context and productivity.

In the past, fisheries management decisions have heavily relied on feedback from biological systems, rather than proactively addressing potential issues. This discourse will provide arguments and evidence supporting the implementation of the latter in policy creation. The Flemish Cap will be used as an example of how changes in policy and management are applied.

MATERIALS AND METHODS

Recent decades, starting with the initial decision to regulate fishing activity on the Flemish Cap in 1949 (Anderson, 1998) have resulted in a substantial amount of research and data available to characterize many abiotic and biotic features of the area. However, oceanographic, biological, ecological and managerial research and reviews have largely been conducted independently, despite their relatedness (which this essay will identify). Understanding how fluctuating environmental conditions and context affects the communities that management strives to govern is imperative, and will become increasingly so in coming decades as environmental change is forecast to continue and accelerate, which may impose additional risks to management strategies that are not adaptive to changing ocean conditions.

Reviewing these research avenues and comparing their interactions is complicated by differences in data availability. In order to draw concrete conclusions on the root drivers of policy change, data must encompass different fisheries disciplines and be contemporaneous. A graphic demonstrating the data availability by discipline, data provider and year is provided below (Figure 2).

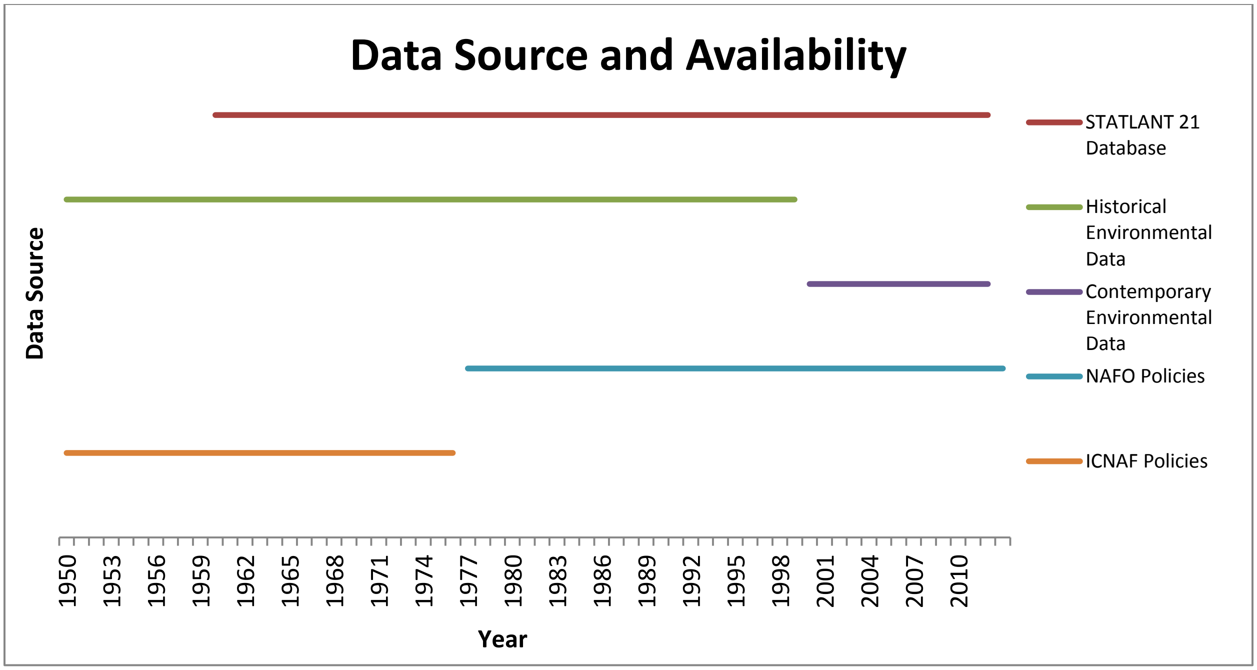


Figure 2 The data divisions and sources that will be used in the synthesis of this report, and their availability. Environmental eras are divided at the year 2000, as this date marks the start of the availability of detailed environmental data from the Atlantic Zone Monitoring Program.

Historical oceanographic data (1950-2000) were obtained from a review of the literature, as were data on contemporary (2000-2012) ocean conditions. Landings data were obtained from NAFO's STATLANT 21A database for the years 1960-2012, and the policies of the international management bodies, ICNAF (International Commission for the North Atlantic Fisheries) and NAFO are reviewed from 1950-2013.

This combination of data enables an effective review of how environmental conditions have changed on the Flemish Cap, and what this has meant for landings and policy.

Chapter 1. The role of ocean conditions in regulating marine food web production and fisheries yields in temperate regions

1.1 Introduction

Ecosystems exist as a function of their environment. The many variables that determine the makeup and extent of biological communities range in influence from local to global scales and include abiotic and biotic regulators. Productivity is allowed and restrained in marine systems based on area characteristics, with repercussions for harvestable yield at higher levels of the food chain (Chassot et al. 2010). Here I provide an overview of abiotic and biotic regulators that constrain primary productivity and ultimately fisheries productivity across the global ocean.

1.2 Abiotic regulators

1.2.1 Currents

Water movement patterns are well documented as an important regulator of biological production in marine ecosystems based their influence on multiple trophic levels and life stages. Movement of nutrients from the benthic environment to the euphotic zone occurs through upwelling, which can directly impact primary production totals in the area receiving nutrient influxes (Dugdale, 1972).

Water movement can also influence the productivity of an area through the dispersal of egg, larvae or juvenile life stages. The anticyclonic movement of water over the Flemish Cap (which will be discussed in further detail later on) has been identified as a major factor determining the year-class strength of cod through augmented egg and larvae retention (Stein, 2007). Wind influence on currents was shown to impact larval fish abundance in the waters around Newfoundland (Pepin et al., 1995). Similarly, on the Northeast Atlantic, Santos et al. (2004) found that wind driven currents transport sardines in early life stages, with larvae rentention linked to shelf-slope circulation.

1.2.2 Depth

Production through the water column varies inversely with depth. The vast majority of marine production occurs in the euphotic zone, the depth of which varies depending on local conditions but is generally not more than the ~200 m through which sunlight can penetrate.

1.2.3 Temperature

Ocean temperature is another fundamental regulator of rates of marine production that affects physiological rates, mortality rates, growth rates, and constrains spatial distributions. Temperature has been correlated to growth rates in salmon (Mortensen et al., 2000), and identified as the explanation for over 90% of the growth rate variance of marine copepods (Huntley & Lopez, 1992). Similarly, McLaren (1978) found that temperature was a more important copepod production regulator than food availability.

Aside from growth regulation, thermal gradients can act as a distribution regulator by creating environmental boundaries restricting movement (Welch et al., 1998). Global climate forecasts have resulted in a focus on how marine species will be affected by temperature shifts (Hughes, 2000). Climate change driven shifts to marine species distribution have been identified for many functional groups and trophic levels, including demersal finfish (Perry et al., 2005), corals (Walther et al., 2002), and plankton (Hays et al., 2005). Distribution shifts have been suggested to have important implications for commercial fisheries (Roessig et al., 2004; Perry et al., 2005).

1.2.4 CHEMISTRY

1.2.4.1 ACIDITY

Ocean pH and acidity have received increased attention recently because of the marine environment's relationship with atmospheric carbon dioxide (CO_2) concentrations. Atmospheric CO_2, when reacting with water (H_2O) yields carbonic acid H_2CO_3 through the following reaction:

$$CO_2 + H_2O \rightarrow H_2CO_3.$$

Greater concentrations of CO_2 yield more carbonic acid, driving pH downward. The ocean-atmospheric interface, the site of oceanic CO_2 absorption and pH decrease, overlaps with the euphotic zone, where the majority of oceanic production occurs. Plankton are highly sensitive to environmental fluctuations, and can be impacted in numerous ways, including pH shifts (Rost et al., 2008; Wootton et al., 2008).

In addition, pH is an important variable influencing species distribution and growth. Hansen (2002) showed that phytoplankton growth is restricted to a certain pH range, with species-dependent optimal growth occurring between pH 7.5-8.

However, while acidification is a major concern for the future of marine ecosystem productivity, ocean pH has also been shown to impact secondary production by inducing basic (as opposed to acidic) conditions. Phytoplankton blooms have the ability to elevate pH of the surrounding environment (to as high as pH 10 (Hansen 2002)), which can limit the growth of heterotrophic protists susceptible to high pH (Pedersen & Hansen, 2003).

1.2.4.2 Salinity

Local salinity is an important variable that influences biomass production by regulating the size and development of individual animals and stratification that may enhance or restrict primary productivity. Salinity has been shown to influence developmental characteristics such as egg fertilization and incubation rates, yolk sac resorption, larval growth, and swim bladder inflation (Boeuf & Payan, 2001). Since fish growth is continuous throughout the animal's lifespan, environmental conditions (along with genetic predisposition) determine body size (Boeuf et al., 1999). Maximum, minimum and optimal salinity levels for growth have been identified in many species of teleosts, including tilapia (Suresh & Lin, 1992), sea bream (Woo & Kelly, 1995), Rainbow trout (Morgan & Iwama, 1991), Arctic char (Arnesen et al., 1993), and others.

Clearly, salinity can influence growth of fish and therefore, production totals in higher trophic levels. Salinity has also been shown to influence reproduction rates in primary producers, with laboratory experiments revealing boundaries and optima in oceanic phytoplankton (Braarud, 1951; Brand, 1984).

In addition to regulating growth on an individual level, salinity has been identified as an important factor influencing recruitment. In the Northwest Atlantic, salinity is positively correlated with cod recruitment (Sutcliffe, et al., 1983; Myers, et al., 1993), with consequnces for species population dynamics.

1.2.4.3 Elemental nutrients

Along with sunlight, marine autotrophs require nutrients in order to synthesis carbon to sugar via photosynthesis. Major dietary requirements include nitrogen (N) and phosphorus (P), the availability of which varies on local scales.

Continual nutrient availability is essential to maintain the primary productivity that drives marine ecosystem productivity at higher trophic levels. Nutrient influx from external sources (i.e. river output and rainfall) accounts for less than 1% of the annual nutrient requirements to sustain marine primary production (Hanson, 1980); the vast majority of nitrogen and phosphorus is made available to autotrophs by internal recycling, carried out by *in situ* regeneration (20%) and upwelling from the deep ocean (80%) (Hanson, 1980).

Nutrients must occur in the photic zone of the water column (i.e. the top ~200 m) to be of use to phytoplankton, which are also limited by sunlight availability. Nutrient availability acts as a production limiting mechanism; elements of particular importance are described in Section 1.3.

1.3 Biotic regulators

1.3.1 Primary production

In large marine ecosystems, average and maximum fisheries production is limited by primary production (Chassot et al., 2010). Global catch totals in large marine ecosystems are increasingly constrained by primary productivity (Pauly & Christensen, 1995) at both regional scales (Ware & Thomson, 2005; Chassot et al., 2007) and at global scales (Chassot et al., 2010). Simply put, consumer biomass is ultimately dependant upon food availability. In marine systems, low transfer efficiencies of energy from predator to prey (on the order of 10%; Barnes et al. 2010), predators at high trophic levels are therefore dependent on very high levels of primary production. As primary production cannot be infinite, the biomass of the system it supports cannot be infinite either. The ability of the global marine ecosystem to sustain fisheries yield is tied to its ability to generate the primary production required to supply the system with energy; Pauly and Christensen (1995) estimated that 8.0% of the world's total aquatic primary production is accounted for by the animals contributing to global catch totals.

So which factors dictate the amount of primary productivity in a system? The availability of sunlight and nutrients largely constrain rates of photosynthesis. Sunlight availability is restricted to the photic zone, while nutrient supply is determined by many abiotic factors, including ocean circulation/currents, mixed-layer dynamics, upwelling, atmospheric dust deposition, and the solar cycle (Behrenfeld et al., 2006). Of the various substances required for primary productivity, nitrate (NO_3^-) is considered to be the chemical compound whose availability is most responsible for limitations on ocean primary productivity (Codispoti, 1989; Krom, et al., 1991), although iron-facilitated N_2 fixation should drive ecosystems to a phosphorus-limited state in iron rich systems (Schindler, 1977). Simultaneous production limitiation by nitrogen and phosphorus has also been argued (Eppley et al., 1973), as has seasonal shifts between the limiting elements (D'Elia et al., 1986).

Silicate ($Si(OH)_4$) is another important nutrient that can act as a regulator of primary production. This compound is required by diatoms to complete their life cycle (Conley & Malone, 1992), and plays an important role in phytoplankton bloom development (Brzezinski, 1992). Environmental scenarios have been described where silicate availability is the overall limiter of system growth (Dugdale et al., 1995).

As energy is transferred through food webs by predation and lost via metabolism, fisheries that exploit targets in lower trophic levels have the potential to harness considerably more energy from a system than fisheries that target top predators (Pauly & Christensen, 1995; Chassot, et al., 2010), although these animals do not provide as many direct economic incentives for industry (Pauly & Christensen, 1995).

1.3.2 Secondary production

The amount of secondary production in marine ecosystems is an important factor determining system productivity as well. Estimating secondary production is important for resource managers to consider as it is an important indicator of the potential of various trophic levels in an ecosystem (Tumbiolo & Downing, 1994). Just as primary production provides energy to fuel biomass growth (and in the interest of this essay, fisheries yield), secondary production offers an important energy source to marine ecosystems by linking producers and higher level consumers. Friedland et al. (2012) found that while concrete relationships between primary production and system output have been difficult to prove (but see Chassot et al. 2010), the ratio of secondary production to primary production has been shown to be positively correlated to fishery yields. In addition, shifting secondary production has been proposed as a trait that can be useful for quantifying the ecosystem impacts caused by fishing (Libralto et al., 2008).

1.3.3 Trophic dynamics

Just as abiotic factors provide the baseline conditions that determine autotrophic biomass production in marine ecosystems, the interaction of biological components plays a large role in determining heterotrophic production and fisheries yield. Ecological traits determine this production; the number of feeding links in the system, the efficiency at which energy moves between trophic levels (through predation (Barnes et al., 2010)), and temperature-dependant metabolism are features identified as secondary production regulators (Chassot et al., 2010). Other ecological factors impacting system production include the number of food chain links (Chassot et al., 2010), with the number of links (or feeding interactions) determined by ecosystem size (Post et al., 2000). Consumer body size (Denney et al., 2002; Barnes et al., 2010) and species richness (Frank et al., 2007) also influence system production and fisheries yield.

1.4 SUMMARY

No matter the spatial scale in question, the production capacity of the marine environment is contingent upon many factors that are increasingly known and quantified. Natural or imposed shifts in any of these variables can change the size, arrangement and functioning of ecosystems, with consequences for fisheries yields and industry participants. The biological attributes of past, present, and future marine systems are characterized by the factors and trends governing production; management strategies that ignore this fact may experience reduced ability to reach desired outcomes. This theme is central within the forthcoming chapters that specifically characterize the physical, biological, and fisheries management dynamics of the Flemish Cap region.

CHAPTER 2. OCEANOGRAPHIC SETTING AND BIOLOGICAL STRUCTURE OF THE FLEMISH CAP

2.1 INTRODUCTION

A combination of oceanographic characteristics on the Flemish Cap makes the area among the most productive fishing areas in the Northwest Atlantic. Location, depth, current influence, and the host of other factors outlined in Chapter 1 align in the area in a manner that has allowed for tremendous biological production and fisheries yields since the area was discovered.

This chapter reviews the oceanographic features that make the Flemish Cap a unique environment that has supported fishing effort for over 60 years, along with the biological structure and interactions that determine the relative populations and productivity of various species within the community.

2.2 OCEANOGRAPHIC

2.2.1 LOCATION

The Flemish Cap is an underwater seamount in the Northwest Atlantic Ocean. It is much smaller than the adjacent Grand Banks, with an area of 4 870 km^2 at 200 m depth (Stein, 2007) and 27 337 km^2 at 730 m depth (Perez-Rodriguez et al., 2012); it is located approximately 600 km east of Newfoundland (Figure 1). The shallowest sections (~125 m deep) are found on the southwest section of the plateau (Perez-Rodriguez et al., 2012) at 47° N, 45° W (Stein, 2007). The Cap is separated from the Grand Banks by the Flemish Pass, a rift zone (~ 1 100 m deep) that defines the Cap's western border.

Access rights to marine resources are dictated by UNCLOS; Parties to UNCLOS are provided exclusive rights to marine resources within 200 nautical miles of their coastline. The Cap's distance from land defines the access rights to its resources, biological and otherwise. As it lies beyond the limits associated with domestic access rights, the Cap's resources are managed by NAFO, an international governmental organization whose party members are states with fisheries interests in the area.

2.2.2 CURRENTS

As discussed in Chapter 1.2.1, currents have a direct and substantial impact on the abiotic and biotic characteristics on the areas over which their force is felt. Importantly, the patterns of water movement on and around the Flemish Cap partly characterise its unique setting and contribute to its productivity.

From the north of the Cap, the southern-flowing Labrador Current transports cold and low salinity water from Canada's Arctic. The Labrador Current splits twice before its main branch parallels the Gulf Stream near the southern tip of the Grand Banks; the first split occurs to the northeast of the Grand Banks, with the Labrador Current water mass flowing westward to traverse the north and western sides of the Banks. The downstream split occurs north of the Flemish Pass with the new branch of the Labrador Current travelling in a clockwise fashion around the Cap. Although both of these splits are important to recognize when considering current influence over the Flemish Cap region, they represent a relatively small percentage of the overall water movement when compared to the main branch of the Labrador Current. After these splits, the majority of the Labrador Current continues south along the eastern side of the Grand Banks at around 30 cm/s (Stein, 1996). A diagram showing water transport is provided in Figure 3.

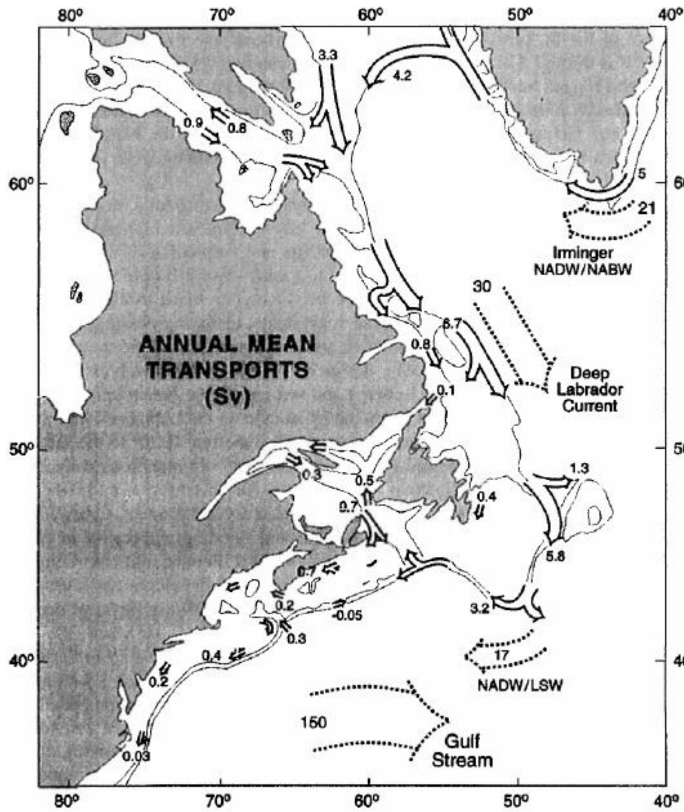


Figure 3 Major transport features in the Northwest Atlantic Ocean (from Loder et al., 1998). The numbers indicate the annual mean transport in Sverdrups (Sv), with solid line arrows representing shelf and slope currents, and dotted line arrows showing transport levels in the deep Northwest Atlantic (Loder et al., 1998).

The warmer and more saline waters carried northeast by the Gulf Stream also factor strongly into the oceanographic context of the Flemish Cap. The Gulf Stream travels northeast from the southeast coast of the United States and splits into the northeast travelling North Atlantic Current (NAC), with the rest of the flow classified as the continuation of the Gulf Stream. This divide occurs southeast of the Grand Banks, with the North Atlantic Current travelling the eastern side of the Banks from 40° to 51°N (Rossby, 1996). These current patterns and the paths of the Labrador Current are depicted in Figure 4.

There are two flow patterns the North Atlantic Current takes after its separation from the Gulf Stream (Krauss et al., 1987) (see Figure 4). The 'classical path' of the Gulf Stream travels north past the Flemish Cap into the Northwest Corner, where the Stream turns to the east. In another flow scenario, the majority of the water in the North Atlantic Current heads east in the vicinity of the Flemish Cap rather than north (although a percentage of the Current does still flow in the 'classical' path) (Stein, 2007). This eastward flow proceeds through gaps in high pressure cells on the eastern side of the current (Krauss et al., 1987). According to Krauss et al. (1987), the current's path and the strong eddies around the Cap vary in space and time. The Mann eddy (an anticyclonic water flow located just offshore of the NAC (Meinen, 2001)) is an exception here, as it considered a permanent feature in the waters of the Northwest Atlantic (Rossby, 1996). The flow rate of the North Atlantic Current is approximately 30-50 cm/s (Stein, 1996).

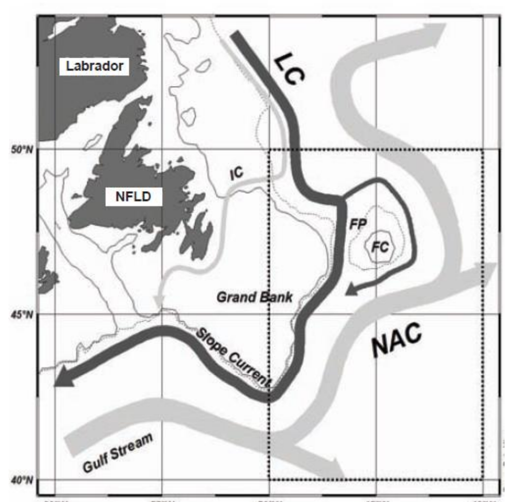


Figure 4 Major currents in the Flemish Cap Region of the Northwest Atlantic (from Stein, 2007). The Gulf Stream path is evident, along the location where it branches off to form the North Atlantic Current (NAC). The southward path of the Labrador Current (LC) is also noted, along with its westward split north of the Grand Banks, and its eastward split that occurs northwest of the Flemish Cap (FC). The main branch of the Labrador Current flows southward through the Flemish Pass (FP), following the topography of the Banks.

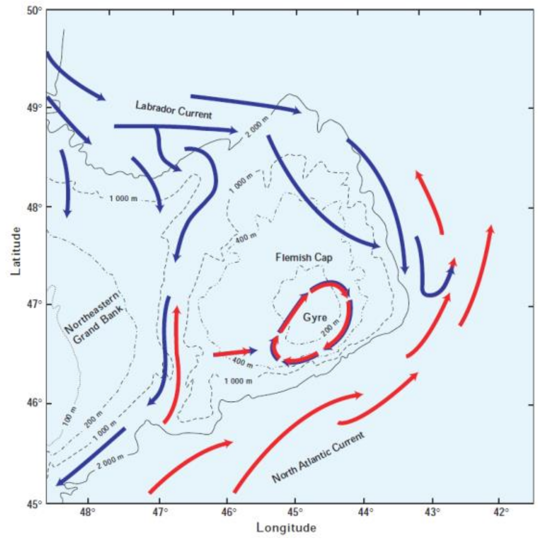


Figure 5 Water movement patterns around the Flemish Cap (from Colbourne and Foote, 2000). Blue arrows denote the flow of the Labrador Current, and red arrows denote the flow of the North Atlantic Current. The anticyclonic gyre present on the Cap is portrayed as a function of the move of the North Atlantic Current and Labrador Current. Topographical lines are included.

Water movement over the Cap area is predominantly anticyclonic (clockwise) (Stein, 1996). The eastern Cap experiences southward movement with a speed of 5-15 cm/s, and the western cap is subjected to northern water movement with velocity in the same range (Stein, 1996). Assuming an average velocity of 10 cm/s, the rotational period around the Cap's borders is approximately 10 weeks (Stein, 1996). This anticyclonic gyre (Figure 5) displays different circulation patterns year to year, shifting between a well-developed anticyclone gyre with a defined core over the top of the bank, and a highly variable circulation pattern where numerous eddies exist along with a poorly defined central gyre Gil et al. (2004). Gil et al. (2004) concluded that the Labrador Current is the driver of the anticyclonic gyre over the cap; the stronger the current's influence, the greater the likelihood a strong, well defined anticyclone will be formed, anchored to the topography of the bank. This oceanographic characteristic is tied to global atmospheric forcing, as increasing strength of the Labrador Current is associated with a diminishing value of the

North Atlantic Oscillation (NAO) (Perez-Rodriguez et al., 2012), a mechanism that is detailed in the following section.

Along with the Labrador Current, the bathymetry of the Cap plays a major role in determining the water movement over the area. Variability in the offshore branch of the Labrador Current and oscillations of the north wall of the North Atlantic Current provide variation in the water dynamics over the Cap (Gil et al*.,* 2004).

2.2.3 The North Atlantic Oscillation (NAO)

The North Atlantic Oscillation (NAO) is responsible for many major variations in regional weather and climate, with corresponding impacts on marine life, fish stocks and fisheries production (Stenseth et al., 2002). The NAO is defined as the difference in sea-level atmospheric pressure between the Azores high and the Icelandic low, and fluctuates unpredictably.

The NAO influences atmospheric variables including wind speed and direction, air temperatures, heat and moisture transport and precipitation (Drinkwater et al., 2003) and its influence is heterogeneous across ocean basins and within regions (Petrie, 2007). Shifts in these variables influence the marine environment's salinity and temperature characteristics, vertical mixing, circulation patterns and ice formation (Drinkwater et al., 2003)- variables that impact fish and shellfish production (Mann & Drinkwater, 1994). A recent analysis of hydrographic data in the Northwest Atlantic found large spatial variation in salinity and temperature responses, the polarity of which was dependent on the polarity of the NAO (Petrie, 2007). The environmental characteristics associated with strong NAO values, and the overall mechanisms impacting biological production in the vicinity of the Flemish Cap and Newfoundland and Labrador waters are outlined in Figure 6.

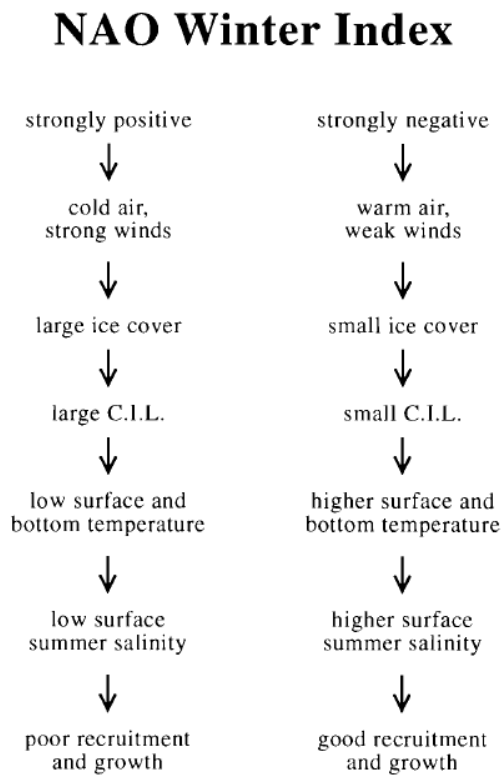


Figure 6 The environmental ramifications of NAO values and corresponding impact to recruitment and growth in the Canadian Northwest Atlantic (from Mann & Drinkwater, 1994). An important difference is the size of the cold-intermediate layer (CIL), which impacts water column temperature and subsequently, recruitment and growth in the area.

There is substantial evidence suggesting that the NAO impacts marine ecosystem structure in the Northwest Atlantic. Aside from fish and shellfish production, abundance and fluctuations of calanoid copepods *Calanus finmarchicus* and *C. helgolandicus*, (ecologically important zooplankton species that will be mentioned in greater detail in subsequent sections) are closely linked to the sign and magnitude of the NAO (Fromentin & Planque, 1996; Stenseth et al. 2002). The NAO has also been identified as the cause of major environmental shifts in the past, with biological consequences. In the summer of 1882, a mass mortality event occurred in a tilefish stock in the Middle Atlantic Bight, likely caused by an extreme cold period from April to August. This period is thought to have been a consequence of elevated transport of cold water to the area introduced by the Labrador Current. As current activity in the area is tied to the NAO, and empirical evidence suggests a higher than normal influence by the Labrador Current (with more ice coverage than average) in this timeframe, the NAO has been proposed as the mechanism for this climatological abnormality (Marsh et al., 1999).

2.2.4 Bathymetry

The Flemish Cap is roughly circular with a radius of about 200 km, and varies in depth from 125 m to 700 m (Stein, 2007). The dome-shaped plateau slopes gradually downward on its western section until the meeting point with the Flemish Pass (Stein, 2007). The Cap drops steeply to the seafloor at its southern terminus (Stein 1996, 2007), making this area difficult for trawling (Wareham & Edinger, 2007). The north section of the Cap is comparatively smooth, and as such, it has been the centre of concentrated fishing effort (Wareham & Edinger, 2007).

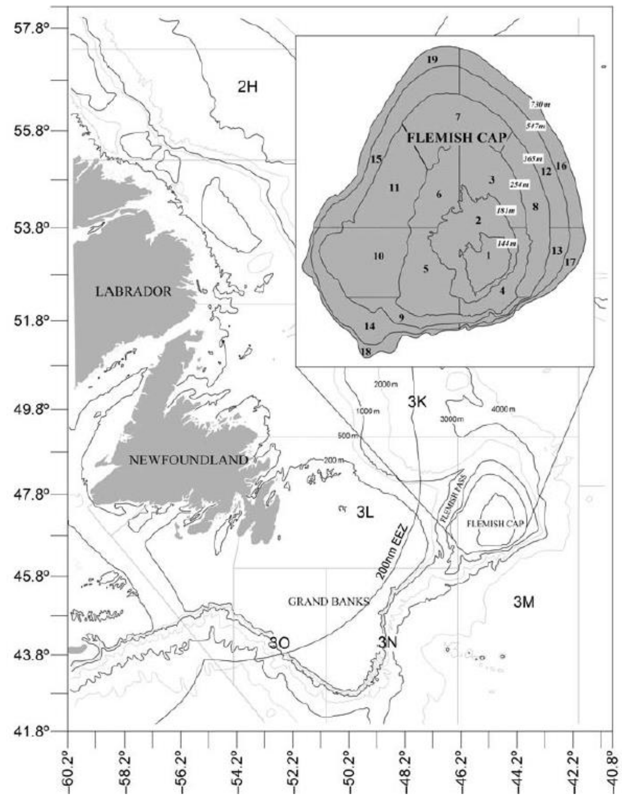


Figure 7 Features and NAFO statistical Divisions in the Northwest Atlantic Ocean. A top-down view of the Flemish Cap and 19 survey strata sampled by Spanish surveys are provided in the insert (from Pérez-Rodríguez et al., 2012).

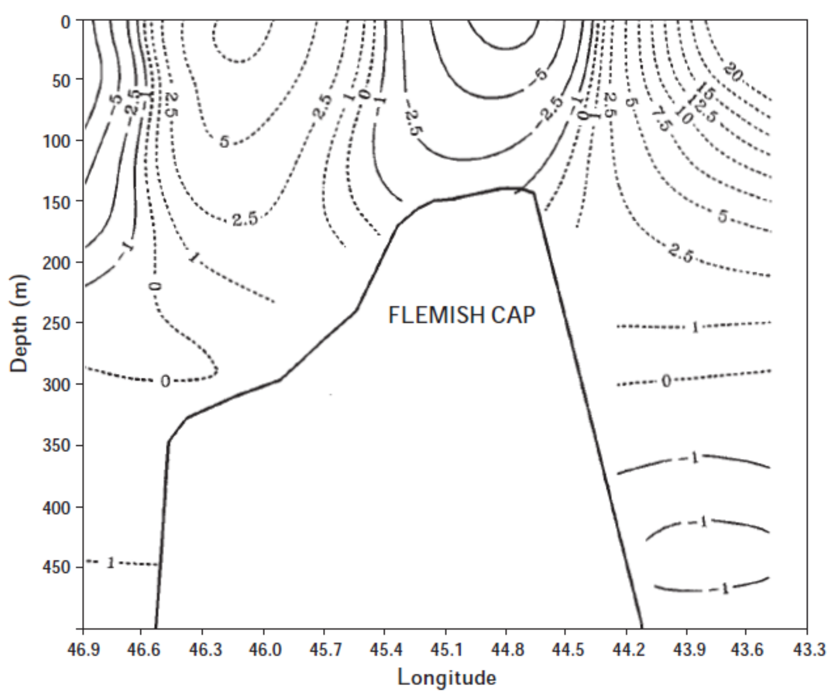


Figure 8 Bathymetry and current direction on the Flemish Cap (from Colbourne and Foote, 2000). Broken, positive lines are northern flows, and solid, negative lines indicate southward movement. The current speed is denoted in the lines (in cm/s).

2.2.5 Substrate composition

Substrates on the Cap are primarily sand and shell beds, with a mixture of mud and sand covering the slopes (Wareham & Edinger, 2007). The shallower areas have a mix of fine or medium sand, with the northern and deeper areas of the Cap are mostly muddy sediment (Murillo et al., 2011). In some of the deeper areas of the southern Cap, pebbles and cobbles have been found (Murillo et al., 2011). In the centre of the dome there is a large patch of sand, and stones are found throughout the Cap (Murillo et al., 2011).

2.2.6 Temperature

Water temperature in the Flemish Cap undergoes both seasonal and annual variations (Stein, 1996). Seasonal cycles in water temperature occur to a greater extent in the upper water column, where storm-forced mixing and cycles of solar energy input are the most intense (Colbourne & Foote, 2000). Variations in the influence of the different currents on the area may further explain temperature changes in the area (Stein, 1996).

Fluctuations over larger time scales (multiyear and greater) can be attributed to the North Atlantic Oscillation, as heavy ice conditions, cold air temperatures and strong northwest winds can be attributed to a strongly positive oscillations (Drinkwater, 1994; Petrie, 2007). Shifting NAO values and the resulting environmental fluctuations (through these mechanisms) can directly impact fish populations in the Northwest Atlantic, as commercial sized cod, for example are largely found within a thermal range of 0-5°C (Rose & Leggett, 1989). This temperature requirement is met on the Flemish Cap due to the persistence of a strong thermo-haline front that exists about 100 km east of the Flemish Cap between the

NAC and the waters around the Cap, allowing for continual adherence to this thermal window (Stein, 2007).

2.2.7 Unique setting in the Northwest Atlantic

While the adjacent Grand Banks has also long been known as a highly productive fishing area, the Grand Banks and the Cap have distinct environmental contexts. These differences provide unique frameworks supporting the biological communities and fisheries in the respective areas.

The size differential of the seamounts is a superficial difference that is easy to note. The Grand Banks cover 280 000 km^2 (DFO, 2012), larger than the Cap's 30 000 km^2 (Colbourne & Foote, 2000). With depths ranging between 36 m to 185 m the Grand Banks are also shallower than the Cap (DFO, 2012). The water movement patterns over the shallow seamount and continental shelf is another important difference; the Grand Banks are bordered by different branches of the southern-flowing Labrador Current; the currents dictating water movement over the Cap were detailed in the preceding section.

The two areas are separated by a rift valley and a strong thermohaline front (Colbourne et al., 2012) induced by the strong arm of the Labrador Current; both features act to keep the respective biological communities distinct. The strength of the anticyclonic gyre over the Cap is positively correlated to the strength of northerly winds (Akenhead, 1982), directly impacts the movement of pelagic eggs and larvae in the area (Kudlo & Boytsov, 1979), and influences year-class strength of cod through increased prey survival and abundance (Kudlo & Boytsov, 1979). While these abiotic regulators restrict migration between the Cap and the Grand Banks, Frank et al. (1996) suggest that during colder periods, biological and physical scenarios may allow for migration of pelagic species between the two areas. Further to these differences, Maillet et al. (2005) discuss many other important variances between the Banks and the Cap, which the author's postulate to be the reasons for productivity differences between the two areas. These environmental differences are outlined in Table 1.

Table 1 A summary of some key abiotic and biotic differences between features of the Grand Banks and Flemish Cap, with respect to primary and secondary production.

Comparing the Grand Banks and Flemish Cap				
Feature		**Grand Banks**	**Flemish Cap**	**Source**
Abiotic	Primary and secondary production	lower	higher	(Maillet et al., 2005)
	Currents	More dominated by Labrador Current	Influenced heavily by Labrador Current but also by North Atlantic Current	(Colbourne & Foote, 2000)
	Size	Larger	smaller	(Colbourne & Foote, 2000; DFO, 2012)
	Ice presence	Higher	Lower	(Maillet et al., 2005)
	Length of primary/secondary production season	Shorter	Longer	(Maillet et al., 2005)
	Temperature	Lower	Higher	(Maillet et al., 2005)
	Salinity	Lower	Higher	(Maillet et al., 2005)
	Nitrate	Lower	Higher	(Maillet et al., 2005)
	Silicate	Lower	Higher	(Maillet et al., 2005)
	Spring nutrient levels	Lower	Higher	(Maillet et al.,

				2005)
	Spring phytoplankton bloom	Earlier	Later	(Anderson, 1990)
	Position of nitracline[1] in the water column	Deeper	shallower	(Maillet et al., 2005)
	Stratification and mixed layer depth	See Table 2		(Maillet et al., 2005)
Biotic	Average body size of copepods	Smaller	Larger	(Maillet et al., 2005)
Biotic	Dominant copepod species (biomass)	See Figure 9		(Maillet et al., 2005)
Biotic	Dominant copepod species (abundance)	See Figure 9		(Maillet et al., 2005)

Table 2 Seasonal Stratification Index (SI) and mixed-layer depth (MLD) for the Grand Banks (GB), Cap Slope (SL) and Flemish Cap (FC) (from Maillet et al., 2005). Stratification Indexes are measured in Kgm^{-4}, and is a method to compare the degree of stratification in the water column seasonally or by location. This index is defined by Maillet (et al., 2005) as the difference in sigma-t values between 50 m and 5 m divided by 45 m. Mixed layer depth is the depth centre of the pycnocline (layer where density shifts occur rapidly with depth (Maillet et al., 2005)).

Season	Location	Avg S.I. ($Kg\ m^{-4}$)	Avg. MLD (m)
Spring	GBS	0.0031 ± 0.002	64.3 ± 15.2
	SL	0.0034 ± 0.002	57.9 ± 15.0
	FC	0.0013 ± 0.001	75.4 ± 16.7
Summer	GBS	0.0341 ± 0.003	15.6 ± 2.6
	SL	0.0357 ± 0.006	16.4 ± 1.7
	FC	0.0317 ± 0.006	15.6 ± 2.3
Autumn	GBS	0.0181 ± 0.007	44.1 ± 2.4
	SL	0.0085 ± 0.005	65.7 ± 16.9
	FC	0.0070 ± 0.004	75.4 ± 10.4

2.3 Biological

2.3.1 Chemistry

[1] Defined as the depth at which nitrate concentration exceeds 0.5mmol/m^3 (Maillet et al., 2005)

Water chemical properties on the Flemish Cap provide local abiotic context as well. The elemental nutrients supplied to the region are the result of mixing and upwelling, processes that are governed by water movement, wind, and topography.

Salinity in the Cap region tends to be uniform according to depth, except for the upper layer which undergoes an annual cycle with peak salinity in February, waning through the summer to its low point in August (Stein, 2007). Due to the presence of North Atlantic waters, the Flemish Cap tends to have persistently higher salinity (>34 PSU) than the adjacent Grand Banks salinity (~33 PSU) across an area that receives, cold, relatively fresh Labrador Current waters (Colbourne et al., 2012).

2.3.2 PRIMARY AND SECONDARY PRODUCTION

The large fish and invertebrate biomass in the Flemish Cap region is enabled by high primary and secondary productivity (Maillet et al., 2005). The general drivers of primary and secondary production in marine ecosystem are outlined in Chapter 1.3; more specifically, the Cap is home to augmented primary and secondary production due to the Labrador Current's cold influx, mixed with the North Atlantic Current's warm, nutrient rich influx, the resulting retention properties of the anticyclonic gyre and elevated inorganic nutrient levels from mixing and upwelling. The relative contribution of the various plankton genera to production is provided in Figure 9; copepod abundance and biomass are provided in Figure 10.

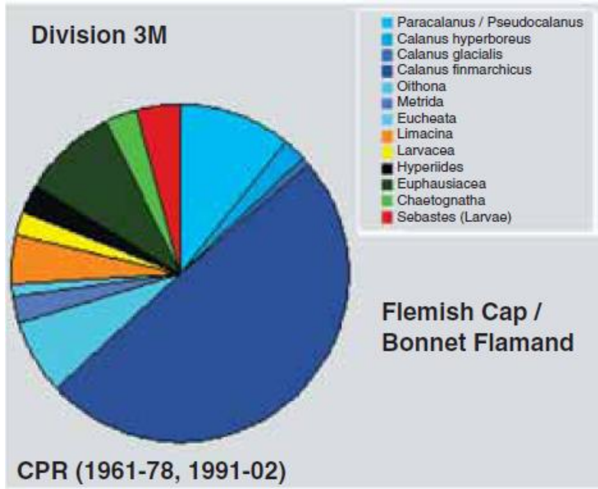


Figure 9 The relative contribution of various zooplankton genera to secondary production on the Flemish Cap (from Maillet et al., 2005a).

The composition of the copepod community is important to consider as early life stages of demersal and pelagic fish have strong preferences for (and aversions to) various species and developmental stages of copepods (Maillet et al., 2005). This has implications for the predator-prey dynamics in higher trophic levels involving animals dependant on copepods as a food source (Maillet et al., 2005). More simply, copepod predators that have increased access to their preferred type will have a competitive advantage over their competitors, with consequences for overall community structure.

Copepod biomass on the Cap is mostly accounted for by three large species from the genus *Calanus* (Maillet et al., 2005). However, species abundance and zooplankton community composition also varies by season (Figure 11); this is exemplified by *Oithona* sp. In summer this genus is more abundant, but due to their small size do not account for a proportional share of community biomass (Maillet et al., 2005).

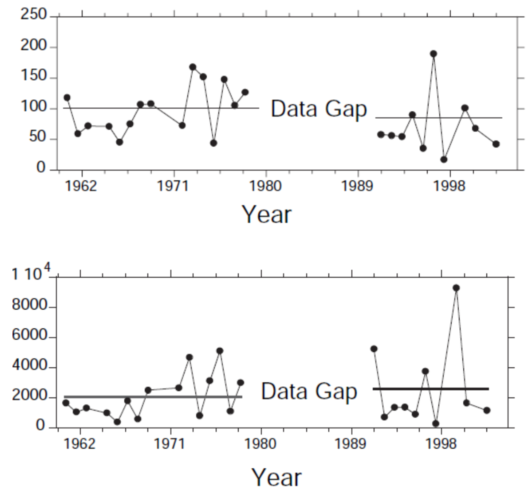


Figure 10 Abundance (top, in #/m3) and biomass (bottom, dry weight in ug/m3) of all copepod genera on the Flemish Cap 1961-2002, as measured by a Continuous Plankton Recorder (CPR) (from Maillet et al., 2005).

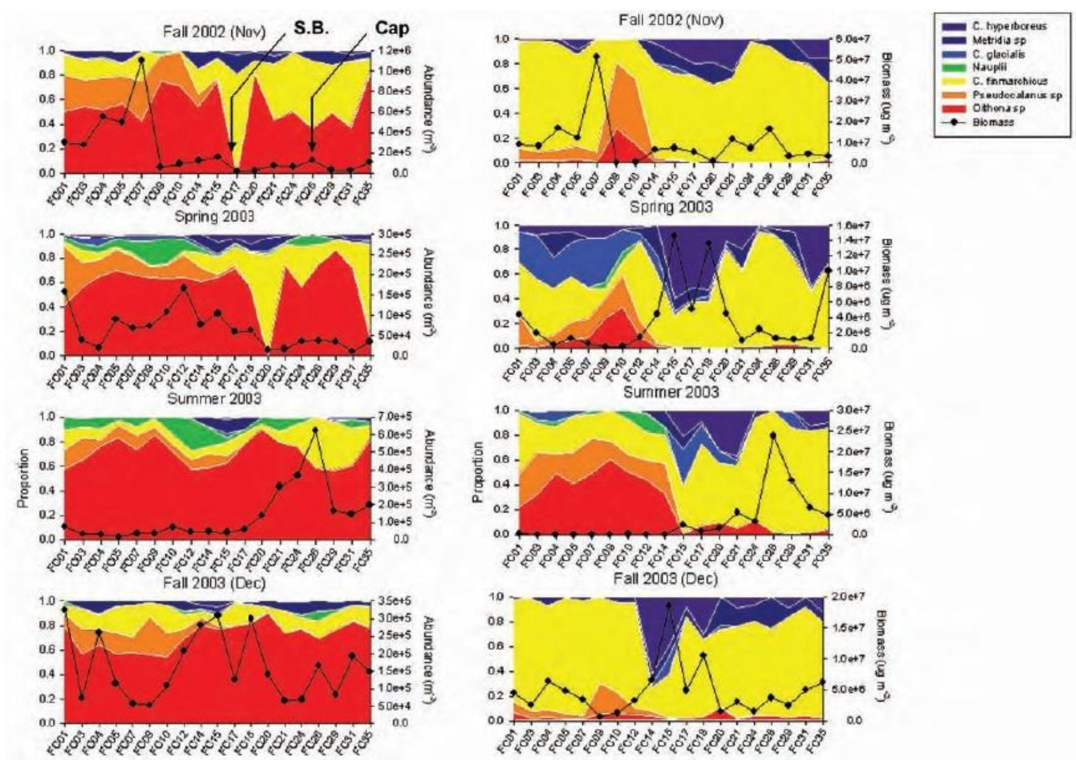


Figure 11 Proportional abundances (left panels) and biomasses (right panels)of the major copepod genera present in the waters of the Flemish Cap. Positions of the centre of the Flemish Cap (Cap) and the Shelf Break (S.B.) are noted (from Maillet et al., 2005). Data were obtained from net tows in 2002 and 2003.

While the currents surrounding the Flemish Cap area provide the region with elevated nutrient availability, they also represent oceanographic borders that increase ecosystem stability and the formation of well-defined zooplankton communities when compared to marine ecosystems without such natural borders (Pepin et al., 2011). On a more local scale, secondary boundaries may exist in the form of eddies or Taylor columns (akin to the anticyclonic gyre present on the Cap) that further differentiates planktonic communities (Pepin et al., 2011).

2.3.3 DOMINANT SPECIES/COMMERCIAL SPECIES

Substantial research has focused on the various characteristics of the Flemish Cap and surrounding areas with the purpose of informing management of commercial species. A summary of the species present on the Flemish Cap is provided in Table 3. This table includes species whose management falls under NAFO jurisdiction, and intentionally omits sedentary benthic invertebrates and highly migratory species of commercial value that may occur in the area.

Table 3 Commercial species of the Flemish Cap.

Species			**Classification (Family)**
	Scientific name	**Common name**	
Commercially-targeted species	*Gadus morhua*	Atlantic cod	Gadidae
	Sebastes spp.	Redfish/ocean perch	Scorpaenidae
	Hippoglossoides platessoides	American plaice	Pleuronectidae
	Pandalaus borealis	Northern shrimp	Pandalidae
	Reinharditius hippoglossoides	Greenland halibut	Pleuronectidae
	Illex illecebrosus	Northern shortfin squid	Ommastrephidae
	Mallotus villosus	capelin	Osmeridae

2.3.3.1 Atlantic cod

Perhaps the fish most associated with the waters of the Northwest Atlantic, Atlantic cod is an apex predator in the region. The Cap's cod population is distinct from the stock found on the nearby Grand Banks (Lear et al., 1979). It is a demersal schooling fish, heavily involved in predation, which represents a dominant controlling mechanism that determines the structure of the Cap's biological community. A hearty, palatable fish, cod was a target of an offshore fishery for generations of Canadians and Europeans. Cod stocks were plentiful enough and the fishing was so rewarded in the Northwest Atlantic that European boats ventured to the Grand Banks and the Flemish Cap to fish, later setting up villages on Newfoundland's coast as launching points of excursions. Eventually, harvesters settled permanently in Newfoundland, their catches used to feed communities in the New World, but also sold to distant-water fleets when possible.

Stock instability, to the extent documented in recent decades, is likely the first such instance since anthropogenic exploitation. High fishing effort from the 1950s-late 1980s, exacerbated by poor environmental conditions resulted in stock (and fishery) collapse by the early 1990s (Figure 12).

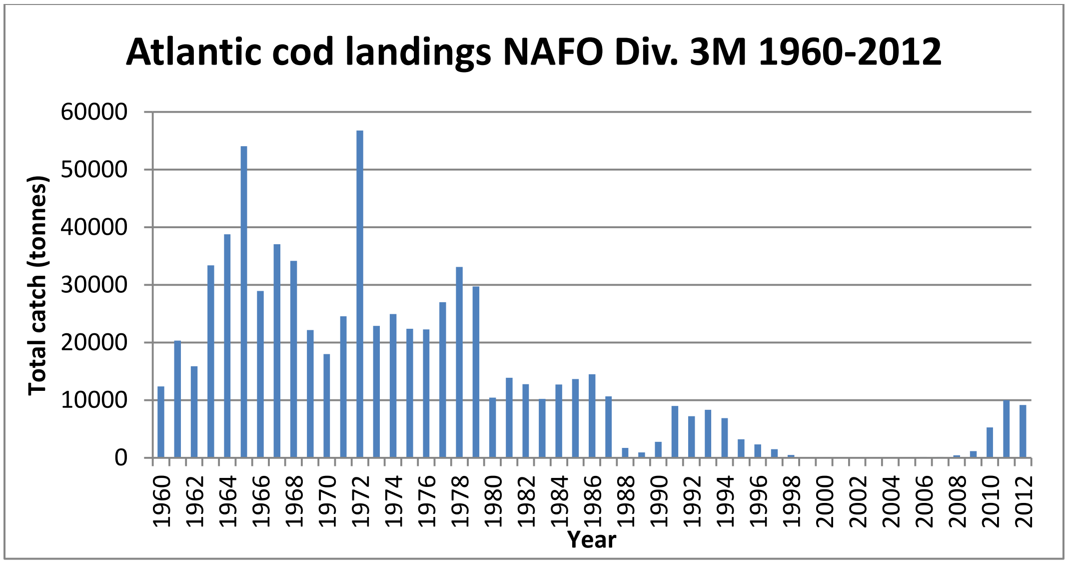


Figure 12 Historical cod landings from the Flemish Cap, 1960-2012. Source: NAFO STATLANT 21A Fisheries Database. The decline in landings in the early 21st century is partly due to policy- 3M cod were subject to a moratorium from 1999-2009. The moratorium was lifted for the 2010 season.

2.3.3.2 Redfish

Redfish (or ocean perch) became an increasingly important commercial species in the years following the collapse of groundfish stocks in the Northwest Atlantic (Marcogliese et al., 2002). There are three distinct but morphologically similar redfish species on the Cap- *Sebastes mentella, S. marinus,* and *S. fasciatus*, with *S. mentella* and *S. marinus* having greater commercial importance (Marcogliese et al., 2002).

The morphological similarity between the redfish species has precluded good biological research of the respective species. This lack of knowledge has complicated management by preventing stock delineation (Marcogliese et al., 2002) and effective quota estimation (due to a lack of information on population dynamics and age structure) (Saborido-Rey et al., 2004).

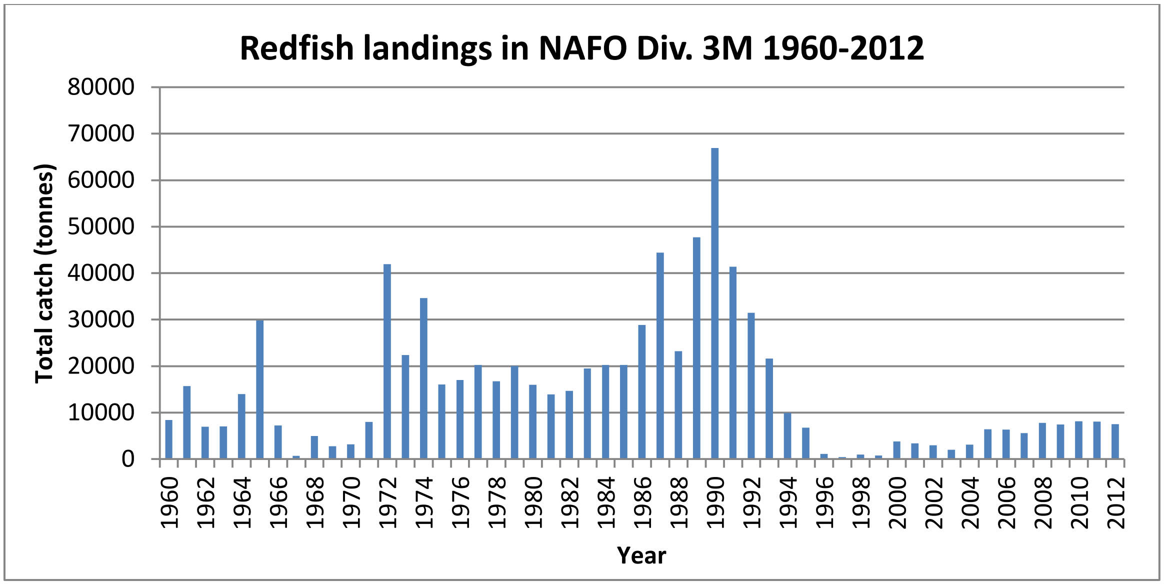


Figure 13 Historical redfish landings from the Flemish Cap, 1960-2012. Source: NAFO Fisheries Database. A drastic reduction in landings occurred in the 1990s driven by quota reduction after peak historical landings in the late 1980s. The late 1980s spike coincides with arrested cod productivity.

Population concerns have existed since effort and catch levels spiked in the late 1980s (Figure 13), with the total allowable catch (TAC) falling from 50 000 tonnes in 1991 to 5 000 tonnes in 2002 (Ávila de Melo et al., 2002).

2.3.3.3 American plaice

American plaice is a demersal flatfish, preying primarily on echinoderms in the Cap region (Paz et al., 1989). The Flemish Cap stock is discrete from the Grand Banks stock (Bowering & Brodie, 1994), and occurs at depths shallower than 600 m (NAFO, 2011a). American plaice spawns in April in the Flemish Cap, earlier than the Grand Banks stock (González et al., 2004). The animal is ecologically and economically important, but population concerns have kept a directed plaice fishery closed since the mid 90s (González et al., 2004; NAFO, 2011b). Historical plaice landings on the Cap have been low relative to cod and redfish and are provided in Figure 14.

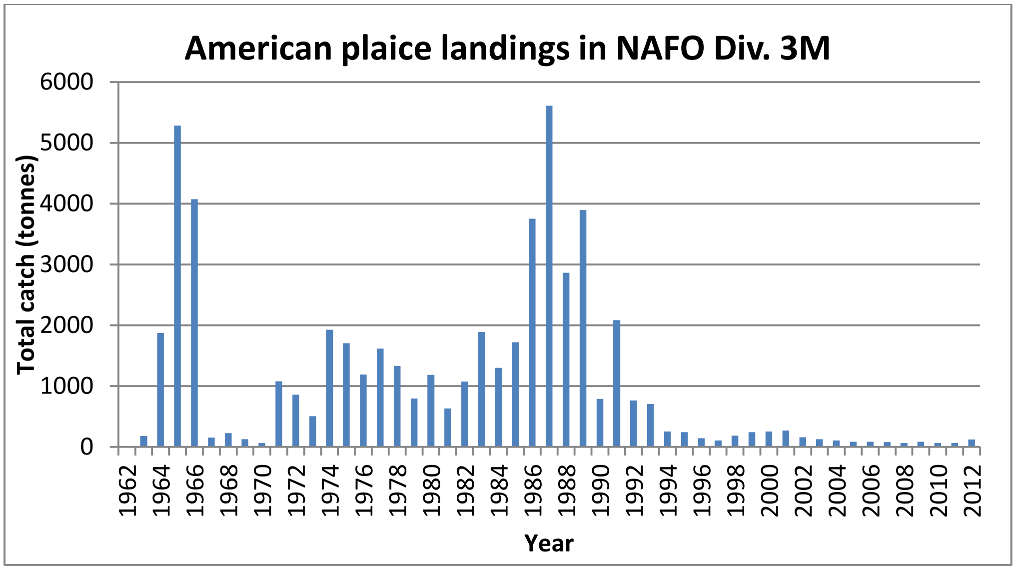


Figure 14 Historical American plaice landings from the Flemish Cap, 1960-2012. Source: NAFO STATLANT 21A Fisheries Database. Landings have been kept to a minimum through the implementation of a moratorium, installed in 1994 (NAFO, 2011b).

2.3.3.4 Northern shrimp

The Northern shrimp is a cold-water, pelagic crustacean whose distribution in the Northwest Atlantic ranges from Georges Bank to the Davis Strait. All Northern shrimp are born as males, and pass through a transitional phase where the animal undergoes a sex change and spends the rest of its life as a female (Parsons et al., 1998). The age at which this transformation occurs varies by animal (Parsons et al., 1998).

Surveys have indicated that the highest densities of shrimp are found in depths between 250 and 500 m on the western, northern and northeastern areas of the Cap (Parsons et al., 1998). Shrimp populations are heavily regulated by predation, as it is targeted by many species in the North Atlantic (Parsons, 2005).

The Northern shrimp fishing industry essentially commenced in the 1990s, as population densities before this era were low. Since a peak in 2003, shrimp catch rates have continued to decline (see Figure 15).

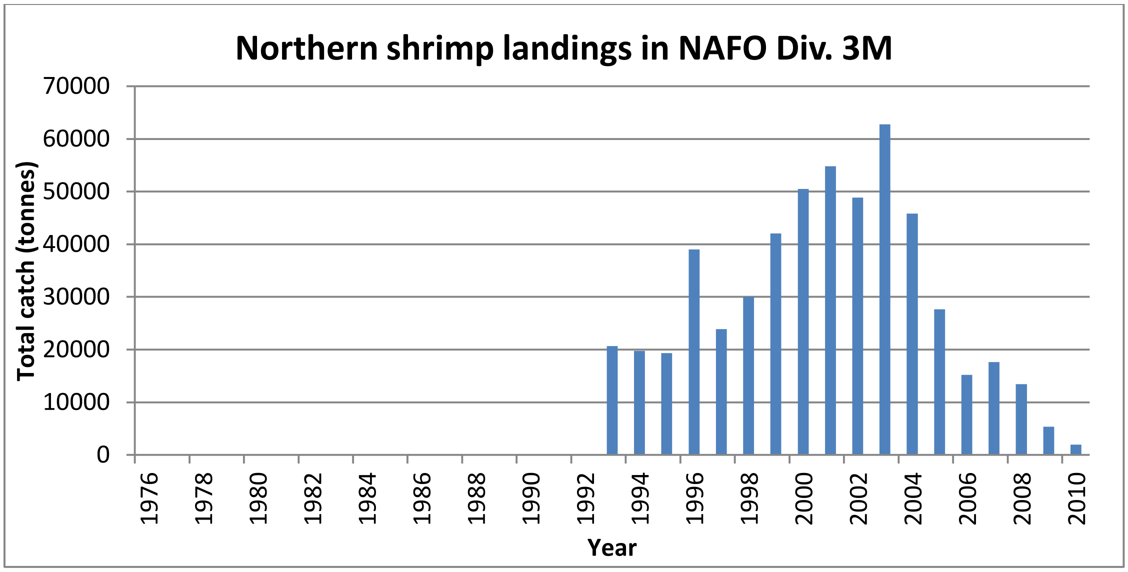


Figure 15 Historical Northern shrimp landings from the Flemish Cap, 1960-2012. Shrimp exploitation has predominantly been a contemporary activity, with minor landings recorded in 1976. Declines in landings and biomass led to the implementation of a moratorium in 2010. Source: NAFO STATLANT 21A Fisheries Database.

2.3.3.5 Greenland halibut

Another demersal flatfish of importance on the Cap is Greenland halibut (*Reinhardtius hippoglossoides*). The population is genetically homogenous (Vis et al., 1997), with NAFO Divisions 3KLMNO and Subareas 0 and 1 encompassing the range of the species in the Northwest Atlantic (González-Troncoso et al., 2007).

Landing totals specific to the Flemish Cap area have increased since the 1980s and are provided in Figure 16.

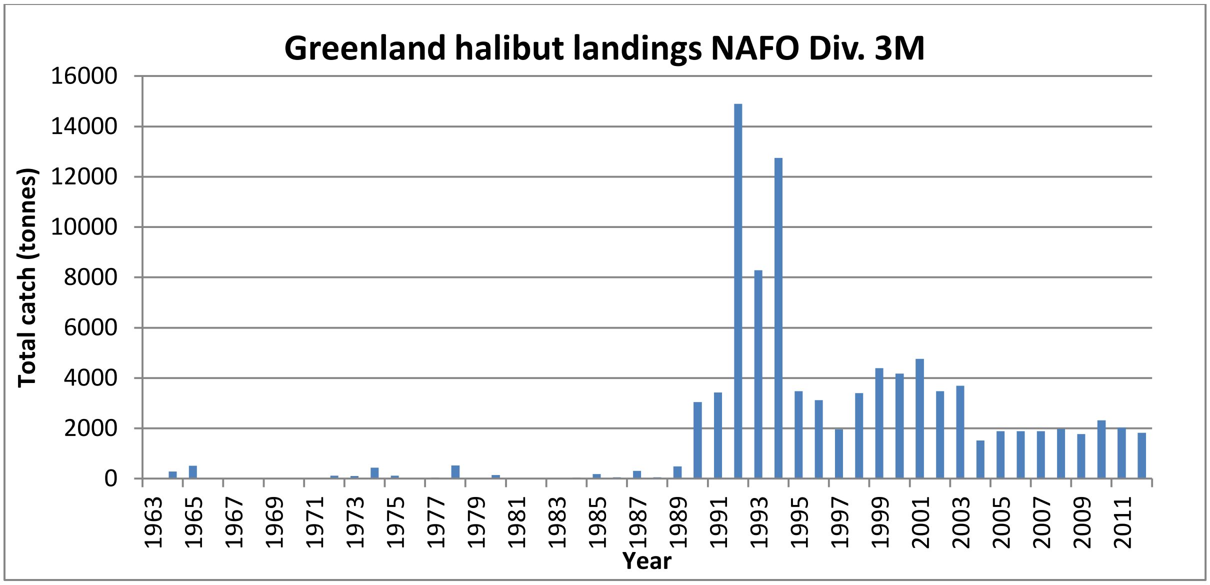


Figure 16 Historical Greenland halibut landings from the Flemish Cap, 1960-2012. Source: NAFO STATLANT 21A Fisheries Database.

2.3.3.6 Northern shortfin squid

Although ideal and production promoting conditions exist for many marine species, the oceanographic setting on the Cap is only marginally acceptable habitat for Northern shortfin squid in most years (Hendrickson & Showell, 2010). This has resulted in low population counts in surveys (Hendrickson & Showell, 2010), and low landing totals (Figure 17). The animal has a lifespan of less than one year (Hendrickson, 2004), and is considered a unit stock throughout its range in the Northwest Atlantic (Dawe & Hendrickson, 1998).

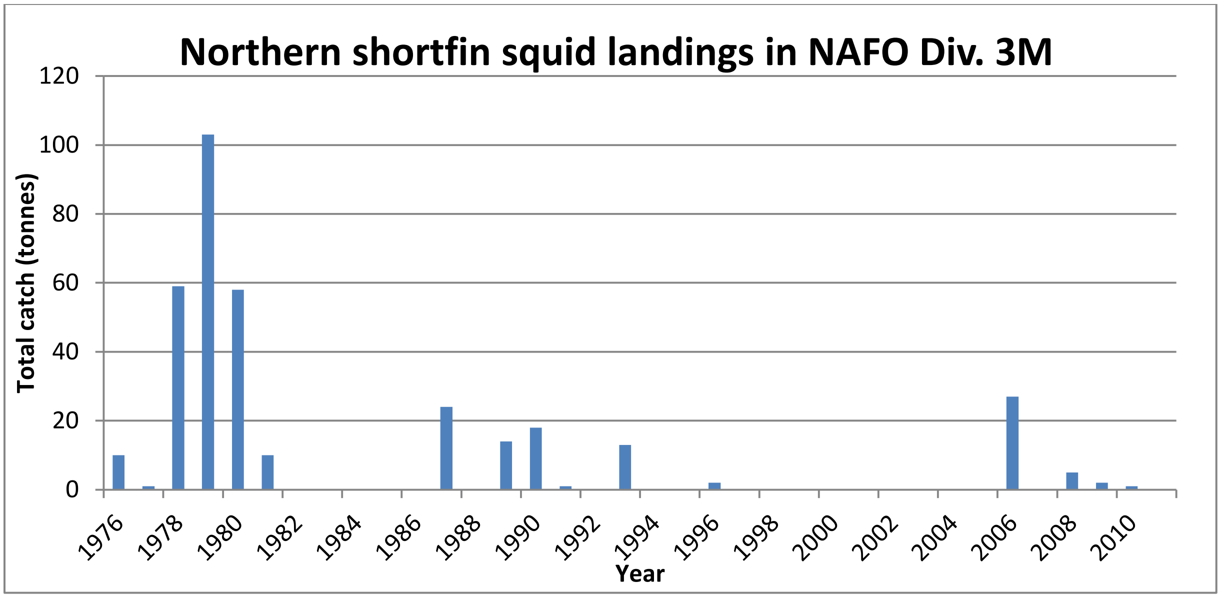


Figure 17 Historical Northern shortfin squid landings from the Flemish Cap 1960-2012. Squid has not been a major resource in Division 3M, as environmental parameters are not conducive to squid growth. Source: NAFO STATLANT 21A Fisheries Database.

2.3.4 Trophic dynamics and apparent trade-offs in biomass production

Aside from the influence of abiotic regulators, complex marine ecosystems are governed by multiple modes of biological control. Top-down (predation) and bottom-up (resource availability) limiting processes shape system identity and production on the Flemish Cap; understanding how these mechanisms function in different environmental contexts is essential when designing appropriate policy response to climate shifts.

2.3.4.1 BOTTOM-UP REGULATION

As mentioned earlier, global fisheries production is ultimately tied to global primary production (Pauly & Christensen, 1995; Chassot, et al., 2010). Although a concrete relationship between primary production levels and system production has not been established, fisheries variability has been linked to composition of the plankton community (Maillet et al., 2005). Runge (1988) found that in the North Atlantic, cod and redfish productivity is strongly tied to primary production in areas where *C. finmarchicus* is the abundant copepod, but primary production and biomass in higher trophic levels is weakly linked when smaller copepods are the most abundant energy source. On the Flemish Cap, environmental factors have been found to influence composition of the copepod community, with consequences for predator-prey dynamics in trophic levels that rely on this forage base (Maillet et al., 2005).

2.3.4.2 Top-down regulation

These regulating processes can result from, as well as contribute to, shifts in community dynamics. Interactions between cod and shrimp are a prominent example of regulation via predation on the Flemish Cap. Cod is an apex predator in the system, with shrimp constituting an important food source for the animal (Worm & Myers, 2003; Parsons, 2005; Casas, 2012; Iglesias & Casas, 2012). As shrimp biomass increased in the Northwest Atlantic, predation by cod was found to increase (Iglesias & Casas, 2012); this predation peaked between 1999-2008, which was directly followed by a decline in shrimp biomass (Casas, 2012). A diagram comparing the biomass fluctuations of shrimp and cod on the Flemish Cap is provided in Figure 18.

Both cod and shrimp populations are influenced by the nature of their relationship as well as environmental factors. An apparent productivity trade-off exists here.

Figure 18 shows the biomass fluctuations of this predator-prey couple. Through the 1990s cod biomass fell, while shrimp biomass increased. Once cod biomass rebounded, predation on shrimp increased and we see an increase in cod. It appears that trophic interactions preclude both species from experiencing elevated biomass levels simultaneously.

Within this context, Frank et al. (2005) noted that such apparent alternate state ecosystems, even if providing economically favourable conditions (as was the case when shrimp landings increased), should not be preferable to original state systems if the biological and/or functional diversity of the system is compromised (through the effects of overexploitation of top predators such as cod, for example). However, the example from the Flemish Cap (Figure 18) indicates an apparent reversal in recent years, which strongly suggests that the trophic effects of exploitation can be reversed in some systems.

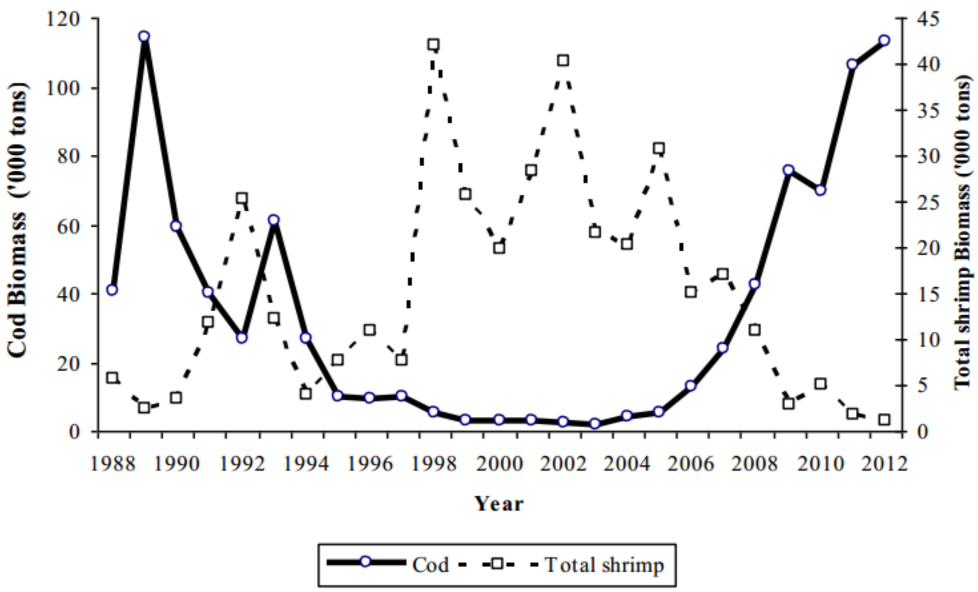


Figure 18 Cod (solid line) and shrimp (dotted line) biomass estimates for the Flemish Cap region. Data obtained from EU survey trawls 1988-2012 (from Casas, 2012).

The system productivity trade-off between cod and shrimp has not gone unnoticed by policy makers- with an eye on increased predation by cod resulting in poor recruitment, and unfavourable environmental conditions, the shrimp fishery in 3M has been placed under a moratorium since 2011 (Casas, 2012).

2.3.5 Environmental influences on trophic dynamics

Annual variations in the processes that impact primary and secondary production have long been thought to cascade up food webs and impact recruitment of commercial fishes (Parsons, 1975; Cushing, 1982; Runge, 1988).

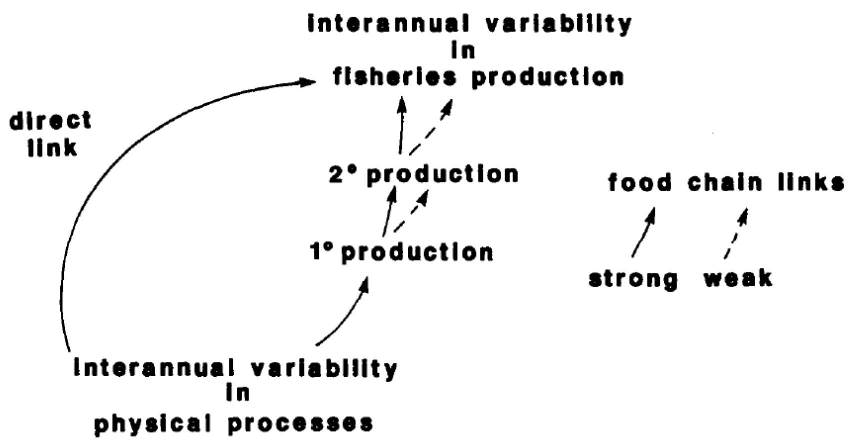


Figure 19 A flowchart indicating the strength of the ecological and environmental relationships that drive variations in annual fisheries production (from Runge, 1988).

As discussed in Chapter 2.3.1, the presence of specific copepod species is determined by environment conditions, with implications for the predator-prey dynamics in higher trophic levels (Maillet et al., 2005). A graphic interpreting how environmental variability influences production leading to variability of fisheries output is provided in Figure 19. An example of environmentally-driven ecosystem impacts elsewhere in the Northwest Atlantic is provided in Table 4.

Table 4 Environmentally-induced changes in capelin biology in the Northwest Atlantic (Carscadden et al., 2001).

	Prior to 1990 (baseline)	After 1990
Distribution	Centred in Newfoundland	Southward shift from Labrador; expansion to Flemish Cap (east) and Scotian Shelf (southwest)
Growth	Population mean body size large	Population mean body size small
Time of spawning	June	Late July – August
Natural mortality	High	Low
Recruitment	Variable	Variable and uncertain

Shifts in cod biomass can result in shifted predator-prey dynamics, with trophic rearrangement possible in extreme circumstances (Frank et al., 2005). As cod stocks are limited (in part) by food availability (another example of bottom-up regulation), they may experience biomass shifts when energy sources fluctuate. It has been noted that redfish, calanoid copepod, and shrimp abundance are subject to environmental conditions; since these species are important food sources for adult and juvenile cod (Konstantinov, et al., 1985; Albikovaskaya & Gerasimova, 1993; Rodriguez-Marin, et al., 1994) environmental shifts driving prey biomass would likely reverberate through cod stocks.

Environmentally driven trophic effects have been shown elsewhere in the North Atlantic, as in Iceland, cod biomass is dependent on capelin (bottom-up control), and capelin biomass is dictated by environmental conditions rather than predation pressure (Carscadden et al., 2002). Determining the exact correlations between stock sizes and environmental conditions is difficult as other factors, including fishing effort and gear type have frequently changed (Mann & Drinkwater, 1994), although ecologically and commercially important species such as shrimp, squid and haddock have been identified as species in the Northwest Atlantic whose distribution and recruitment are impacted by environmental variables (Mann & Drinkwater, 1994). While it has been difficult to attribute ecosystem fluctuations in a discrete manner to either fishing practises or environmental shifts, and the exact impact to predator-prey relationships are difficult to quantify, there is clear evidence that environmental context can determine the availability of energy supplied by forage species, with ramifications for the biomass of adjacent trophic levels.

2.4 SUMMARY

Despite its relatively small area, the Flemish Cap has traditionally been one of the most highly productive areas in the Northwest Atlantic Ocean. The Cap's unique combination of temperature, salinity, depth, current influence and nutrient availability, among other factors, has enabled tremendous production throughout the system. But fisheries production is not a constant- species, system and ocean productivity fluctuate as environmental context dictates. Poor productivity conditions and increased mortality have been identified as drivers of low productivity eras in the Northwest Atlantic, and production rates on the Flemish Cap have not been immune (Shelton et al., 2006). The nature of this production has varied over longer timescales, as environmental conditions select for or against particular species, controlling mechanisms, and regimes. This section has provided a qualitative summary of the factors at play on the Cap- further review of historical environmental trends and their impacts to the Flemish Cap's various commercial species will be discussed in the following sections, along with the drivers of management decisions.

CHAPTER 3. HISTORICAL OCEANOGRAPHIC CONDITIONS ON THE FLEMISH CAP (1950-2000)

3.1 INTRODUCTION

To determine if environment changes can be linked to tangible alterations in Flemish Cap management policy, long term oceanographic trends must be compared with biological shifts and management response on comparable timescales. As the focus of this discourse shifts to the historical community of the Flemish Cap, it is prudent to consider the environmental context that influenced the identity of the ecosystem. This chapter summarizes the environmental conditions in the area between 1950 and 2000, fulfilling the first of these criteria; long-term reviews of the biological community and management will be presented in Chapters 4 and 5.

3.2 Historical conditions

3.2.1 Temperature and Salinity

Just as contemporary ecosystems exist as a function of environmental context, historical systems were a product of the conditions of their era. The large scale oceanographic patterns in the North Atlantic produced similar patterns of variation from historical averages on the Grand Banks and Flemish Cap in the decades following the Second World War (Colbourne, 2004).

It has been noted thus far that temperature is an important variable influencing species growth, geographic distribution and abundance in marine ecosystems, with implications for the relationships between trophic levels throughout the web.

In a review of long-term oceanographic conditions on the Flemish Cap, Colbourne and Foote (2000) compiled temperature and salinity data, and appropriated it over seasonal, annual and inter-decadal scales. Mann and Drinkwater (1994) noted that temperature and salinity levels appear to be the most important environmental factors influencing cod stocks; as such, average seasonal temperature and salinity fluctuations at the sea surface of the Cap are provided in Figure 20 and Figure 21, respectively.

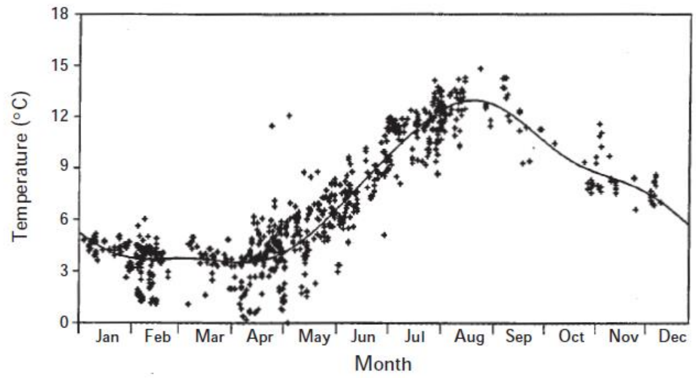


Figure 20 Sea surface temperature averages by month in the Flemish Cap area (from Colbourne and Foote, 2000). The solid line is a least-squares regression to the seasonal cycle.

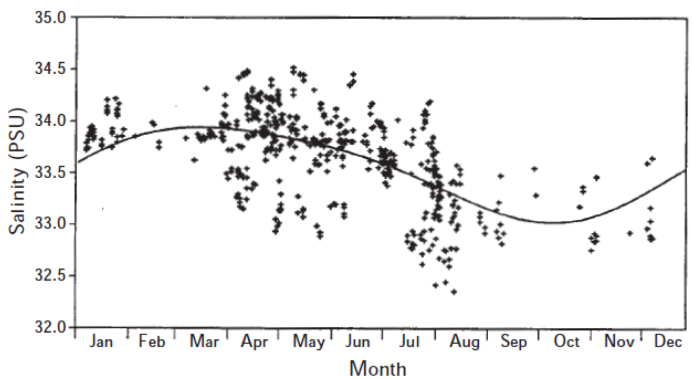


Figure 21 Monthly sea surface salinity averages by month in the Flemish Cap area (from Colbourne and Foote, 2000). The solid line is a least-squares regression to the seasonal cycle.

Just as year to year changes in the water properties can result in short-term variations in productivity, long-term shifts in oceanographic conditions can have profound effects on productivity as well. The sea temperature at various depths from 1950-2000 is shown in Figure 22; the salinity variance over the same time frame is shown in Figure 23.

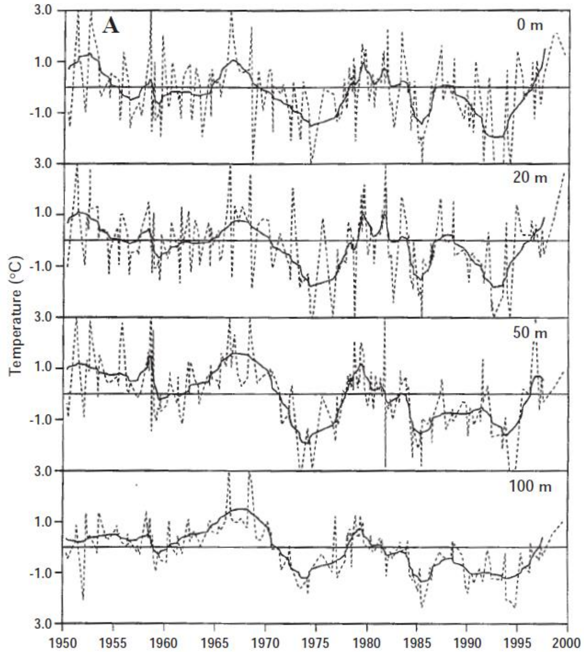


Figure 22 Flemish Cap temperature anomalies from 1950-2000 at various depths (from Colbourne and Foote, 2000). Anomalies are measured relative to the average temperature on the Cap from 1961-1990.

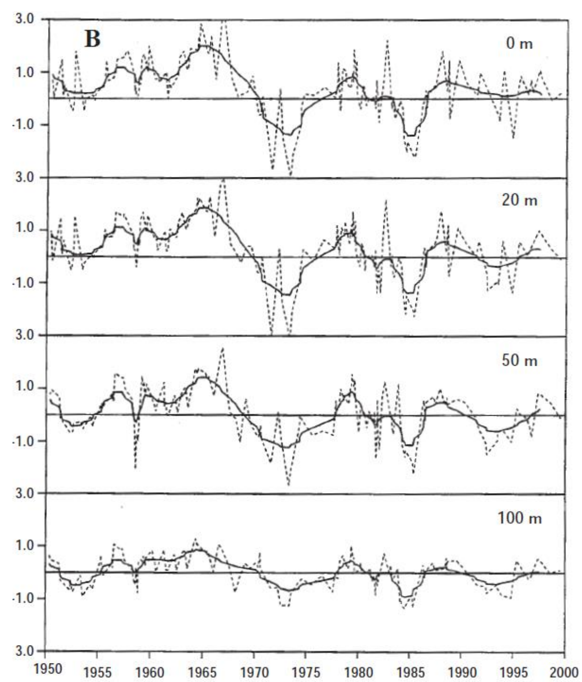


Figure 23 Flemish Cap salinity anomalies from 1950-2000 at various depths (from Colbourne and Foote, 2000). Anomalies are measured relative to the average salinity on the Cap from 1961-1990. The Y axis represents Practical Salinity Units.

Figures 22 and 23 contain important information regarding the historical oceanographic conditions that undoubtedly influenced the biological community on the Cap through different environmental eras. It is important to note that these figures depict temperature anomalies (specifically, in this case anomalies are compared to the average conditions from 1961-1990) rather than actual system temperature. Presenting information in this manner serves to highlight important shifts that may not be as visible or apparent when expressed over greater scales.

These data have been presented in Figure 24 after being averaged out and the depth variable removed. Four temperature trends can be seen in this figure- a relatively warm period starting in the 1950s and continuing for the majority of the 1960s, and three colder than normal periods in the 1970s, late 1980s and early to mid-1990s (Colbourne & Foote, 2000).

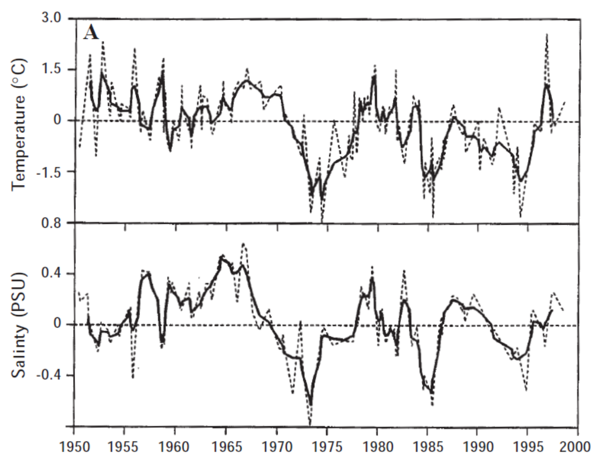


Figure 24 Vertically averaged temperature and salinity anomalies across the Cap region 1950-2000 (from Colbourne and Foote, 2000). The zero line is the average temperature and salinity for the period 1961-1990.

From this figure, it is apparent that important parameters determining system output have fluctuated in the Cap region over decadal timescales. According to Umoh et al. (1995), 77% to 89% of the variance in the annual temperature on the Newfoundland Shelf can be attributed to local air-sea heat flux, but a similar link has not been drawn over decadal scales (Colbourne & Foote, 2000). A likely explanation for the root driver of environmental fluctuations on sub-decadal timescales appears to be the NAO, which has been identified as an important cause of environmental shifts in the Northwest Atlantic (Petrie, 2007).

3.2.2 CURRENTS

Current positions fluctuate over different timescales; the average position of the North Atlantic Current is shown in Figure 25. The meander patterns of the current are persistent with differing seasons and over multiple decades (Kearns & Rossby, 1998). As this current is partially responsible for nutrient transport to the Cap region, changes in its path and distance to the Cap (and the anticyclonic gyre that maintains nutrient rich water) influence the nutrient availability to the Cap system. Changes in the relative influences in source waters (Labrador vs. North Atlantic Currents) may also be evident in the dynamics illustrated in Figure 22, as warm, salty conditions (vs. cold, fresh) are evident in different years.

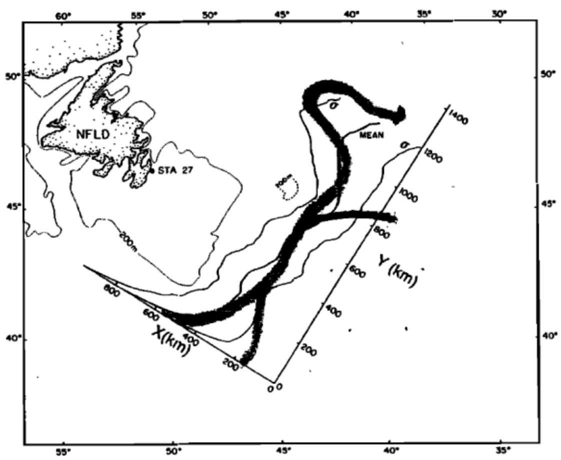


Figure 25 The average path (thick lines) and standard deviation (thin lines) of the North Atlantic Current (from Kearns & Rossby, 1998).

3.2.3 BENTHIC/SEDIMENT CONDITIONS

There is no mention in the literature of a documented shift in the sediment conditions in the Cap region from 1950-2000. However, benthic and sediment conditions during the last ice age are of some interest here. Shaw (2006) found that although the Cap is a shallow-water environment with hard substrates (making it a likely candidate for glaciation), the area was free of ice cover during the last glacial period. As such, the Cap may have provided a refuge from glacial conditions to the flora and fauna of the time (Shaw, 2006).

Continuing with Shaw's (2006) characterization of the Cap's terrain, the seafloor is rugged with sediment ranging from bouldery gravel to coarse sand, with evidence of iceberg pitting.

3.2.4 Historical strength of the North Atlantic Oscillation

Chapter 2.2.3 briefly touched on the importance of the North Atlantic Oscillation on the environmental parameters that dictate system productivity on the Flemish Cap. Figure 26 (Stenseth et al., 2002) demonstrates the variability in the NAO since 1860.

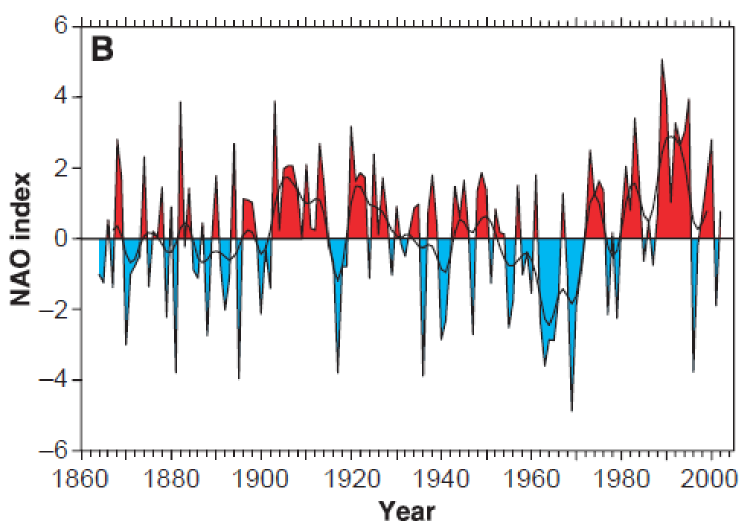


Figure 26 Historical values for the NAO index (from Stenseth, et al., 2002). The Y axis measures historical NAO variation by the number of standard deviations from the historical mean.

As was shown in the conceptual model (Figure 6), good recruitment and productivity in the Northwest Atlantic is associated with a strongly negative NAO index where relatively low convective mixing in the Labrador Sea leads to warmer more saline conditions downstream in the Newfoundland and Labrador regions and in the vicinity of the Flemish Cap. In contrast, poor recruitment and productivity is associated with strongly positive indices that are indicative of increased mixing and cold, fresh conditions downstream.

Figure 26 therefore indicates that the 1940s to early 1970s, along with short periods in the mid-late 70s were eras where NAO conditions were most conducive to groundfish production in the Northwest Atlantic.

According to Visbeck et al. (2001) the NAO has shifted from mostly negative to mostly positive index values from 1970-2000. There is a clear lack of consensus on the mechanisms that are responsible for variations in the NAO, with surface, stratospheric and anthropogenic processes suggested as sources influencing its phase and amplitude (Visbeck et al., 2001).

3.3 Summary

Environmental trends that range in length from seasonal to inter-decadal heavily influence North Atlantic waters. Temperature and salinity trends, driven by the large-scale North Atlantic Oscillation provide a shifting stage for the biological community. Seemingly separate variables are connected through the NAO, whose influence is consistent, but varies in degree and polarity. How specific environmental contexts have impacted individual biological components and the system as a whole will be analysed in the following section.

Chapter 4. Flemish Cap fisheries history and management structure from European arrival to the year 2000

4.1 Introduction

As the goal of this discourse is to investigate how changing oceanographic conditions on the Flemish Cap relate to changes in the biological community and management atmosphere, a historical overview of the Cap's fishery and management will now be provided that spans the area's timeline as an important fishery resource.

The prominence of the various commercial resources will be discussed for five different eras, with a stronger focus on the three temporal divisions since 1960. The focus will be more detailed for recent history as comprehensive landings data are provided by NAFO only since 1960 (Figure 27), and also because this timeframe encompasses the majority of the major industrial fisheries efforts in the Cap region.

Quick synopses of the biological community starting before the arrival of Europeans, continuing through the Industrial Revolution until 1960 will provide a long term picture of the area. Landings data for the major commercial species have been provided in Chapter 2.3.3, but will be included in the form of relative contribution to total industry activity by species for the periods 1960-1976, 1977-1999, and 2000-2012.

These temporal delineations are not arbitrary. The first window spans the start of comprehensive landings data for the area until Canada's declaration of a 200 nautical mile Exclusive Economic Zone (EEZ), which occurred 01 January 1977. The second window starts at this date and continues until the end of 1999, coinciding with the end of a cooler than normal period in Cap water temperature (Colbourne et al., 2012). The third window runs from 01 January 2000 until the end of 2012, the most recent year for which landings data are available.

Although selecting Canada's declaration of a 200 nautical mile EEZ is intuitive and seemingly provides a neat division, this introduces some complexities where the Flemish Cap is concerned. As the international fleet lost access to productive areas now in Canada's EEZ (specifically, the Grand Banks), effort was relocated to the Nose and Tail of the Grand Banks and the Flemish Cap, which remained in NAFO-regulated waters. Member and non-member states quickly exceeded TAC levels in these areas (Anderson, 1998). Although exclusive access to the 200 mile zone was obtained by Canada, there have been allocations of catch shares to some countries for stocks in Canada's jurisdiction (Anderson, 1998).

Unfortunately, fish stocks do not always neatly comply with anthropogenically designed boundaries. This is particularly true for highly migratory species, complicating the work of organizations responsible for their management, but a degree of this complexity exists in the comparatively sessile stocks of the Northwest Atlantic. Legal jurisdictions are rarely solely designed around fisheries resources, and the extension of Canada's EEZ created straddling stocks (stocks that are divided into different management zones, 'straddling' jurisdictional boundaries).

Straddling stocks create difficulties for managers. Fish mobility precludes concrete estimates of how animals (or biomass) are distributed between jurisdictions. Even if distribution estimates are made, they are likely to be obsolete in future periods. This has implications for how quotas are divided, as disproportional allocation between jurisdictions relative to the size of fish stocks creates biological, ecological and economic inefficiencies.

There are complications for data collection as well. Neighbouring management bodies may have different guidelines or requirements governing data collection, sharing, transparency and enforcement. Data asymmetries reduce management confidence and efficiency, creating liabilities for stock health.

These complexities exist in NAFO's Convention Area. Canada's EEZ claim creates straddling stocks on the Grand Banks due to the 'nose' (NAFO Div. 3L) and 'tail' (NAFO Div. 3N)of the Bank extending beyond 200 miles from shore (Figure 7), resulting in different organizations being responsible for the health of the same stock. The stocks that straddle Canada's EEZ and NAFO's Convention Area are Northern shrimp (Div. 3LNO), Northern shortfin squid (Div. 3+4), Greenland halibut (Subarea 2 and Div. 3KLMNO), witch flounder (*Glyptocephalus cynoglossus*) (Div. 2J+3KL), white hake (Div. 3NOPs), thorny skate (*Amblyraja radiata*)(Div. 3NOPs) redfish (Div. 3O), capelin (Div. 3NO), witch flounder (Div. 3NO), yellowtail flounder (*Limanda ferruginea*) (Div. 3LNO), American plaice (Div. 3LNO), redfish (Div. 3LN), and cod (Div. 3NO).

These problems have not been easily solved by NAFO and Canadian management. Joint management of straddling stocks failed to prevent stock depletion due to a lack of capacity to enforce TACs, allocations and technical regulations (Day, 1995).

Redrawing Canada's national jurisdiction created straddling stocks between Canada's EEZ and NAFO's Convention Area complicates the decision to use 01 January 1977 as a dividing point. Although multinational scientific cooperation and shared resource management have been areas where NAFO has achieved positive results (Anderson, 1998), differing fishing practices and conditions in the adjacent jurisdictions are not reflected in record keeping, limiting data relevance and impairing future regulatory innovation (Halliday & Pinhorn, 1990).

The 1977-2012 era has been divided in this manner is because the end of the 20th century coincides with the end of a cool period on the Flemish Cap. Commencing a comparative era at the start of a documented shift in environmental trends is a convenient way to align catch data and policy events with environmental cues, improving contrast and comparative assessment.

Though perhaps imperfect, dividing the last four plus decades in this manner assists this paper in its goal of determining to what extent, if any, environmental fluctuations have influenced the management and policies that regulate human activity on the Flemish Cap, and how capacity to deal with such fluctuations has changed.

4.2 Biological conditions prior to European arrival

As detailed landings record keeping is a relatively new practise, the makeup of the biological community in the Northwest Atlantic before European arrival can only be hypothesized. Section 3.2.3 noted Shaw's (2006) theory that the Flemish Cap may not have experienced the glaciation pressure found elsewhere in the North Atlantic, making the area a candidate for a underwater species refuge; this doesn't speak to the ecological identity of the system or even the presence of particular species, but does suggest that the area has been continuously populated over geological timescales. Recent findings that Flemish Cap cod are somewhat genetically intermediate between Northwest and Northeast

Atlantic populations (Bradbury et al., 2013), contribute to the notion that the Flemish Cap may have been a glacial refuge (or bridge) between populations over larger spatial scales.

John Cabot's arrival in Newfoundland marked the first European presence in what would become Canada since the Vikings settled in L'Anse aux Meadows, and the anecdotes he brought to England served as the evidence used by many seafaring European countries to set up temporary fishing communities in Newfoundland. The Grand Banks was the target of most of this effort, as the Flemish Cap was isolated and perhaps small enough that technological limitations prevented significant exploitation. This remained the case until fleets became powered by steam rather than wind, an innovation of the Industrial Revolution.

4.3 Biological conditions from the Industrial Revolution to 1959

The Industrial Revolution was an era originating in the United Kingdom where technological advancements and automation improved quality of life and allowed for significant population growth. Technological advances were experienced by the global fishing fleet during this time, and fishing vessels increasingly changed from sail-powered to steam-powered and grew in size. These advancements, in combination with improved gear design, increased capacity to catch (and store, by salting) cod. The combination of longer fishing trips and increased ability to access the remote region transformed the Flemish Cap region from one of minor importance to one of significant fisheries yield by the end of the 1940s. Effort and landings became intense enough after the Second World War that resource stability was questioned, resulting in the formation of the ICANF in the mid-20th century (Anderson, 1998).

4.4 SUMMARY OF COMMERCIAL LANDINGS FROM 1960-2012

The six species on the Flemish Cap that have been the focus of directed industry effort are noted along with their historical landings data in Chapter 2.3.3. Although landings summaries will be provided later that divide this information into the previously noted eras, the following figure has been included to show the relative contribution of the various commercial species to total landings since 1960 (Figure 27). From this figure it is clear that industry effort has been opportunistic in its aim, changing focal species as yield of initial targets decreases, yet the overall catch has tended to vary within wide boundaries and has in recent years been among the lowest in the time series.

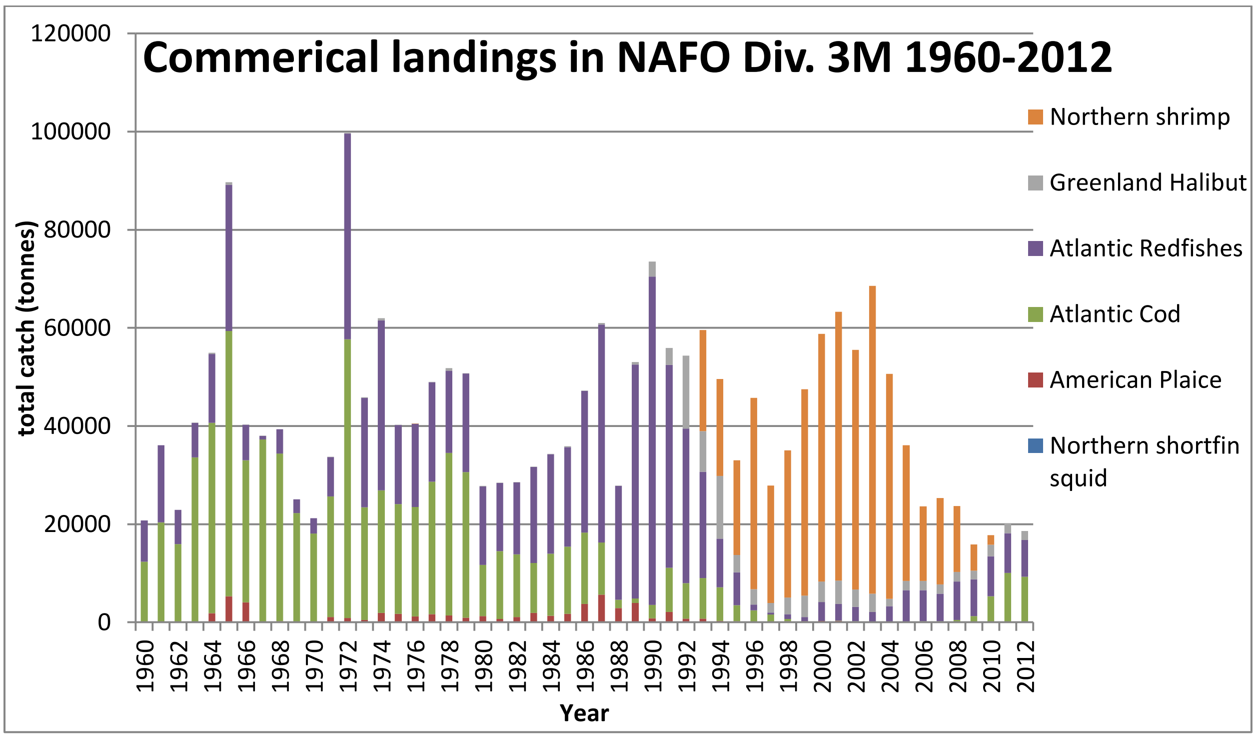


Figure 27 Historical landings of the six major commercial species present on the Flemish Cap, 1960-2012. Source: NAFO STATLANT 21A Fisheries Database.

4.5 Biological conditions 1960-1976

4.5.1 Overview

The end of the Second World War meant the seas were once again safe for passage, and the increase in technological capabilities, combined with relatively uninformed management (see Chapter 5.3.3) made the 1950s-70s an era where effort and landings increased dramatically. Some of the biggest annual cumulative landings were recorded in this period (see Figure 27 and Figure 28).

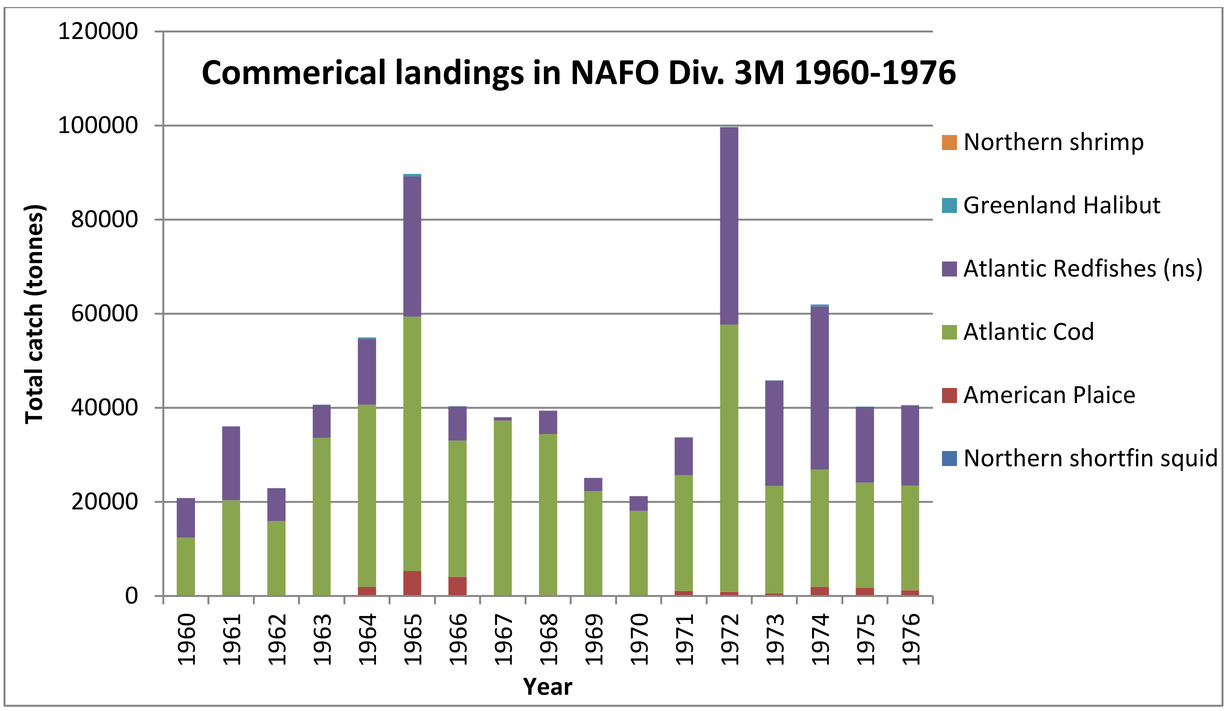


Figure 28 Landings of major commercial species from the Flemish Cap 1960-1976. Cod and redfish dominated the landings for the era, with American plaice represented in landings data to a much smaller extent. Source: NAFO STATLANT 21A Fisheries Database.

4.5.2 Atlantic cod

In the period 1960-1976, cod made up the majority of landings (63% of all landings). Peak annual catches were recorded in 1965 and 1972, partly due to the level of effort in the area, but also because oceanographic conditions favoured cod production throughout the 1960s. A strongly negative NAO index was observed during this decade (Figure 26), driving recruitment through higher temperatures and salinity (see Figure 6), as well as egg and larval retention through a strong anticyclonic gyre.

4.5.3 Redfish

Devine and Haedrich's (2011) model showed that redfish populations on the Flemish Cap are a function of bottom temperature and fisheries catch. These determining factors were found to have a delayed response time of one and three years, respectively, with the Flemish Cap redfish stocks more affected by environmental conditions and prone to longer lag times than other redfish stocks of the Northwest Atlantic (Devine & Haedrich, 2011).

Redfish catches, as evident from Figure 28, constituted an important ratio of total landings in the Cap region during this time, especially in the early part of each decade, when NAO values were negative and temperature anomalies in the region trended warmer.

4.5.4 American plaice

Perhaps the most productive years for American plaice occurred in the 1960-1976 era, with peak landings of about 5 000 tonnes in 1965 and just over 4 000 tonnes in 1966. Landings subsequently dropped below 2 000 tonnes until the 1980s. Rather than targeted by a direct fishery, the majority of American plaice landings on the Cap have resulted from bycatch in the cod and redfish fisheries (Bowering & Brodie, 1994).

4.5.5 Northern shrimp

Northern shrimp were not a major commercial species in this timeframe. Aside from a 27 tonne harvest by Spain in 1976, there were no recorded landings of the animal between 1960 and 1976. This was the result of the environmental and biological contexts of the era;

shrimp habitat is at least partly determined by abiotic variables, including temperature and salinity (Parsons et al., 1998). Shrimp recruitment and landings have been inversely linked to sea water temperatures (Appolonio et al., 1984), and as the 1960s and early 1970s were warmer with higher than average salinity, the area was not suitable for substantial shrimp production.

The biological characteristics of the area during this time were not optimal for shrimp growth either. In addition to thermal and saline boundaries, Northern shrimp populations are regulated in the North Atlantic via predation (Koeller, 2000). Shrimp constitute an important food source for cod in 3M (Paz Canalejo et al., 1989), and the cod-dominated ecosystems of this era controlled shrimp populations through predation and top-down control (Worm & Myers, 2003).

4.5.6 Greenland halibut

Greenland halibut landings from the Flemish Cap were essentially inconsequential between 1960-1976 (see Figure 16, Figure 28). Cod and redfish dominated the landings of the era, and Greenland halibut, although subjected to minor fishing effort since the mid-1800s, was a less profitable fishery than cod, and therefore did not receive significant industry attention on the Cap until the 1990s (Bowering & Nedreaas, 2000).

4.5.7 Northern shortfin squid

As previously noted, the waters of the Flemish Cap provide marginally acceptable habitat for Northern shortfin squid (Hendrickson & Showell, 2010). Annual landings on the Cap have been a fraction of other commercial species, and in the 1960-1976 timeframe the only squid landings were reported by Portugal and totalled 10 tonnes (see Figure 17).

4.5.8 Overall system stability 1960- 1976

From the landings data presented in Figure 28, and assuming that landings data are somewhat representative of abundances, it appears that the community structure on the Flemish Cap was stable between 1960 and 1976. Landings in all years presented were predominantly accounted for by cod (63% of all landings) and redfish (31% of all landings). Compared to other eras, target species remained static for the duration of the period.

While exploitation rates in this era may have been unsustainable, the combination of fishing effort and focus, oceanographic conditions and regulatory regime did not result in apparent shifted community dynamics, nor were population crashes experienced. Landings dropped off towards the end of the era, coinciding (after the lag period is considered) with a positive shift in the NAO index.

4.6 Biological conditions- 1977-1999

The era following Canada's declaration of a 200 nautical mile EEZ and subsequent dissolution of ICNAF saw dramatic changes in the Northwest Atlantic. Based on landings information, clear shifts occurred in this era, in terms of system productivity as well as community structure and dynamics. Landings data for this 23 year period are presented in Figure 29.

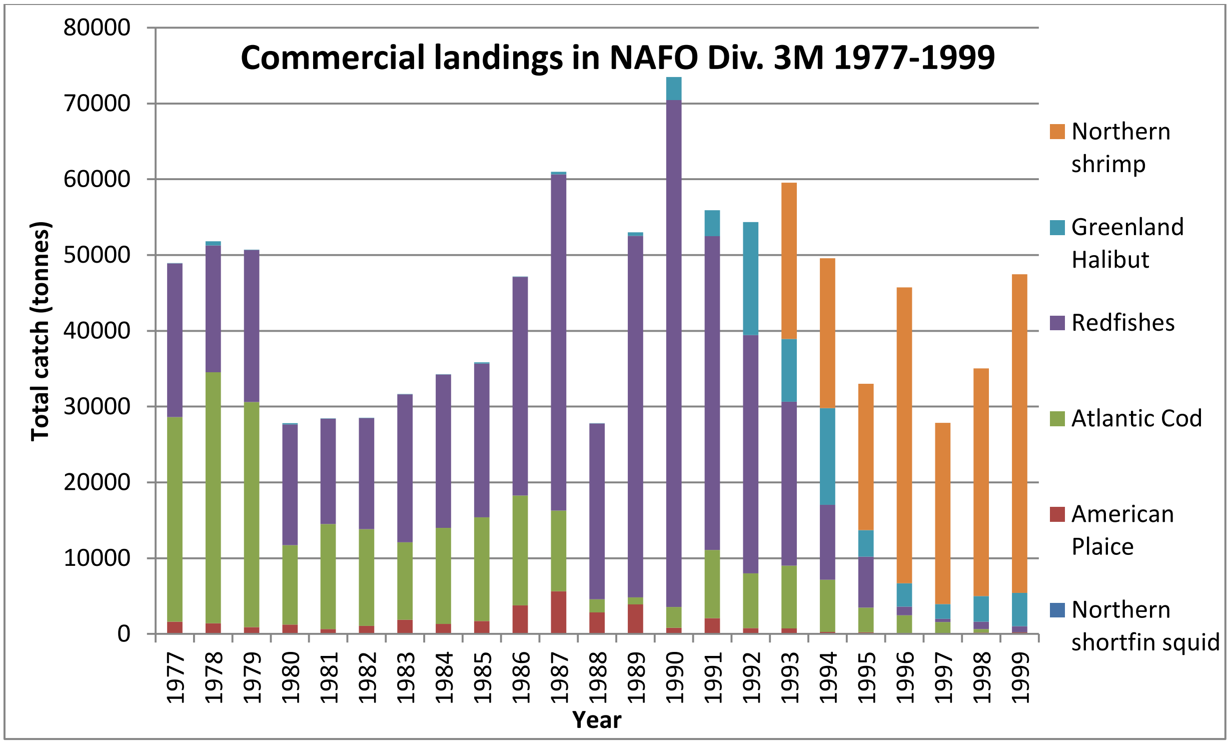


Figure 29 Landings of major commercial species from the Flemish Cap, 1977-1999. There are clear changes in catch trends depicted here; early in the era cod accounted for the majority of landings, with redfish landings dominating catch totals in the mid-1980s to early 1990s. A second shift in landings dominance occurred starting in the early to mid-1990s, when Northern shrimp landings accounted for the majority of landings. Major changes in the species that account for landings is an indicator of ecosystem instability. Source: NAFO STATLANT 21A Fisheries Database.

4.6.1 Atlantic Cod

Perhaps the most dramatic shift in the Flemish Cap's known history was the drop in cod landings in the late 1980s and early 1990s. This stock collapse is well documented, and followed a similar if not more striking decline on the adjacent Grand Banks. Although the decline in landed cod is obvious within this timeframe, it is considerably more apparent when the large landings recorded in previous decades are considered.

The collapse of the stock's biomass has been largely attributed to overfishing (Hutchings and Myers, 1994; Hutchings & Myers, 1994), but environmental factors have also been identified as contributors (Drinkwater, 2002). A strongly-positive NAO in the 1980s and 1990s was accompanied by a colder and less saline than average period (see Figures 22, 23 and 26), conditions counterproductive for cod growth. Regulation of the Cap's cod stock started in 1980 (NAFO, 2011b) with the installation of a TAC (set at 10 280 t), and increased in 1993 through a minimum fish size requirement (see Table 7); a moratorium was placed on the 3M cod fishery in 1999.

Stock biomass for 3M cod between 1988 and 1998 is provided in Figure 30.

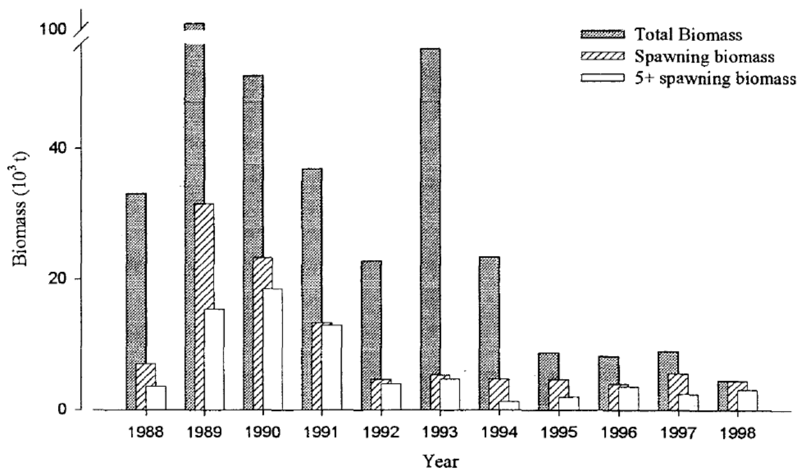


Figure 30 Atlantic cod stock biomass estimates for the Flemish Cap, 1988-1998 (from Saborido-Rey & Junquera, 1999). Estimates for total biomass, spawning biomass and 5+ spawning biomass are included together to provide a sense of age composition and future recruit classes.

4.6.2 Redfish

Redfish had been an important throughout the 1977-2012 timeframe, with redfish landings being similar to cod in the early to mid-1980s. The collapse of cod removed the traditional primary target of the Flemish Cap fishery, so industry focus intensified on redfish stocks in the late 1980s. Landings of *Sebastes* spp. increased dramatically in the late 1980s and early 90s, both in total catch and as a percentage of total Cap landings. The shift to redfish was most apparent in 1990, when redfish landings comprised 91% of the total landings for the six major commercial species on the Cap. This total (>60 000 t) was well above the maximum sustainable yield. Subsequently, fishing effort, stock biomass and Total Allowable Catch (TAC) declined quickly and substantially in the following years (Ávila de Melo et al., 2002).

Redfish abundance and biomass estimates from the late 1970s to early 2000s are shown in Figure 31.

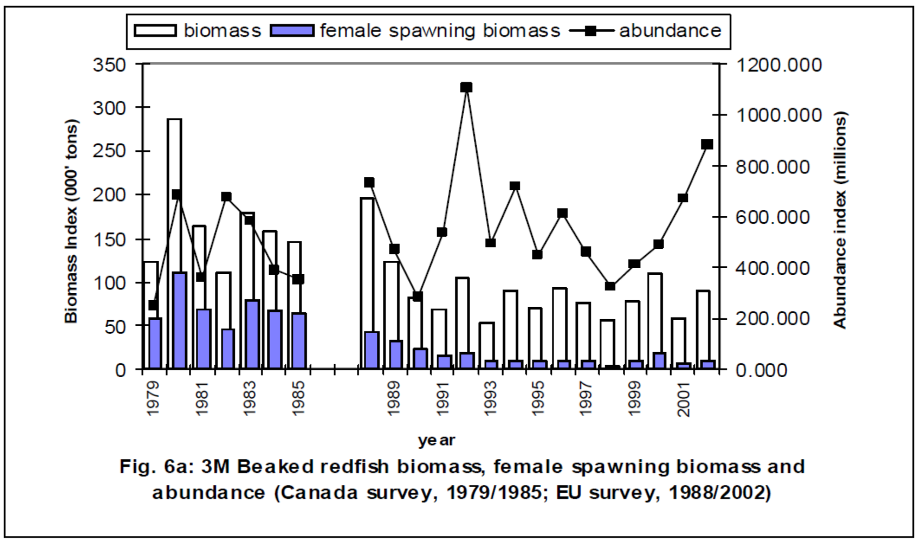


Figure 31 Biomass and population estimates for Flemish Cap redfish stock from 1979 to 2002 (from Ávila de Melo, et al., 2002).

4.6.3 American Plaice

First appearing in NAFO's Annual Quota Table in 1980, American plaice landings dropped considerably as stock concerns grew. Landings exceeded TAC levels in the late 1980s, with landings in 1987 reported at 2.5 times the allowed level. Allowable catch fell below 1 000 tonnes from 1992 onward (Figure 32), and a moratorium on the stock was implemented in 1995 (NAFO, 2011b).

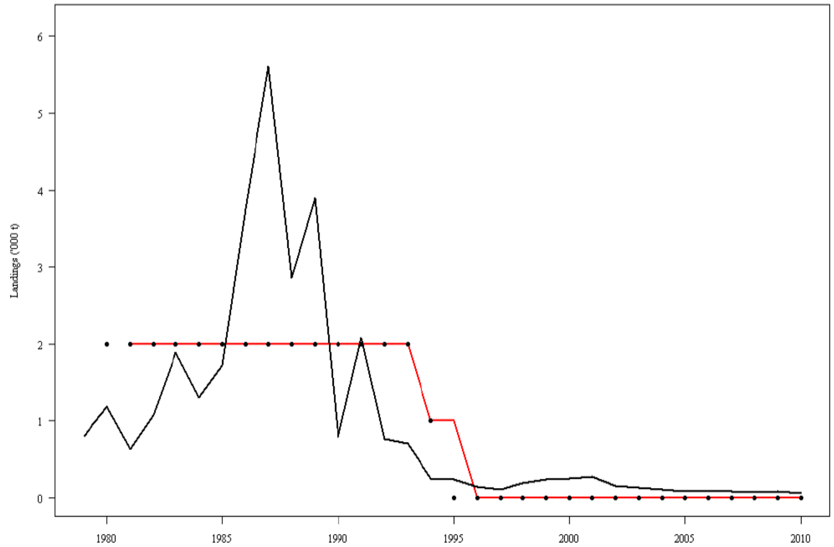


Figure 32 American plaice catches (black line), recommended TAC (black dots) and implemented TAC (red line) for NAFO Div. 3M (from NAFO, 2011a).

4.6.4 Northern shrimp

Following the collapse of 3M cod and the decreasing stock size and TAC for redfish coinciding with environmental conditions beneficial for shrimp growth, a fishery targeting Northern shrimp formed.

After decades of low shrimp productivity on the Flemish Cap, stock biomass and landings increased dramatically in the 1990s. Decimated cod populations lowered natural mortality in shrimp stocks through decreased predation (Lilly, et al., 2000; Worm & Myers, 2003), and a strongly positive NAO, combined with lower temperatures and salinity produced favourable conditions for shrimp on the Cap. The animal quickly changed from an insignificant resource to one that dominated landings totals in the area for a number of years.

Biomass estimates for shrimp were not conduced until 1988. Biomass estimates from this point until the mid-1990s are provided in Figure 33.

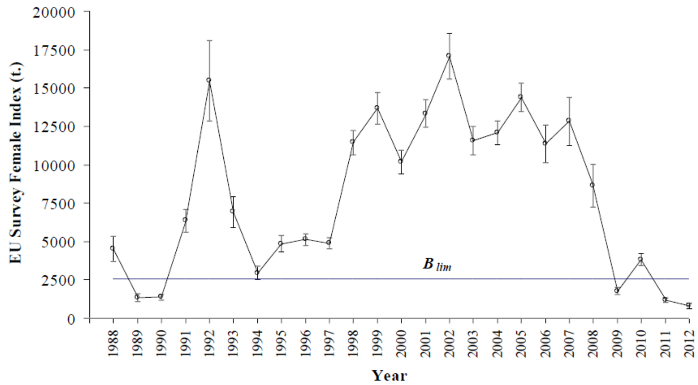


Figure 33 Female shrimp biomass estimates 1988-2012 (from Casas, 2012). The B_{lim} line is a stock reference point equal to an 85% decline versus shrimp's maximum observed level.

4.6.5 Greenland halibut

The late 1980s through late 1990s was the first period where Greenland halibut was targeted by substantial direct effort, as the species had become a priority for some countries in all NAFO Divisions (Ávila de Melo et al., 2002). Regulatory efforts focused on halibut starting in 1995, with dependable biomass estimates being produced for 3M starting in 1996; biomass estimates decreased from 10 175 tonnes in 1996 to 2 408 tonnes in 1999 (Bowering, 2000).

4.6.6 Northern shortfin squid

Northern shortfin squid landings peaked in the late 1970s (the early portion of the selected timeframe) at around 100 tonnes. It is clear from Figures 27, 28 and 30 that even during peak years, squid landings did not represent a substantial percentage of ecosystem exploitation. As with the 1960-1976 era, the waters of the Flemish Cap were not conducive to squid biomass growth, resulting in low landing totals.

4.6.7 Overall system stability during 1977-1999

It is obvious that the compositional stability of the Flemish Cap's fisheries landings was very low in this time period. Primary target species shifted from cod to redfish, and then again to shrimp. Landings, direct effort and biomass of cod and redfish declined so substantially that by the late 1990s, these species which had once dominated the ecosystem and catch totals represented just a small fraction of fishery exploitation, which was restricted to by-catch. Shrimp was not targeted by a fishery at all until 1993, and then became responsible for a large, increasing percentage of Flemish Cap catches. Greenland halibut became a priority target on a larger scale than ever before.

Aside from instability in landings and biomass of the respective commercial species in the area, rearrangement of community structure is an important source of system instability. Removal of cod has been identified as a mechanism resulting in trophic cascades and ecosystem rearrangement in the North Atlantic (Frank et al., 2005).

Wild fluctuations in landings and species targeted resulted in decreased TAC's for redfish, Greenland halibut, cod, and American plaice, with the latter two fisheries being closed. For the other two commercial targets, squid TAC's did not change (as landings were very low); shrimp stocks in 3M were only subject to regulation starting in 2004 (NAFO, 2011b).

CHAPTER 5. INTERNATIONAL MANAGEMENT OF THE NORTHWEST ATLANTIC AND DRIVERS OF POLICY SHIFTS 1950-1999

5.1 INTRODUCTION

The early sections of this essay focus on the biotic and abiotic drivers of productivity in marine systems with special emphasis on the Flemish Cap. Omitted from this discussion was the potential influence fishing activity has on the structure, population and distribution not only of target species, but entire ecosystems (through bycatch and forced shifts in community dynamics).

Management of the Flemish Cap system has taken many forms throughout the Cap's time as an important fishing ground of the Northwest Atlantic. Management bodies and policies have changed along with the political and legal contexts in various eras. Policies have shifted as scientific knowledge has increased. The core drivers of policy transformations that have governed the Cap's resources are important to consider when analyzing how future management strategies might approach climate-induced productivity shifts.

Although policy response strategies have shifted with scientific advancements, these core drivers remain essentially the same and vary from resource stability (at species and ecosystem levels) to system stability and data integrity.

These drivers and responses will be noted in this section for the 1950-1999 period, along with the history (formation, challenges, etc.) of management bodies active in the era. A discussion of how environmental shifts have influenced policy will conclude the section.

Dividing the fisheries policy history of the era into two eras has been performed in this manner as necessitated by windows of environmental data availability. As previously mentioned, data from the Atlantic Zone Monitoring Program are available starting in 1999, and because of this, this chapter, and an upcoming chapter (7) uses the turn of the century as the dividing point between historical and contemporary management timeframes.

5.2 POLITICAL DRIVERS OF FLEMISH CAP MANAGEMENT CONTEXT

5.2.1 INTERNATIONAL AGREEMENTS AND THEIR RELEVANCE TO FLEMISH CAP MANAGEMENT

Through international policies and declarations, the world's ocean territory has been increasingly allotted to the states that border the sea. This trend of legally asserting domestic access rights was inspired by national security concerns. For example, with an eye on improving American security after the Second World War, the Truman Administration laid claim[2] to the continental shelf surrounding American territory. Controlling oil access was a central theme in the war, and the Americans wanted to ensure access both for their growing economy, and to provide a tactical upper-hand in the event that future conflict might break out.

Coastal South American countries also aimed to solidify sole access rights to the substantial fish resources on the west coast of the continent. This desire resulted in the first claim of a 200 nautical mile exclusive access zone (which would eventually become known as the Exclusive Economic Zone as defined by UNCLOS), with similar claims made by members of the international community- a significant extension beyond the 12 mile territory afforded to them under previous international agreements. In the Northwest Atlantic, Canada's EEZ claim (officially announced on 01 January 1977) extended east and covered the majority of

[2] Via the Truman Proclamation on Policy of the United States With Respect to the Natural Resources, signed on 28 September 1945

the Grand Banks, although important fishing areas, including the Nose and Tail of the Banks, and the Flemish Cap, remained in international waters (see Figure 34).

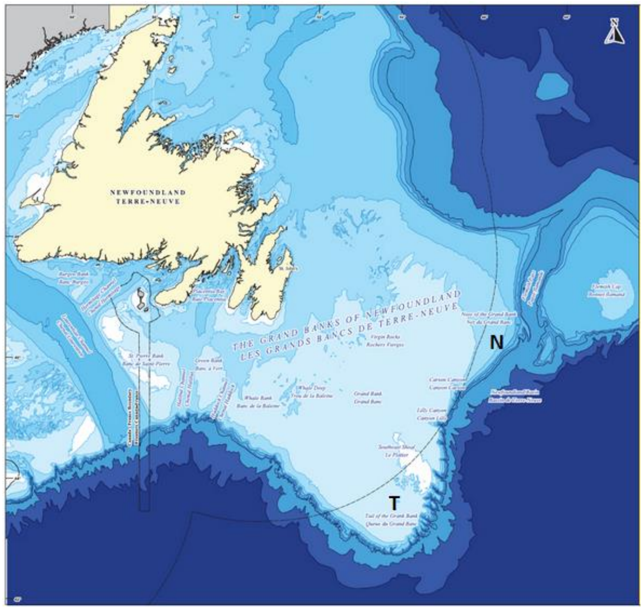


Figure 34 Canada's Exclusive Economic Zone (EEZ) claim in the Northwest Atlantic Ocean. The dotted line denotes the EEZ boundary. The Nose (N) and Tail (T) of the Grand Banks are shown, and along with the Flemish Cap, lie outside of Canadian jurisdiction (modified from DFO, 2013).

5.3 International Commission for the Northwest Atlantic Fisheries (ICNAF)

5.3.1 Formation

The combination of location (and therefore, access context) and resource availability in these areas resulted in the creation of international government organisations tasked with managing the Cap's resources. The International Commission for the Northwest Atlantic Fisheries (ICNAF) carried out this responsibility from 1949 to 1978, and was one of the first regional fisheries management bodies in the world (NAFO, 2013a). ICNAF's original jurisdiction was defined as the area west of 42°W longitude and north of 39°N latitude, and was divided into five subareas (Anderson, 1998). The Commission's jurisdiction was extended southwards to 35°N in 1967, with the new area named Statistical Area 6

(Anderson, 1998). The original jurisdiction, along with the extension, is displayed in Figure 35.

In an effort to address overfishing, eleven countries with fishing interests in the Northwest Atlantic attended a conference in Washington, DC in early 1949, which produced the International Convention for the Northwest Atlantic Fisheries, the convention that would provide the operational framework for soon to be established ICNAF empowered by the Northwest Atlantic Fisheries Act of 1950 (NAFO, 2013a). The stated purpose of the treaty was to ensure 'investigation, protection and conservation of the fisheries of the northwest Atlantic Ocean, in order to make possible the maintenance of a maximum sustained catch from those fisheries' (NAFO, 2013a). This intention, according to Kulka (n.d.) was the introduction of the concept of sustainable fisheries into international law.

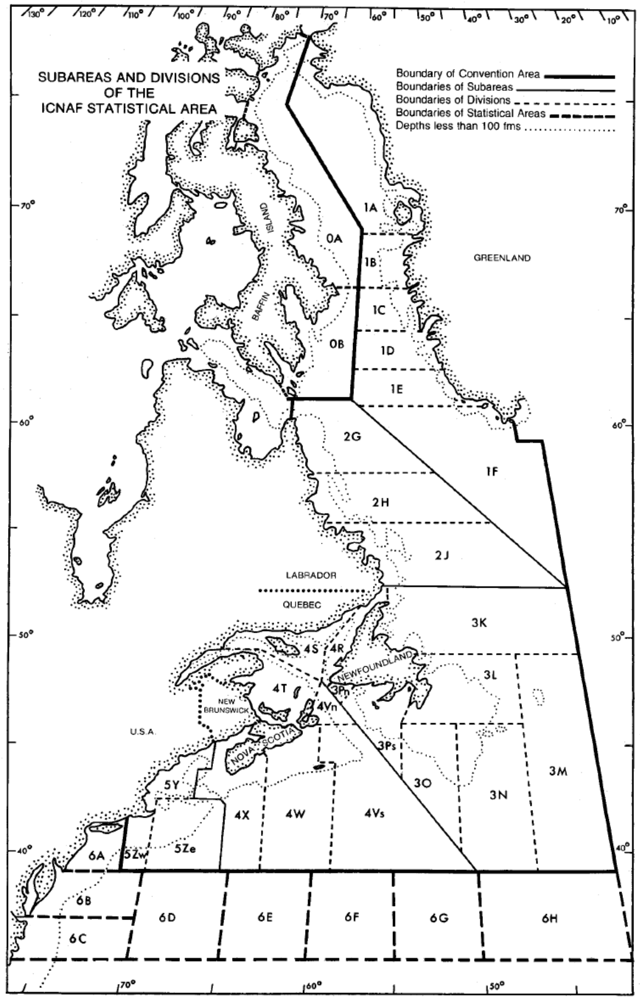


Figure 35 ICNAF Subareas (from Anderson, 1998). The Flemish Cap seamount is depicted by a circular dotted line in the northwest corner of Division 3M. The solid black line encompasses the original Convention Area; the thick dotted line running horizontal at 35° latitude is the southern extension of the Convention Area. This extension was incorporated in 1967, and named Statistical Area 6.

5.3.2 Dissolution

The international trend of declaring a 200 mile Exclusive Economic Zone impaired the ICNAF's ability to function in its original form, as the new national jurisdictional boundaries of the Convention's member states overlapped with the ICNAF's Convention area (Anderson, 1998). The organization officially dissolved at the end of 1979, with a new management body, the Northwest Atlantic Fisheries Organization (NAFO) formed to oversee the fishery activity in the former convention area that extended beyond the 200 mile domestic EEZs (NAFO, 2013a).

5.3.3 Achievements and failures

The overall impact of the ICNAF has been criticised for its inability to meet its stated goal of maximizing resource output and resource stability, but rather than negligence this can be attributed to the steep learning curve in this type of management, particularly with respect to the biological understandings of overexploitation and the limits on potential controlling mechanisms that could be imposed, in combination with a dramatic increase in effort by long distance fleets (Kulka, n.d.). Nevertheless, the organization made significant strides in research and collaboration, resulting in innovative management approaches; INCAF was the first Regional Fisheries Management Organization (RFMO) to establish control of overall exploitation, adopt total allowable catch (TAC) regulations, divide TACs between member nations, and attempt multispecies management (Anderson, 1998).

5.4 Northwest Atlantic Fisheries Organization

5.4.1 Formation

Changing domestic marine jurisdictions resulted in the requirement of a new regional fisheries management organization in the Northwest Atlantic. The Northwest Atlantic Fisheries Organization was comprised of 13 member states when it opened in 1979, after the *Convention on Future Multilateral Cooperation in the Northwest Atlantic Fisheries* was signed in Ottawa, Canada (both RFMO's were active in 1979 for a year to facilitate transition).

Table 5 Member states of ICNAF and NAFO at inception. Source: Anderson, 1998.

Member states to the respective regional fishery management organizations of the Northwest Atlantic		
ICNAF	**NAFO**	
Founding		**Current**
Canada	Bulgaria	Canada
Denmark	Canada	Cuba
France	Cuba	Denmark (in respect of the Faroe Islands and Greenland)
Italy	Denmark (in respect of the Faroe Islands)	European Union (EU)
Iceland	European Economic Community (EEC)	France (in respect of Saint Pierre et Miquelon)
Newfoundland	German Democratic Republic	Iceland
Norway	Iceland	Japan
Portugal	Japan	Korea, Republic of
Spain	Norway	Norway
United Kingdom	Poland	Russian Federation
United States	Portugal	Ukraine
	Romania	United States
	USSR	

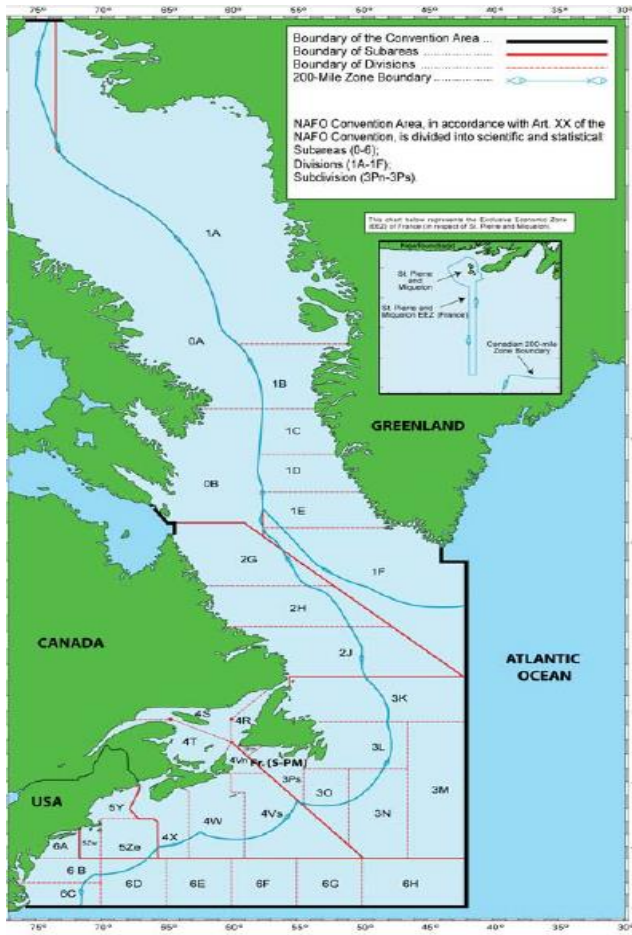


Figure 36 NAFO management subdivisions (from NAFO, 2011b). Canada's EEZ is noted by the blue line, NAFO Subareas are divided with thick red lines, and Divisions are divided with dotted red lines.

5.4.2 SUCCESSES AND FAILURES (1979-1999)

The jurisdictional realignment that preceded the ICNAF's realignment into NAFO has had greater impacts than simply refocusing management effort. As is apparent from Figure 35 and Figure 36, the area over which NAFO has regulatory authority was greatly reduced (Halliday & Pinhorn, 1996) from its predecessor, owing to the extension of national jurisdictions. This territory shift was favourably received by the inshore fishery, as their waters were now protected from international effort (Anderson, 1998), but NAFO's diminished regulatory area resulted in reduced biological control. ICNAF's jurisdiction included complete governance over 70 different stocks, but NAFO's jurisdiction contains only a handful (Anderson, 1998), with a number of stocks now straddling jurisdictional boundaries, complicating management.

NAFO has also succeeded in reducing landings by Non-Contracting Parties through diplomatic and monitoring efforts (this will be examined in greater detail later in Chapter 5). Figure 37 shows a clear decline in landings by Non-Contracting Parties as a percentage of catch and total catch.

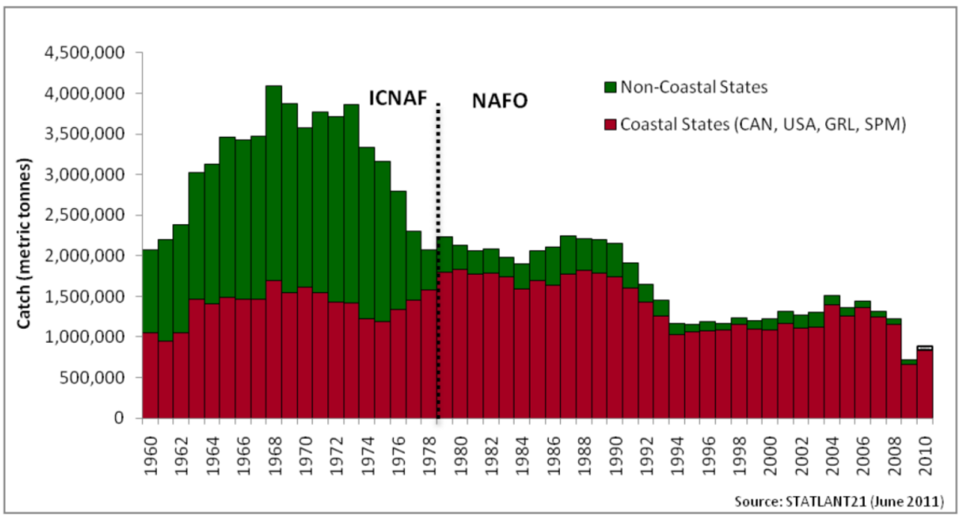


Figure 37 Total catches in the Northwest Atlantic by NAFO's Coastal and Non-Coastal States 1960- 2010 (from NAFO, 2011b). In this graphic, GRL stands for Greenland, and SPM stands for Saint Pierre and Miquelon.

5.5 Approaches and reforms instituted in Northwest Atlantic fisheries management from 1950-1999

A fundamental goal of fishery management, whether domestic or international, is the quest to maximize resource stability while allowing maximum harvest. Maintaining harvest and economic gain over the long-term is only possible through sustainable exploitation, and management strategies in the Flemish Cap region have evolved with these goals in mind as new information regarding the biological resources is uncovered.

Collaborative, internationally coordinated fisheries management started in the Northwest Atlantic when the International Commission for the Northwest Atlantic Fisheries was formed. This organization and its successor carried out considerable assessment and reform throughout the 1950-1999 period, especially considering that the resources in the Northwest Atlantic had been essentially unregulated before this era.

5.5.1 MANAGEMENT INITIATIVES AND STRATEGIES EMPLOYED BY ICNAF

5.5.1.1 GEAR REGULATIONS

Initially, management aimed at reducing overexploitation in the INCAF Convention area focused on regulating equipment. In the first 15 years of ICNAF's existence, over 20 different gear regulations were installed for various fisheries and management areas (Halliday & Pinhorn, 1985). The first, developed in 1952 and enforced in 1953, was a 114 mm minimum mesh size imposed on the haddock fishery in Subarea 5 (Georges Bank). Gear requirements expanded to include regulations for cod and pollock fisheries throughout the Convention Area by the 1970s (Anderson, 1998).

5.5.1.2 TOTAL ALLOWABLE CATCH (TAC)

Recognizing that gear and trawling regulations were not providing desired results, ICNAF introduced quota regulation in the early 1970s. Haddock was again the initial target for this new type of management; quota regulation of haddock stocks began in 1970.

Table 6 Initial year for quota management of 3M resources.

Regulated Stocks in Division 3M (Flemish Cap)		
Stock	**First year present in ICNAF quota table**	**First year present in NAFO quota table**
Northern shortfin squid (Subareas 3+4)	1974	1979
Atlantic cod	1974	1980
Redfish	1974	1980
American plaice	1974	1980
Greenland halibut	3M population not regulated via quota	1995
Northern shrimp	Not regulated via quota	2004

Flemish Cap stocks received management regulation starting in 1974, when squid[3], Atlantic cod, redfish and American plaice fisheries were subjected to catch controls via quotas. In early years quota totals did not vary often in early management when compared with the number of changes closer to the end of the 20th century and management since 2000. Quota shifts for 3M species from 1950-1999 are provided in Figure 39 and Figure 40.

5.5.1.3 Seasonal restrictions and area closures

Seasonally-regulated effort control was introduced by ICNAF in 1970. This strategy initially targeted the silver hake (*Merluccius bilinearis*) and red hake (*Urophycis chuss*) fisheries in Subarea 5, resulting in winter closures in areas these species frequented between December and March (Halliday & Pinhorn, 1996). Closures were implemented

[3] Regulated in Subareas 3-4 as a single stock

rather than catch restrictions via TACs as the scientific knowledge required to set quotas was insufficient (Halliday & Pinhorn, 1996). Similar closures targeted the haddock fishery starting that year, protecting the animal from fishing effort during spawning season (Halliday & Pinhorn, 1996).

5.5.1.4 Quota allocation and the 40-40-10-10 Rule

Once ICNAF decided that stocks in their jurisdiction were to be regulated by TAC quotas, it became imperative to decide how quotas would be divided among contracting parties. In 1972 the 40-40-10-10 rule was designed to resolve the allocation issue (Anderson, 1998). These numbers represent percentages of the TAC, allocated in the following manner (ICNAF, 1972);

- 40% in proportion to average catches over the most recent 10-year period
- 40% in proportion to average catches over the most recent 3-year period
- 10% to the Coastal States
- 10% for special needs

This scheme was used until ICNAF dissolved in 1979.

5.5.1.5 Minimum fish sizes

Reducing the catch of small, undesired fish was the purpose of minimum mesh size requirements, but regulating catch size through instituting a minimum fish size was considered to be more effective for pelagic species (Halliday & Pinhorn, 1996). As such, minimum fish size was introduced as a regulatory requirement starting in 1972 in the herring fishery in Statistical Area 6. This type of management has been included in INCAF and NAFO strategies since this introduction, and has expanded to include Atlantic cod, Greenland halibut, American plaice and Yellowtail flounder in contemporary management.

5.5.1.6 Effort from non-coastal states

In the latter part of ICNAF's existence, the Commission developed a policy aimed at reducing effort by non-coastal states on the groundfish stocks of Subareas 2-4. ICNAF's goal was to reduce effort by non-coastal states to 40% of 1973 levels (Halliday & Pinhorn, 1996). Effort was regulated by limiting the number of days fished and was scaled back based on vessel characteristics (Halliday & Pinhorn, 1996).

5.5.1.7 Opening areas for distant fleet fishing

In an effort to resolve gear conflict problems between American fishermen and foreign fleets and lower by-catch of traditional US target species, specific fishing areas for foreign fleets were created (Anderson, 1998). These windows were discussed in late 1976, and were proposed for silver and red hake, squid, mackerel and herring. These initiatives were implemented in 1977 (ICNAF, 1977; Anderson, 1998), but were not maintained after implementation of EEZs. The windows for distant fleet hake fishing are provided in Figure 38.

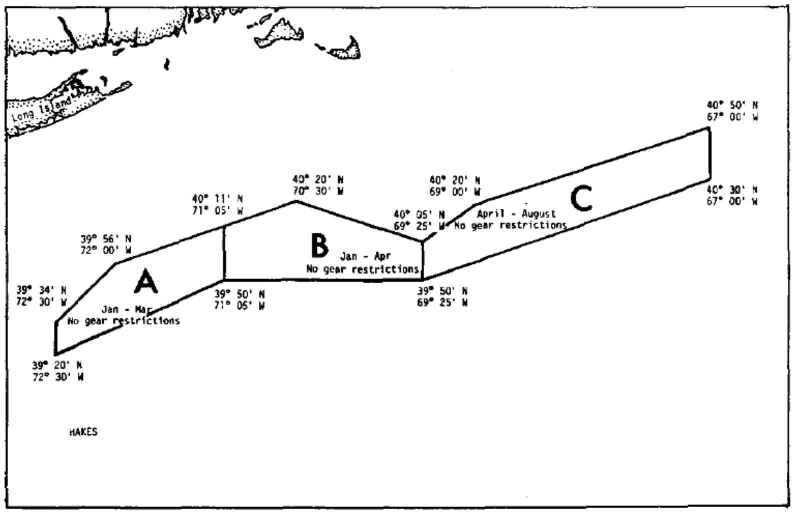


Figure 38 The areas, or 'windows' where distant fleet fishing for hake were permitted. This strategy was introduced in 1977, and served to reduce bycatch and gear conflicts. Other species for which windows were implemented were mackerel, squid and herring (ICNAF, 1977).

5.5.2 Management initiatives and strategies employed by NAFO

Many of the policies developed by ICNAF were maintained when NAFO formed. However, ICNAF's policies on minimum fish sizes and seasonal closure restrictions were abandoned (Anderson, 1998). There were important Resolutions made by NAFO between its formation and the end of the 20th century, which focused on the improvement of data collection and maintaining data reliability as well as reducing fishing effort of non-Contracting Parties in the Regulatory Area.

5.5.2.1 Minimum fish sizes

Although this management technique was eschewed when INCAF became NAFO, it was later reinstalled for Atlantic cod (41 cm), American plaice (25 cm) and yellowtail flounder (25 cm) in 1993 (NAFO, 1992; NAFO, 2011a), and later expanded to include Greenland halibut (30 cm).

5.5.2.2 NAFO Resolutions 1979-1999

Important changes to NAFO's Convention and management strategy have occurred throughout its existence. Such changes are termed 'Resolutions'; those applicable to fisheries management (rather than administrative reform) are noted below.

With the exception of Resolutions (2) and (3) (installed in 1979), the date of implementation is in the title. Listing the major policy events in chronological order allows for a picture of how management goals changed in different eras, the problems of different eras and the solutions that were entered into policy. Brief descriptions are included to explain the rationale or drivers of implementation.

- Resolution (2) Adopted by the Fisheries Commission of NAFO, regarding vessels of non-member countries operating in the Regulatory Area

This Resolution states that member countries will not facilitate fishing activities by non-members, and that NAFO's president will inform authorities in Mexico, Panama and Venezuela that vessels flying their national flags are creating difficulties with stock conservation (NAFO, 1979a)

- Resolution (3) Adopted by the Fisheries Commission of NAFO, regarding the establishment of a scientific observer scheme

The third NAFO Resolution calls upon Contracting Parties to develop an international scientific observer program, on a voluntary basis (NAFO, 1979b).

- Resolution (1/81) Adopted by the Fisheries Commission of NAFO, expressing serious concern at the activities of Spanish vessels and inviting Spain to adhere to the Convention.

This Resolution identifies Spanish vessels as violating NAFO regulations, exceeding special reservations allocated to their nation, and invites Spain to become a Contracting Party to the NAFO Convention (NAFO, 1981).

- Resolution (1/85) Adopted by the Fisheries Commission of NAFO, concerning reporting on catches and scientific samples.

In the only Resolution in 1985, the Fisheries Commission called upon members to ensure proper sampling and reporting requirements were being followed (NAFO, 1985).

- Resolution (1/88) Adopted by the Fisheries Commission of NAFO, regarding reporting of provisional monthly catches by species and stock area.

Similar to the Resolution in 1985, Resolution (1/88) officially requests Contracting Parties to regularly obtain and report catch data in the Regulatory Area (NAFO, 1988a).

- Resolution (3/88) Adopted by the Fisheries Commission of NAFO, urging the Contracting Parties to continue and improve the Annual Scientific Program, requesting the same Contracting Parties and the Executive Secretary to urge non-members of NAFO to cooperate with the Program and requesting the Scientific Council to evaluate at the 1989 Annual Meeting the progress of the Program.

As the name of this Resolution indicates, adoption resulted from the desire to ensure Contracting Parties provide NAFO with complete and accurate statistics regarding catches, discards and directed fishing efforts to improve management deficiencies (NAFO, 1988b).

- Resolution (1/89) Adopted by the General Council of NAFO, calling on all Contracting Parties for compliance with the NAFO management framework in place since 1979, and compliance with NAFO decisions in order to provide for conservation and maintain the traditional spirit of cooperation and mutual understanding in the Organization.

This Resolution calls for increased compliance to the NAFO management framework (NAFO, 1989). This Resolution does not explicitly addresses Contracting or Non-Contracting Parties.

- Resolution (1/90) Resolution adopted by the General Council of NAFO on non-NAFO fishing activities: Declares that all members of the international community whose nationals carry out fishing activities in the NAFO Regulatory Area should ensure that such activities do not have an adverse impact on the stocks or NAFO's ability to ensure conservation; Resolves for all Contracting Parties' communications through diplomatic channels with non-Contracting Parties whose vessels fish in the NAFO Regulatory Area and for adoption of all necessary measures (a harvest origin certificate, etc.) to prevent any fishing contrary to NAFO conservation measures.

Continuing with the theme surrounding NAFO Resolutions from the 1980s, this Resolution is another formal recognition that NAFO policies are being violated, particularly by vessels based in non-Contracting nations, impairing the organization’s ability to ensure resource stability. It also introduces the concept of a certification program noting where products have been harvested from (NAFO, 1990).

- Resolution (1/93) Resolution adopted by the General Council of NAFO on non-Contracting Parties fishing activities in the NAFO Regulatory Area; introduces the landing declaration scheme and means of its implementation.

The only Resolution agreed to in 1993 takes the next step from the diplomatic efforts designed in previous Resolutions designed to stop fishing by non-Contracting Parties. This included NAFO representation in meetings with senior officials in the governments of non-Contracting Parties urging them to withdraw vessels. In addition, a landing declaration scheme was finalized and implemented in Resolution (1/93), which was designed to help non-Contracting Parties collect catch statistics by their vessels in the NAFO Regulatory Area (NAFO, 1993).

- Resolution (1/94) Resolution adopted by the General Council of NAFO re acceptance of UN "Agreement to Promote Compliance with International Conservation and Management Measures by fishing Vessels on the High Seas".

This Resolution calls upon Contracting and non-Contracting Parties with fishing vessels active in the NAFO Regulatory Area to accept the United Nations Food and Agriculture Organization’s "Agreement to Promote Compliance with International Conservation and Management Measures by fishing Vessels on the High Seas" in their respective jurisdictions, and to apply this legislation to their vessels immediately (NAFO, 1994).

- Resolution (2/99) Resolution adopted by the Fisheries Commission of NAFO to guide implementation of the precautionary approach within NAFO

The final Resolution of the 1990s is the start of investigation of how the precautionary approach can be inserted into NAFO management (NAFO, 1999). It is the first NAFO Resolution that addresses fundamental changes to ICNAF management ideologies rather than data quality and external fishing.

These Resolutions addressed several different problems that were limiting the effectiveness of management efforts.

5.6 DISCUSSION

The major policy developments and innovations enforced in the NAFO Regulatory Area noted above have been listed in Table 7 along with their drivers. In order to understand how policy shifts have coincided with fisheries production between 1950 and 1999, they have been marked in Figures 39 and 40, along with landings and quota for the commercial species on the Flemish Cap. This information has been displayed in two figures rather than a single chart due to the amount of information being displayed and wide temporal scope. Additionally, a climate bar has been placed on the graphs. This bar notes the different climatic eras (with respect to temperature) over the timeframe to provide insight into how temperature conditions have overlapped with shifting landings, quotas and policies. Years where temperature anomalies were below average are indicated by a blue line; years where temperature anomalies were above average are indicated by a red line. This climatic information is an interpretation of the data presented in Figure 22.

Previous chapters have provided environmental data for 1950-2000 and landings data from 1960-1999. The following figures (Figure 39 and Figure 40) summarize the data types listed above for the 1950-1999 era; following chapters will combine contemporary policy, temperature and landings for the 2000-2012 period.

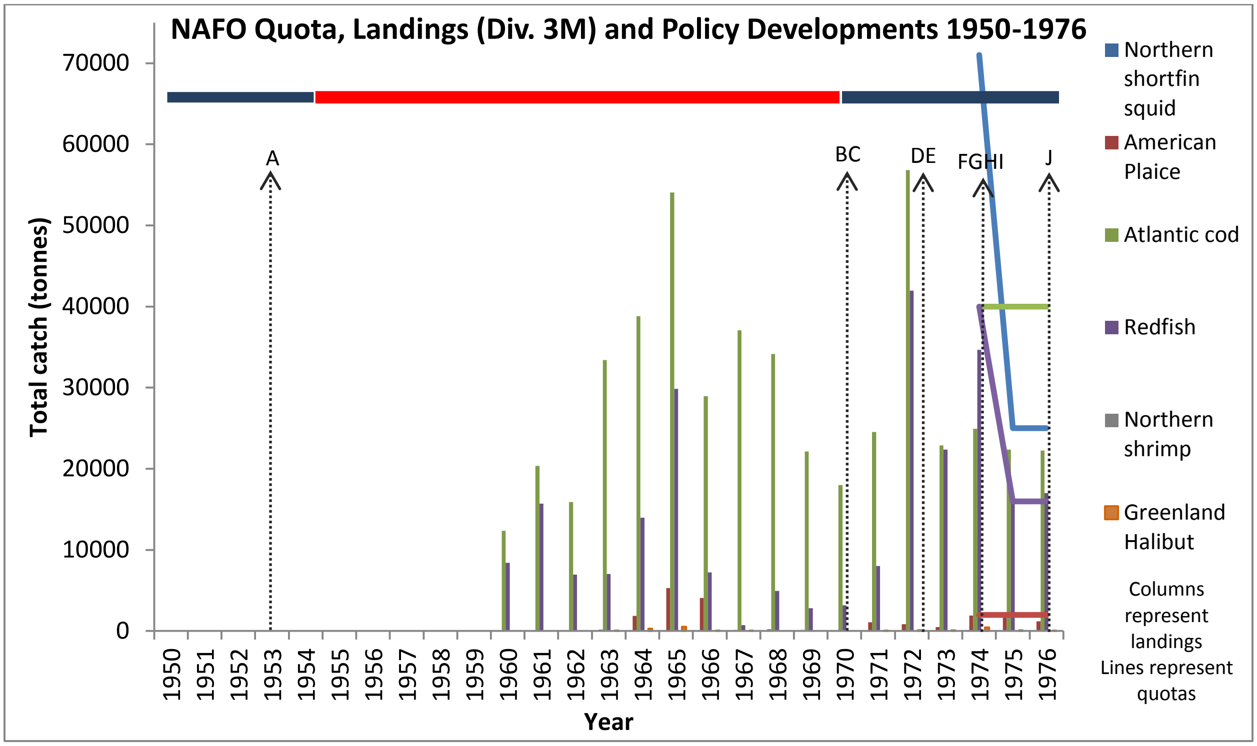


Figure 39 Combining quota, landings, policy and ocean temperature in NAFO Div. 3M 1950-1976. Letters identify policy implementations outline in Table 7. Columns in the figure represent landings, while lines represent quotas. There are no line graphs before 1972, as quotas were not used to regulate catch before this time. The climate bar, located at the top of the graph provides environmental context; years where temperature anomalies were below average have been marked blue, and years where temperature anomalies were above average have been marked red. There are two shifts in this period- from colder than average to warmer than average in the mid-1950s, and vice versa in the late 1960s. The temperature data used to create this bar is provided in Figure 22 (from Colbourne & Foote, 2000). Quotas and catch use the same scale in the Figure (tonnes).

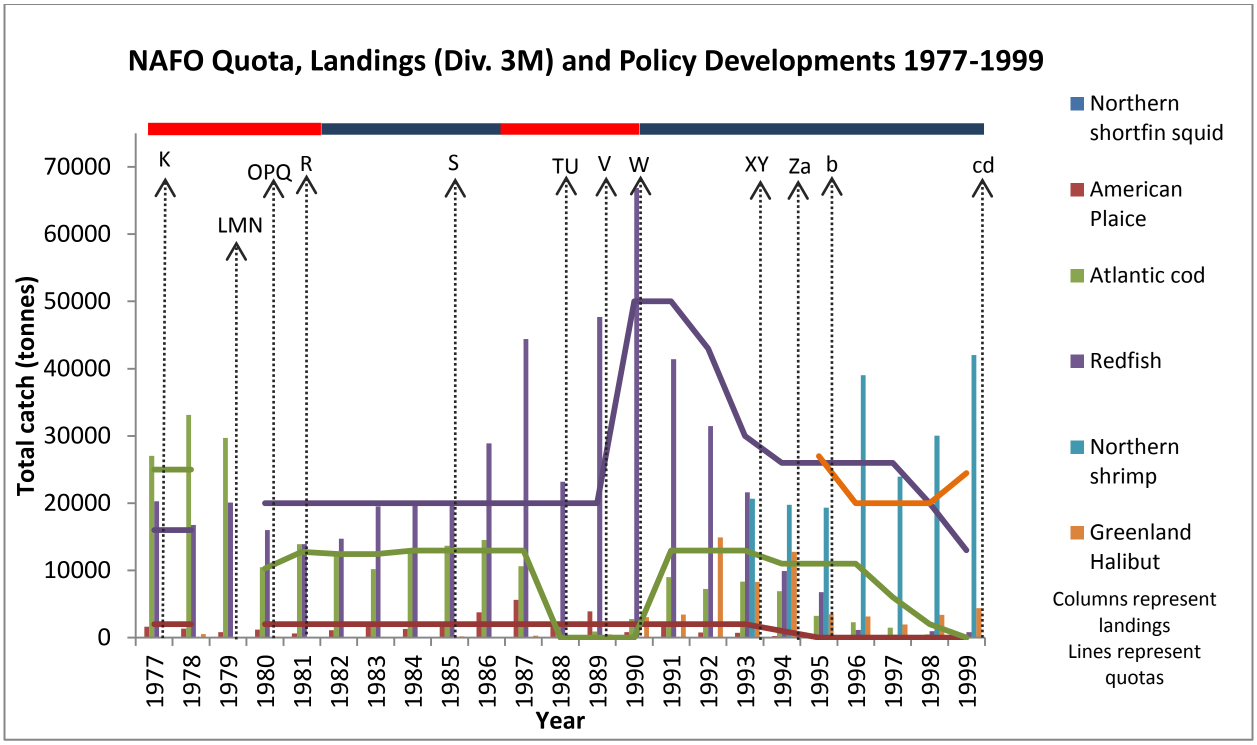


Figure 40 Combining quota, landings, policy and ocean temperature in NAFO Div. 3M 1976-1999. Letters identify policy implementations outline in Table 7. To maximize differentiation between landings bars, the vertical axis was capped at 75 000 tonnes. This is below the majority of northern shortfin squid quotas, which have been excluded for the sake of visual differentiation. The climate bar, located at the top of the graph provides environmental context; years where temperature anomalies were below average have been marked blue, and years where temperature anomalies were above average have been marked red. There were three shifts, with an extended cold period in the 1990s. Quotas and catch use the same scale in the Figure (tonnes).

The policies represented in Figure 39 and Figure 40 are listed in the following table, along with their year of implementation, a brief description, driver, and supporting documentation.

Table 7 Policies in North Atlantic fisheries Management 1950-1999. Policies specific to the Flemish Cap are denoted with an *.

Event	Year implemented	Policy	Root driver of policy	Source
A	1953	Minimum mesh sizes	Ecosystem considerations/ species conservation	(Halliday & Pinhorn, 1996)
B	1970	Total Allowable Catch (TAC) rates developed for haddock fishery	Species conservation	(Halliday & Pinhorn, 1996)
C	1970	Seasonal restrictions (hake fishery)	Species conservation	(Halliday & Pinhorn, 1996)

D	1972	40-40-10-10 allocation rule	Economic considerations	(Halliday & Pinhorn, 1996)
E	1972	Minimum fish size (herring fisheries)	Species conservation/ecosystem considerations	(Halliday & Pinhorn, 1996)
F*	1974	TAC for Northern shortfin squid	Species conservation	(Halliday & Pinhorn, 1996)
G*	1974	TAC for Atlantic cod	Species conservation	(Halliday & Pinhorn, 1996)
H*	1974	TAC for redfish	Species conservation	(Halliday & Pinhorn, 1996)
I*	1974	TAC for American plaice	Species conservation	(Halliday & Pinhorn, 1996)
J	1976	Limiting effort from non-coastal states	Species conservation	(Halliday & Pinhorn, 1996)
K	1977	Open areas for distant fleet fishing	Ecosystem considerations	(Halliday & Pinhorn, 1996)
L*	1979	(NAFO) TAC for Northern shortfin squid	Species conservation	(NAFO, 2011b)
M	1979	Resolution (2)	Species/ecosystem conservation through international diplomacy	(NAFO, 1979a)
N	1979	Resolution (3)	Data/management improvement	(NAFO, 1979b)
O*	1980	(NAFO) TAC for Atlantic cod	Species conservation	(NAFO, 2011b)
P*	1980	(NAFO) TAC for redfish	Species conservation	(NAFO, 2011b)
Q*	1980	(NAFO) TAC for American plaice	Species conservation	(NAFO, 2011b)
R	1981	Resolution (1/81)	Species/ecosystem conservation through international diplomacy	(NAFO, 1981)
S	1985	Resolution (1/85)	Data/management improvement	(NAFO, 1985)
T	1988	Resolution (1/88)	Data/management improvement	(NAFO, 1988a)
U	1988	Resolution 3/88	Species/ecosystem conservation through international diplomacy	(NAFO, 1988b)
V	1989	Resolution (1/89)	Species/ecosystem conservation through international diplomacy	(NAFO, 1989)
W	1990	Resolution (1/90)	Species/ecosystem conservation through international diplomacy	(NAFO, 1990)

X	1993	Resolution (1/93)	Species/ecosystem conservation through international diplomacy	(NAFO, 1993)
Y	1993	Minimum fish sizes reinstalled	Species conservation/ecosystem considerations	(NAFO, 1992)
Z	1994	Resolution (1/94)	Species/ecosystem conservation through international diplomacy	(NAFO, 1994)
a*	1994	Moratorium on American plaice fishery	Species conservation	(NAFO, 2011b)
b*	1995	(NAFO) TAC for Greenland halibut	Species conservation	(NAFO, 2011b)
c	1999	Resolution (1/99)	Ecosystem considerations	(NAFO, 1999)
d*	1999	Moratorium on Atlantic cod fishery	Species conservation	(NAFO, 2011b)

Even though this summary has centred on only the major policy events, there is a substantial amount of information in the preceding table and figures. Table 8 provides a brief summary of the information presented above.

Table 8 Summarizing important fisheries policy events in the Northwest Atlantic 1950-1999.

Policy Characteristics		**Number of implementations**	
		In warm years	**In cool years**
Biological	Ecosystem Considerations	1	4
	Species Conservation	4	12
Social	Species/ecosystem conservation through international diplomacy	4	3
	Data/management improvement	2	1
	(primarily) economic considerations	0	1

From this summary we can see that of the 29 major policy events from 1950-1999, 18 occurred in years that were cooler than normal, and 11 occurred in years that were warmer than normal. Although it is interesting to note the difference in volume of policy reform within different climate contexts, a more genuine measure of the contribution environmental conditions have had on policy is found from the number of policy decisions based on such factors. We can see from Table 7 and Table 8 that environmental conditions were not a direct factor in policymaking, despite the connectedness of fisheries production to environmental variables. Indirectly however, environmental conditions clearly influence policy. Environmental control of individual and population growth rates may result in future policy changes designed around either of these parameters.

The 1950-1999 timeframe analysed in this section was a critically important segment of fisheries management not just in the Northwest Atlantic, but around the world. Increasing awareness of fisheries conservation issues were addressed through increasingly sophisticated scientific and managerial strategies. Policy evolved dramatically on domestic, regional and international scales.

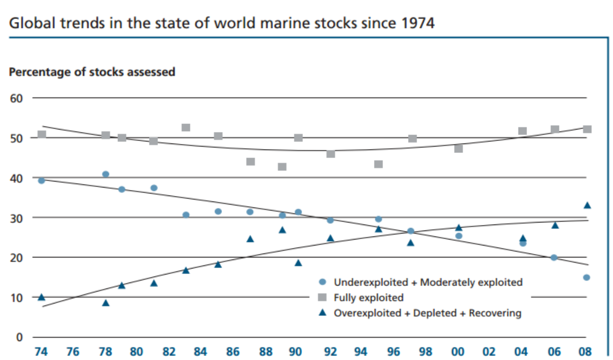


Figure 41 Trends in the classification of world marine fisheries resources (from UNFAO, 2010). Annual findings are smoothed with a best-fit line. The proportion of resources classified as overexploited (triangles) increased steadily from the start of the measurement period until the end of the century, despite improvements in scientific understanding.

Despite these important developments, the proportion of worldwide fisheries classified as overexploited increased (see Figure 41, from UNFAO, 2010). In the Northwest Atlantic, despite increased regulatory involvement, many stocks declined to the point where moratoria were implemented. In the 1990s two of the Flemish Cap's commercial stocks (American plaice and cod) were subject to this management tool. A prudent question to ask here is if scientific understanding and management competency continually increased between 1950 and 1999, why did the health of commercial stocks not improve? Although seemingly more apt, and tailored to specific problems, have management responses delivered desirable outcomes?

Determining the factors that undermine regulatory effectiveness is difficult. Since Resolutions are the major policy installations designed to confront confounding problems, discussing NAFO's enforcement capacity might identify management limitations or flaws.

According to Day (1995; 1997) NAFO's limited ability to monitor fishing activity and enforce TACs, quota allocations and technical regulations is a main reason for stock declines in periods of progressive, otherwise active management.

These characterizations seem accurate. Despite the arrest of two foreign vessels (Spanish and Portuguese) for illegal fishing (cod and Greenland halibut, respectively) in 1995 (Day, 1995), legal action against violators has not been common. Instead, when illegal, unreported or underreported (IUU) fishing was encountered or anticipated, diplomatic channels were employed. There were numerous instances of NAFO Resolutions that sought to increase compliance through diplomatic channels (see Table 7 and Table 8); Figure 42 shows how catch rates compared to TACs for in this era. These totals seemingly point to illegal behaviour as main reasons for NAFO's outcomes, likely driven by lack of enforcement and punitive measures.

Without effective control over IUU fishing, it can be assumed NAFO's (and all fisheries management bodies) management efforts are based on flawed data, with the degree of error relative to the amount of IUU fishing unaccounted for. Although the sophistication of models and overarching frameworks may increase, management success and resource exploitation efficiency are jeopardized by IUU in the short- and long-term. This may prohibit management from empirical improvements despite theoretical advances in approach.

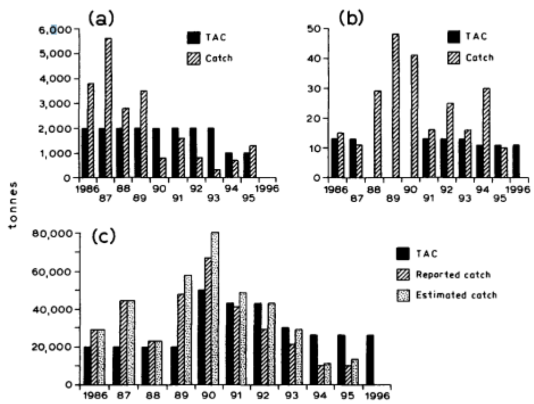


Figure 42 TAC and catches in Division 3M 1986-1996 (from Day, 1997). The species described above are (a) American plaice, (b), cod, and (c) redfish. There are numerous instances where catch totals exceed TACs set by NAFO.

5.7 CONCLUSION

Management of the Flemish Cap's resources started in 1950 with the formation of ICNAF and continues today through NAFO. Management strategies and ideologies have evolved from open-access to restricted access, heavily regulated fisheries. For the most part, this transition occurred in the 1950s through the 1970s, but minor reform continued through the 1980s and 1990s.

Landings data have provided the bulk of the justification for increased regulatory requirements. Ecosystem considerations and species conservation have long been root drivers of policy decisions (Table 7), and have risen from catch data returned to management bodies. The importance of catch data integrity is evident from the several NAFO Resolutions that aspired to improve data collection and data sharing to better inform fisheries scientists and managers and to increase the robustness of their conclusions.

Early management efforts aimed at improving resource stability focused on mesh sizes, but when this failed to improve system health, catch controls were installed. Catch quotas and allocations proved more effective, although fishing in the INCAF and NAFO Convention Areas by non-coastal/non-Contracting states limited the benefits realized by the management strategy. Aside from improving data quality and transmission, Resolutions passed in the early years of NAFO sought diplomatic Resolution to illegal, unreported and underreported fishing in the Regulatory Area.

In Chapter 7, contemporary policy decisions will be reviewed for possible links to environmental conditions on the Cap (or elsewhere in the NAFO Convention Area); findings from Chapters 5 and 7 will be used in subsequent discussions regarding how NAFO management will likely proceed in the medium term future, and how likely management routes may be improved.

CHAPTER 6. RECENT OCEANOGRAPHIC AND BIOLOGICAL DYNAMICS ON THE FLEMISH CAP (CA. 2000-PRESENT)

6.1 INTRODUCTION

Contemporary ecosystems are the summation of all the cycles, trends, factors and stressors that have influenced them since their initial formation. Perhaps analogous to species evolution, the subtleties affecting ecosystems drive changes within the system as a whole. With an eye on historical transformations as a driver of current status, focus will now shift to the recent oceanographic and biological dynamics of the Flemish Cap region.

This section will be laid out in a similar fashion to Chapter 2 but with more quantitative information. An assessment of the oceanographic characteristics from 2000-2012 will be presented, including the temperature and salinity fluctuations at various depths, recent strengths of the NAO, and influence of the Labrador Current. This time period frames the data availability of the DFO's Atlantic Zone Monitoring Program (AZMP).

Following that, the biological developments of the era will be summarized. Shifts in primary and secondary production, landings totals and trends of commercial populations, along with overall ecosystem interactions and stability will characterize this summary.

This Chapter also provides context for the following chapter, which will note the policy decisions of the era, linking the disciplines in the same way the historical oceanographic and biological reviews were accompanied by a summary of the managerial processions applicable to the timeframe. This will provide comparable snapshots of how policy has been formed in different environmental and biological stanzas.

6.2 Oceanographic Characteristics

6.2.1 Temperature and salinity

From their recurring appearance as themes in this paper, it is apparent that temperature and salinity are important oceanographic variables where fisheries yield is concerned. The following figures demonstrate how these variables have fluctuated recently with respect to the historical average- a legend is provided in Table 9 that translates the data in subsequent tables. Summary and analysis will be provided for the 2000-2012 timeframe.

Table 9 Legend for Tables 10-13, where colours correspond to the number of standard deviations measured from the respective historical means (from Colbourne, et al., 2012). This type of depiction standardizes data that are based in different units and emphasizes 'anomalies' in the data, which are presented below as annual values.

				COLD/FRESH		WARM/SALTY					
<-2.5	-2.5 to -2.0	-2 to -1.5	-1.5 to -1.0	-1.0 to -0.5	-0.5 to 0.0	0.0 to 0.5	0.5 to 1.0	1.0 to 1.5	1.5 to 2	2.0 to 2.5	>2.5

Table 10 summarizes the standard deviations from mean salinity and temperatures across the Flemish Cap oceanographic section, the cold-intermediate layer (CIL), and the Labrador Current transport level (which will be discussed further in the Currents section). The majority of the era has been warmer and more saline than the historical average, with 2003 and 2006 having the strongest anomalies from the mean. It should be noted here that these results are across the Flemish Cap region as a whole and do not account for depth-related variance. These factors have been measured with depth variability factored in (see Tables 11 and 12), and compared to annual NAO measurements.

Table 10 Results from Colbourne et al. (2012)'s oceanographic assessment of North Atlantic Waters with a focus on indices related to the Flemish Cap/47°N oceanographic section that transects the northern Grand Banks and Flemish Cap. Anomalies, in standard deviations, are provided for temperature, salinity and Labrador Current transport for 2000-2011.

REGION/SECTION	INDEX	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
FLEMISH CAP													
	MEAN CIL TEMPERATURE (SUMMER)	1.0	0.9	0.2	-0.3	1.3	0.9	1.6	0.3	0.2	-0.7	1.7	2.3
47 ^{O}N	MINIMUM CIL TEMPERATURE (SUMMER)	0.4	1.7	-0.8	-0.1	0.2	0.6	0.8	0.2	-0.2	-0.9	2.8	2.2
SECTION	MEAN SECTION TEMPERATURE (SUMMER)	0.2		-0.4	1.8	0.9	0.8	1.7		0.7	0.7	1.0	1.7
	MEAN SECTION SALINITY (SUMMER)	-0.4		0.9	1.8	0.7	-0.8	1.2		0.9	-0.4	0.6	1.0
	INSHORE SHELF SALINITY (SUMMER)	-0.8	-0.8	0.6	0.2	0.0	-0.2	1.1	0.7	0.6	-0.5	-0.8	-0.9
	LABRADOR CURRENT TRANSPORT (SUMMER)	0.6	0.7	0.9	1.9	0.6	0.6	-0.2	0.4	-2.3	0.6	-0.8	-0.1

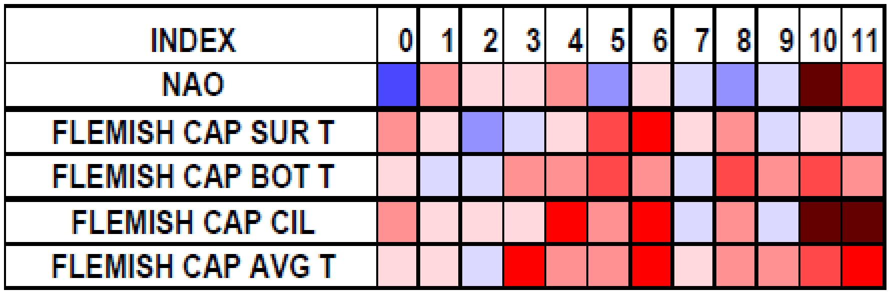
Bottom temperatures on the Cap have trended warmer than average since 2003, with the exception of 2007 which was marginally cooler than the average. The cold intermediate layer also trended warmer during the era, with half of the era at least 0.5 standard deviations warmer than the historical average (Table 12). Surface temperature over the timeframe fluctuated around the long term mean, with anomalies from all years except 2005 and 2006 measured to be less than one standard deviation (Table 11).

Table 11 Depth-related salinity and temperatures anomalies on the Flemish Cap 2000-2011 (from Colbourne et al. 2012).

INDEX	LOCATION	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
T (Surface)	FLEMISH CAP	0.6	0.1	-0.9	0.0	0.3	1.4	2.0	0.2	1.0	-0.4	0.2	-0.3
S (Surface)	FLEMISH CAP	-1.1	0.8	1.1	2.0	1.0	0.9	0.1	0.9	-0.2	-0.7	0.4	0.4
T (Bottom)	FLEMISH CAP	0.1	-0.3	-0.1	0.5	0.8	1.3	0.7	-0.1	1.2	0.8	1.0	0.9

Surface salinity was lower than average in 2000 by 1.1 standard deviation, and then trended warmer than average for the following seven years. The last four years of the era all deviated weakly from the mean and were split between warmer and colder than average.

Table 12 NAO and depth-related temperature anomalies on the Flemish Cap 2000-2011 (denoted as 0-11 here)(from Colbourne et al. 2012).



The depth-averaged mean temperature anomalies are also provided in Table 12 and indicate a clear warming pattern throughout the water column. This is more readily apparent in the intermediate and bottom-layers, possibly because surface water characteristics are more prone to external influences.

The overall picture shown by Colbourne et al. (2012) is one of changing oceanographic norms in the Flemish Cap region. The temperature anomalies in Table 12 show many more warm years than cool, and only once (at the surface) did temperatures trend cooler than the historical average by more than 0.5 standard deviations. There were nine instances where temperatures trended warmer than the historical mean by more than 0.5 standard deviations, a substantial difference. This fact is reinforced when the depth-independent average temperature is considered- there were no instances of temperature trending cooler than average over a year by 0.5 standard deviations or more, whereas four of the 12 years presented trended warmer by at least 0.5 standard deviations.

6.2.2 NAO

The magnitudes of the standard deviations of the North Atlantic Oscillation from its historical average for 1990-2011 are provided in Table 13. Negative values represent standard deviations below the mean, and are colour coded red for resulting temperature and salinity increases in this region, in accordance with Table 9.

In the 2000-2012 timeframe, there were seven years where the NAO anomaly was negative, and five years where the index was positive. There were three years where the recorded value differed from the mean by more than once standard deviation- 2000 (1.1), 2010 (-2.9), and 2011 (1.2). The 2010 event is noteworthy, as it is the lowest record value for the index (Colbourne et al., 2012) and negative values in the past have induced temperature and salinity increases in the Flemish Cap region on the order of 0.25-1°C and 0.1-0.3 relative to positive anomalies, respectively (Petrie, 2007).

Table 13 NAO Standard deviations from the mean historical value, 2000-2011 (from Colbourne et al., 2012).

INDEX	LOCATION	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
SLP (NAO)	ICELAND-AZORES	1.1	-0.9	-0.3	-0.3	-1.0	0.5	-0.3	0.3	0.5	0.2	-2.9	-1.2

6.2.3 CURRENTS

Recent variance in the Labrador Current's transport level is of interest when discussing the overall picture of the North Atlantic's oceanographic conditions. Table 10 includes a summary of the Current's transport volume anomalies in the Cap region, expressed in standard deviations from the mean, and the temperature and salinity of the transport. The first half of the decade saw colder, fresher influx and higher than average transport; in the second half of the decades trends were less apparent, but three of the four years from 2008-2011 experienced warmer, more saline and decreased volume transports in the Cap region.

6.2.4 Benthic/sediment conditions

There have not been any recorded changes in the Flemish Cap's sediment conditions in the contemporary range, owing to the geologic timescale upon which these changes occur. Benthic temperatures have changed during this time, trending warmer when compared to the historical average (see Table 10-Table 12). These temperatures are also substantially warmer when compared to the below average temperatures experienced in the region in the 1990s (Figure 22). Deep-water (>200 m) benthic habitats including cold-water corals and associated fauna have been intensively mapped only within the past decade and are distributed around the Flemish Cap (see Wareham and Edinger, 2007).

6.3 Biological Characteristics 2000-2012

6.3.1 Primary and secondary production

The composition and abundance of the copepod community is another important factor responsible in part for determining the makeup and interactions in higher trophic levels. The recent investigation by Pepin et al. (2011) into zooplankton community structure in the Newfoundland and Labrador region revealed a strong association between structure and water properties in the North Atlantic, including the Flemish Cap. Zooplankton community structures were found to differ in various areas of the Northwest Atlantic, as a result of differing hydrographical contexts. The Flemish Cap's zooplankton community was found to be most similar to communities found in the Labrador Sea and its slope waters having little in common with communities on the Newfoundland Shelf or the Grand Banks, despite their relative proximity (Pepin et al., 2011). These findings solidify the assertion that environmental fluctuations carry ramifications for invertebrate communities and corresponding fisheries yields in the area.

Seasonal variance in production is a staple of the planktonic communities in temperate zones; Pepin et al. (2011)'s findings (Table 14) in the North Atlantic were in line with this expectation, identifying a strong pattern in species composition varying by season.

Table 14 A summary of Pepin et al. (2011)'s investigation into the plankton community in the Northwest Atlantic between 2000-2007.

Seasonal Characteristics of the Plankton Community in the Northwest Atlantic			
Community characteristics	Spring	Summer	Fall
Taxa present	61	60	77
Population density (individuals m^{-2})	154 000	219 000	229 000

The general review of the Flemish Cap's plankton community (Chapter 2.3.2) discussed the importance of copepods as an energy transfer intermediary in the long range history of the Flemish Cap. This has been confirmed for the contemporary Flemish Cap ecosystem as well; copepods were found throughout the Northwest Atlantic from 2000-2007, and dominated the relative abundance counts in all seasons (Pepin et al., 2011).

6.3.2 Population shifts in commercial species

Landings totals on the Flemish Cap, along with community structure in both species targeted by commercial species and non-target species, have fluctuated again in recent years as functions of both changing ocean conditions and management actions (Perez-Rodriguez et al., 2012). Landings data at the start of the era are quite similar to the end of the 1977-1999 era (see Figure 29 and Figure 43), but with overall fisheries yield increasing through 2003 as a result of the dominance of shrimp fishing activity (Figure 43). Overall system yield from 2000-2004 is comparable with the output of other highly productive eras (1972-1979, and 1989-1994 (see Figure 27)), and was only surpassed by the heavily exploited cod stocks of the 1960s and early 1970s, and the explosion in redfish landings in the late 1980s.

System yield has recently declined, driven by declines in Northern shrimp landings following 2004. Landings from the redfish and Greenland halibut fisheries have remained fairly constant, with the apparent landings trade-off between cod and shrimp evident in Figure 43.

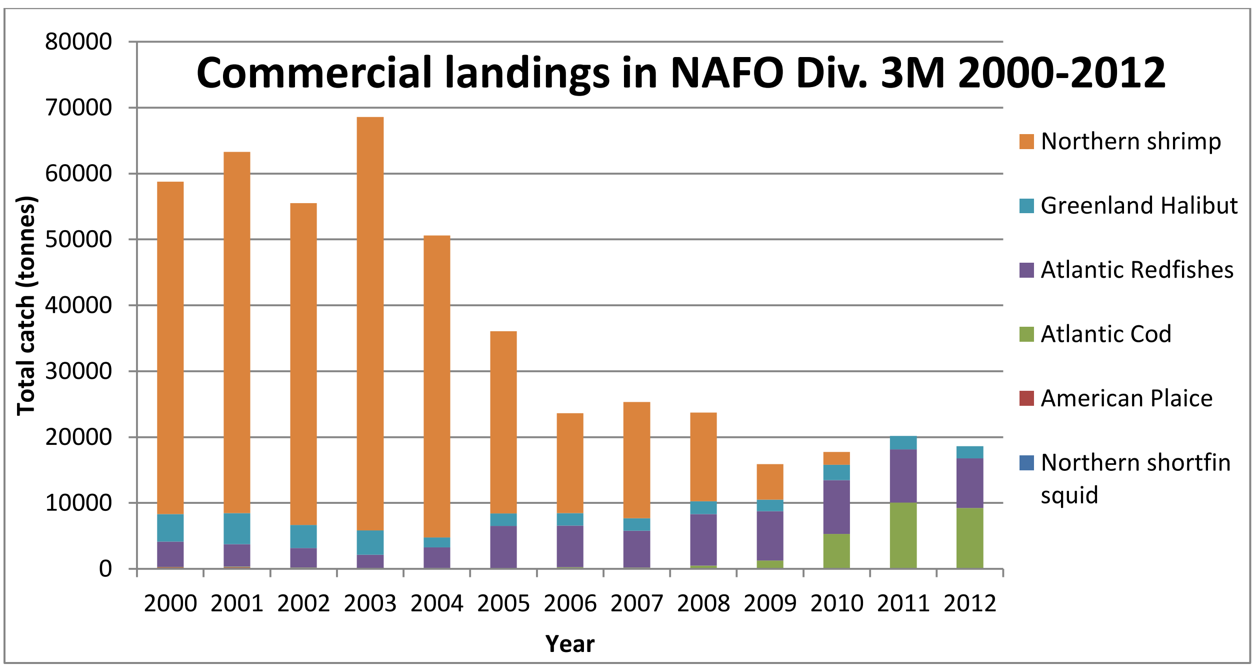


Figure 43 Landings of major commercial targets in NAFO Div. 3M 2000-2012. Shrimp landings dominated the contemporary era until productivity declines warranted the implementation of a moratorium. Cod landings rebounded at the end of the era, coinciding with the removal of a fishing ban targeting the species.

6.3.2.1 Atlantic cod

The effects of the 3M Atlantic cod moratorium established in 1999 are evident in the first two-thirds of the era, where cod landings totals were held very low. As the graph approaches the present period, we see an increase in cod landings coinciding with the removal of the moratorium in 2010. The biomass growth, removal of the moratorium, and increased landings coincide with warmer temperatures on the bottom and throughout the water column in the Cap region and increased consumption of shrimp (Casas, 2012).

6.3.2.2 Redfish

Redfish Total Allowable Catch remained constant and in line with the recommendations of NAFO's Scientific Council between 2000-2007, but from 2009 onwards has been set higher than suggested (NAFO, 2011b)[4]. Landings have increased slightly over this timeframe, probably indicating increased stock levels (NAFO, 2011b).

6.3.2.3 American plaice

The moratorium on 3M American plaice instituted in 1994 has continued through to the present. Recovery of the species has been slow, and fishing effort will continued to be blocked by policy through 2014 (NAFO, 2011a).

6.3.2.4 Northern shrimp

Northern shrimp landings varied wildly though 2000-2012. The shrimp fishery started in the early nineties and fuelled by the environmental context and favourable trophic interactions of the era, continued to account for a large percentage of overall landings in the Cap regions until 2008. Shrimp populations declined along warming conditions and cod biomass growth, the antithesis of the setting that promoted shrimp growth a decade

[4] NAFO 2011c disputes this statement, indicating that TAC levels have been set essentially in line with recommendations in this period.

earlier. Shrimp populations declined so drastically that within eight years the fishery that provided some of the highest yields in the Cap's recorded history (Figure 43) was subject to a (continuing) moratorium, which began in 2011.

6.3.2.5 Greenland halibut

From the landings data provided in Figure 16 and Figure 43 it is evident that halibut landings in this era were highest in the earlier years, decreasing slightly.

6.3.2.6 Northern shortfin squid

As with the previous fisheries eras examined, there were very few squid landings on the Cap from 2000-2012. The biggest annual total was just over 20 tonnes in 2006; no other annual landings surpassed 10 tonnes.

6.3.3 Trophic dynamics and System Stability 2000-2012

Although not as erratic as the 23 year interval preceding the contemporary range, the Flemish Cap's biological community experienced important changes between 2000 and 2012. The apparent biomass production trade-off analyzed in Chapter 2.3.4 (Trophic dynamics and apparent trade-offs in biomass production) between cod and shrimp appears to have shifted in favour of cod once again, with environmental trends, specifically temperature and salinity increases, a likely mechanism driving changes in trophic interactions, community structure, and landings (Perez-Rodriguez et al., 2012). Redfish is another important player in overall system stability, as the species has key interactions with cod and shrimp that influence system shape and functioning (Perez-Rodriguez et al., 2012).

6.4 SUMMARY

Fisheries yields, both in terms of total landings and nature of landings (i.e. what species make up the catch) are heavily influenced by environmental context, as well as by management regulations. Confirming the former relationship, recent environmental data has been presented here and overlapped with the landings data from the era. Although the strategy for creating distinct temporal delineations has made the 2000-2012 the shortest timeframe assessed in this paper, there have been clear, important shifts in landings data in just a few years and changes in management tactics (e.g. lifting the cod moratorium, imposing the shrimp moratorium, shifts to management ideologies). The warming trend has occurred throughout the water column, and is likely a contributing factor for the decline of shrimp populations in the area and the rise of the once dominant cod stocks.

Tying these changes in the biotic community and oceanographic conditions to policy in the modern era will be the focus of the next chapter. This follows the same analytical path followed in Chapters 3 and 4 which targeted this link in previous decades. Together, these summaries will create a picture of how the environmental characteristics, biological attributes and managerial approaches have progressed together since 1960. This picture will serve as a reference for later chapters when NAFO response capacity will be assessed.

CHAPTER 7. MANAGEMENT AND REGULATORY RESPONSES TO RECENT ENVIRONMENTAL AND BIOLOGICAL CHANGES 2000-2013

7.1 INTRODUCTION

Now that environmental conditions and fisheries yields have been presented for the 2000-2013 timeframe, here I explore the management routes taken by NAFO in response to changing conditions and fisheries yields. Contemporary management has expanded into additional avenues than in previous timeframes, and has included classical management options such as TACs, gear and size restriction on catches, but some fundamental approaches have been reformed to address new understandings of ecosystem functioning (colloquially the 'goods and services' provided by ecosystems) and its relationship with fisheries yields. Improving ecosystem functioning and fisheries yield by protecting system components other than solely those directly exploited is an ideology upon which many recent management transitions have been based.

Detailing how management has changed in response to production in recent years will serve as the basis for determining NAFO's capacity to achieve management goals under future ocean conditions, which will be the focus of Chapter 8.

7.2 CHANGES TO FUNDAMENTAL APPROACHES GUIDING NAFO POLICY INTRODUCED BETWEEN 2000-2013

Policy and management strategies, approaches and decisions employed by NAFO are founded on a set of philosophical ideologies that have evolved as dictated by research and wider policy implementation. There has been a substantial shift in these ideologies since

2000, with the background for approaches and decisions shifting in fundamentally important ways. Management frameworks integral to NAFO's process are outlined below.

7.2.1 Precautionary Approach

The Convention on Biological Diversity (CBD) introduced the precautionary approach (or principle) into international environmental legislation at the Rio Earth Summit in 1992. In essence, the approach states that actions or policy whose outcomes are uncertain due to a lack of scientific knowledge should not be taken without proof that damage to the public and the environment will be avoided. In the context of fisheries management, the precautionary approach provides protection to fishery resources by legally requiring[5] management policies to ensure exploitation rates are not at levels which could result in decreasing biodiversity. However, the complex nature of marine ecosystems makes such systems, and their components, difficult to quantify and therefore difficult to accurately model. The uncertainties that, to date, cannot be explained by scientific methods have been addressed by NAFO management strategies in the form of stock limits and reference points, where thresholds exist that, when crossed, trigger management responses.

Stock limits and reference points are biomass or population or fishing mortality levels identified by fisheries scientists that are specific to a stock and are theoretical boundaries that colloquially signify varying degrees of stock health. Upper stock reference points mark the boundary between a healthy stock size and one that needs to be managed cautiously. Limit reference points mark the boundary between a stock size that must be managed with

[5] In jurisdictions where the CBD has been ratified

caution and one that is experiencing a critical population size (where productivity and sustainability are impacted).

Inserting these limits, along with buffer zone limits, serves to incorporate the precautionary principle into stock assessments. The limits allow for measurement, biological and ecological uncertainties to be accounted for (by the buffer zones) in order to improve stock stability. NAFO management has employed these points as an index of stock biomass or as fishing mortality. Figure 44 provides a representation of how, when implemented together, they can describe a stock's stability.

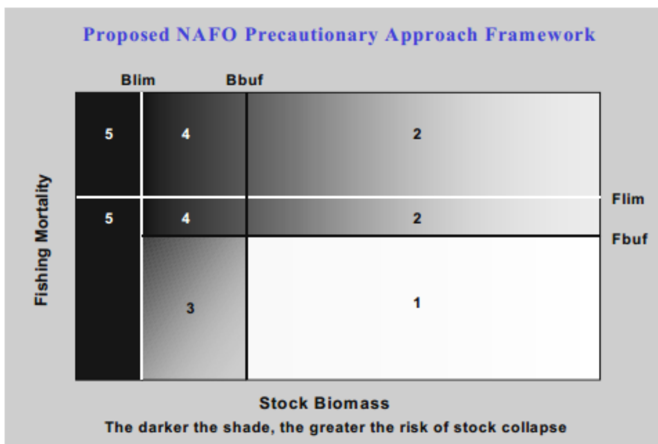


Figure 44 A conceptual diagram noting theoretical stock boundaries divided by limit and buffer points (from NAFO, 2004). Incorporating these reference points are designed to increase stock stability and align management decisions with the precautionary principle. Stock stability is portrayed as a gradient, decreasing as the panels become darker. The most stable stock scenario is labeled 1, and least stable scenarios are labeled 5. Biomass limit and buffer points are portrayed on the horizontal axis (B_{lim} and B_{buf}, respectively); fishing mortality limit and buffer points are placed on the vertical axis (F_{lim} and F_{buf}, respectively).

A Precautionary Approach Framework was adopted by NAFO's Fisheries Commission in 2004 after being proposed in 2003 (NAFO, 2004) (see Figure 44).

7.2.2 Multi-Year Management Plans

Rather than discrete annual assessments and quota decisions, NAFO manages certain stocks through Multi-Year Management Plans. The Greenland halibut stock managed by

NAFO is one example (see 7.3.4- Greenland halibut) where a long-term management goal has been identified, and TAC's have been identified accordingly (NAFO, 2011b).

7.2.3 Ecosystem approach

In previous eras, fisheries resources were managed in a more discrete manner, where single-species biological attributes and time series garnered significant attention largely apart from ecological interactions and environmental conditions. The ecosystem approach incorporates species ecology, i.e. predator-prey relationships and trophic dynamics into management decisions, with the goal of ensuring stock productivity and yields through the maintenance of the ecosystem as a whole and recognition of apparent trade-offs among interacting species.

Incorporating the ecosystem approach into NAFO's management operations started with the creation of the Working Group on Ecosystem Science and Assessment (WGESA) in 2008. Management options suggested by this group (and implemented) were designed with the United Nations Food and Agricultural Organization's International Guidelines for the Management of Deep-Sea Fisheries on the High-Seas in mind (NAFO, 2011d), and include protection of ecologically sensitive areas from bottom-trawling (including areas in the Flemish Pass and areas surrounding the Cap) (NAFO, 2011d) and alleviation of fishing effort focused on important forage fish (capelin, in Division 3NO).

To date, strategies identified by the Working Group for implementing the ecosystem approach into NAFO policies have been limited to these areas, and activities carried out by the Group are otherwise separate from NAFO activities. There is a level of irony embedded in this fact- the ecosystem approach fundamentally is a holistic, encompassing, connecting ideology that recognizes how system components and functional groups are related and dependent. Incorporating the ecosystem approach into policy in a discrete manner, where strategies are carried out independently of other policy contradicts the approach's aims and intentions.

7.2.4 Management Strategy Evaluation (MSE)

The Management Strategy Evaluation framework, introduced in 2010, is a method for determining TACs for Greenland halibut through a formula that incorporates an eXtended Survivors Analysis (XSA, a statistical method for assessing catch-at-age and abundance indices) as well as a Statistical Catch At Age (SCAA) analysis. This TAC determining tool aims to improve stock stability by combining various management strategies, and is designed to include views from different stakeholders, while allowing for management uncertainty and trade-offs. The formula used in this management method varies between species, and can take several years to be developed.

7.2.5 Conservation Plans and Rebuilding Strategies (CPRS)

The UN Fish Stocks Agreement, an important piece of international fisheries legislation, requires contracting parties to develop Conservation Plans and Rebuilding Strategies for depleted stocks. In the contemporary era, NAFO has developed and refined conservation strategies for American plaice in Division 3LNO and Atlantic cod in 3NO (NAFO, 2010a). This work includes assessment of stock limit and buffer points (see Figure 44), establishing timelines for rebuilding strategies to meet their goals, identifying conditions that might allow a directed fishery to operate, and the creation of species specific harvest control rules, implemented in a manner that that promotes stability in response to resource fluctuation that could reasonably be expected (NAFO, 2010a).

7.3 Total Allowable Catch for Commercial Species of the Flemish Cap 2000-2013

Fisheries on the Flemish Cap are managed through an exploitation limitation scheme that regulates the total directed and bycatch take by all contracting parties. This total varies depending on stock health; as Figure 39 and Figure 40 did for earlier periods, Figure 45 shows the TAC's set for the various commercial species in the contemporary period. The rationale behind quota fluctuations will be provided by species.

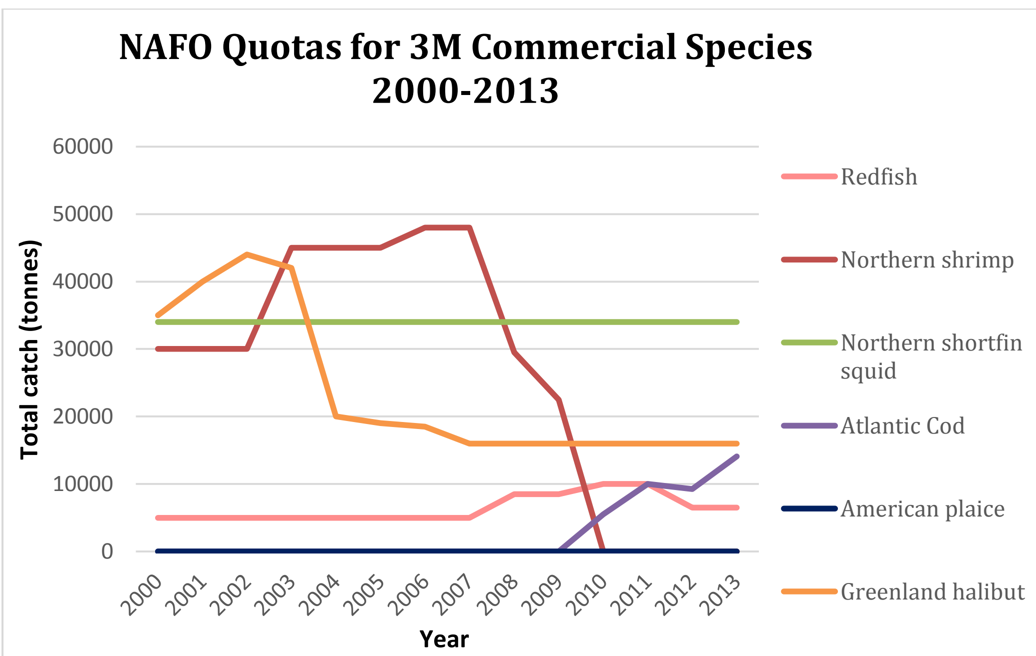


Figure 45 NAFO Quotas for Commercial Species on the Flemish Cap 2000-2013. Note that Greenland halibut TAC is for NAFO Divisions 3 and 4. Shrimp TACs are those recommended by the Scientific Council, as catch levels for shrimp are regulated by effort (fishing days). The data points for 2008 and 2009 are the mid-point of the quota range; for these years, TACs were recommended to be 17 000-32 000 t, and 18 000-27 000 t, respectively.

7.3.1 Atlantic cod

Following the moratorium of the late 20th century, cod quotas on 3M remained at zero until 2010, and since then have risen to 14 113 t (NAFO, 2013b). The environmental and ecological factors leading to the former Atlantic cod productivity decrease have been previously examined; whereas the absence of exploitation, warmer temperatures and elevated salinity have driven strong cod recruitment and production leading to the re-opening of the Flemish Cap's cod fishery in 2010- the same year the Scientific Council started recommending a moratorium for the area's shrimp fishery (a moratorium would be installed starting in 2011).

7.3.2 REDFISH

Redfish quotas were set between 5 000 t and 10 000 t in the contemporary timeframe. Fishing effort since 2000 has primarily been exerted by Russian and Portuguese fleets, but bycatch from the reopened cod fishery has also contributed to redfish mortality (NAFO, 2011c). Redfish biomass in the early 2000s was dependant on the survival and growth of existing cohorts; above average year classes and high survival rates resulted in an increased biomass starting in 2003 and continuing through 2007-2008, with management responding by increasing quotas in 2008, 2010, and 2013 (Figure 38). Total Allowable Catch decreased in 2011 as (non-fishing) mortality increased with biomass decreasing as a result (NAFO, 2011c).

7.3.3 AMERICAN PLAICE

American plaice management has not changed in the 14 years included in the contemporary timeframe as the moratorium installed in the mid-1990s continues to be in effect due to small stock sizes.

7.3.4 Greenland halibut

Management response to a decline in halibut landings in the mid 1990s resulted in the creation of a 15-year rebuilding plan (adopted in 2010). Total Allowable Catch was reduced to 16 000 t with the goal of allowing halibut adult biomass (5+ year classes) to grow to 140 000 t, a level thought to support sustainable exploitation. Since 2011, Greenland halibut has been managed according to a harvest control rule (HCR) that adjusts the TAC from year to year through the following formula[6,7]:

$$TAC\ y{+}1 = TAC\ y\ (1 + \lambda * \text{slope}).$$

This formula is further defined by limitations in year to year quota variance; new TAC's must be ± 5% of the TAC in the preceding year (NAFO, 2012a).

It is important to note that the TAC's presented in Figure 45 are the quotas for NAFO areas 1-4 rather than specifically to 3M. This reflects the genetic homogeneity of the Greenland halibut's population across its Northwest Atlantic distribution.

7.3.5 Northern shrimp

Shrimp management was primarily conducted through quota changes; there were five different quotas recommended for the species on the Flemish Cap in the years 2000-2010 alone. Changing productivity, driven positively in the first half of the decade by favourable

[6] Where λ is set to 2.0 if the slope is negative and 1.0 if the slope is positive
[7] Where slope equals the measure of the recent trend in survey biomass

environmental conditions at the end of the previous decade, and decreased predation pressure by cod resulted in elevated quota and landings. When these conditions reversed in the latter half of the decade (and perhaps after a lag of 4+ years that accounts for the length of time before most adult shrimp are captured by the fishery), shrimp quota declined from its historical peak in 2007 to the moratorium implemented in 2010.

Shrimp TACs are achieved through effort regulation rather than quota allocation. Effort regulation strives to limit catch by limiting effort; in the case of the 3M shrimp fishery, effort was measured by days fishing.

7.3.6 Northern shortfin squid

NAFO's squid management in 3M did not result in any quota shifts from 2000-2013. Landings were essentially insignificant as squid production, restricted by environmental context, was negligible for the duration of the contemporary period when thought of in the context of overall system productivity.

7.4 Gear regulations

Generally speaking, NAFO's regulations on gear requirements apply to the whole of the NAFO Convention Area. Regulatory requirements targeting gear have increased since the turn of the century with the goal of reducing pressure on undersized animals and reducing bycatch as outlined here.

At the start of the century, gear regulation in the form of minimum mesh sizes existed for three fisheries (NAFO, 2000), with three more requirements introduced between 2000 and 2013. The regulations already in place before the contemporary era are denoted with an *.

	Species	Mesh Size
a)	All principal groundfish, flatfishes and other groundfish (with the exception of capelin)*	130 mm
b)	Short-finned squid*	60 mm
c)	Shrimps and prawns*	40 mm
d)	Skate – codend All other parts of trawl	280 mm[8] 220 mm[9]
e)	Pelagic redfish (Subarea 2 and Divisions 1F and 3K)	100 mm
f)	Redfish (for fisheries using mid-water trawls) in Division 3O	90 mm

The first addition to these requirements in the contemporary era occurred in 2002, targeting skate harvesting (below) (NAFO, 2002). Mesh size regulations were introduced for oceanic redfish (*Sebastes mentella*) fisheries in Subarea 2 and Divisions 1F and 3K in 2007 (NAFO, 2007a).

A gear requirement installed by NAFO in 2008 targeted redfish operations focusing on the middle of the water column (NAFO, 2008a), and similar to the requirement added in 2007, targets both specific species (redfish) and regulatory zones (Division 3O).

In 2013, the redfish gear restriction added in 2008 was expanded to include Division 3M (Flemish Cap), and is restricted from coming in contact with the sea floor. Further to this, redfish trawl gear was restricted from including discs, bobbins or rollers on its footrope or any other attachments designed to make contact with the bottom but may have chafing gear attached (NAFO, 2013c).

[8] In effect from 01 July 2002
[9] In effect from 01 January 2003

7.5 Area Closures

The desire to protect ecosystem components other than those targeted by commercial fishery stems from the ecosystem approach to management, incorporated into NAFO's management strategy in 2007 in NAFO's Amended Convention (NAFO, 2007b). This has been integrated into policy through the protection of areas with important biodiversity from bottom trawling. There are currently 18 areas closed to fisheries that involve bottom contact; this practise started with four closures in 2006 (NAFO, 2006a), and was followed with additional closures in 2007 (NAFO, 2007c), 2008 (NAFO, 2008b; NAFO, 2008c), 2009 (NAFO, 2009a; NAFO, 2009b) and 2011 (NAFO, 2011e). These areas (see Figure 46 and Figure 47) protect sedentary benthic invertebrates (corals and sponges) that are widely distributed (Wareham and Edinger, 2007) and considered important for system biodiversity and functioning.

7.6 NAFO Resolutions 2000-2013

NAFO Resolutions are amendments to the Convention on Future Multilateral Cooperation in the Northwest Atlantic Fisheries often installed as new information is provided through research, or to adhere to applicable legislation that did not exist when the Convention was originally developed. There have been three Resolutions entered into force by NAFO since the turn of the century, addressing different management deficiencies.

7.6.1 Resolution to Reduce Sea Turtle Mortality in NAFO Fishing Operations

The Resolution to Reduce Sea Turtle Mortality in NAFO Fishing Operations was proposed and entered into force on 22 September 2006, and formally recognizes the cultural and ecological significance of sea turtles in the Northwest Atlantic Ocean (NAFO, 2006b). The Resolution introduces conservation strategies with the goal of reducing by-catch, mainly through data recording (gear type, condition of animal upon catch and release) and fostering international cooperation.

7.6.2 Resolution on the Interpretation and Implementation of the Convention on the Future Multilateral Cooperation in the Northwest Atlantic Fisheries

The second Resolution in the contemporary timeframe (entered into force in January 2008) aims to clarify specific interpretation and implementation of the legal Convention that gives NAFO its mandate and authority. Of the eight measures, the most notable are the application of the precautionary principle, integration of the ecosystem approach to fisheries management (stated as 'taking due account of the impact of fisheries on other species and marine ecosystems, and in doing so adopt measures to minimize harmful impacts on living marine resources and marine ecosystems'), ensuring compliance with guidelines while adequately penalizing violations, and developing measures to prevent, deter and eliminate illegal, unreported and unmanaged fishing activities (NAFO, 2008b).

7.6.3 Resolution on the Protection of Vulnerable Marine Ecosystems From Activities Other Than Fishing

Entered into force in January 2012, the most recent Resolution strives to protect vulnerable systems in NAFO's jurisdiction by urging other international organizations to mitigate and reduce the risk of damage from at-sea activities (NAFO, 2008d). Efforts taken by NAFO to protect Vulnerable Marine Ecosystems (VMEs) include closures to areas where bottom trawling may cause damage to important species and contribute to biodiversity decline; these closures are also justified by NAFO's ecosystem approach (see Section 7.2.3). Closures in the vicinity of the Flemish Cap installed in 2011 are noted in Figure 46 (NAFO, 2011f); 2012 closures are noted in Figure 47 (NAFO, 2012b).

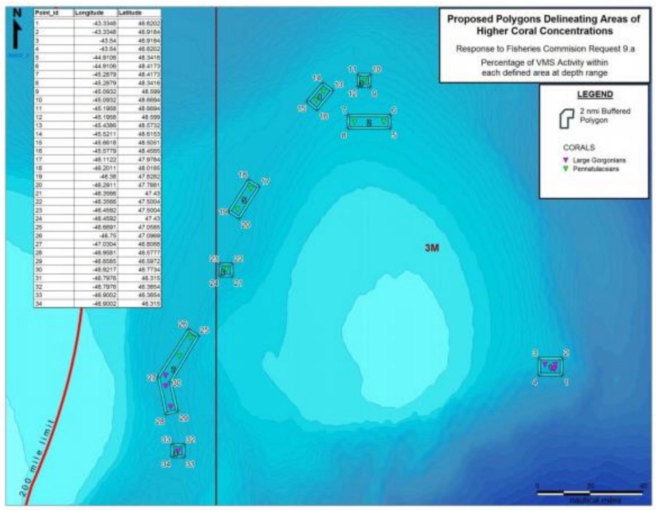


Figure 46 Areas in the Flemish Cap region closed to bottom fishing starting in 2011 (NAFO, 2011f). The closures are designed to protect Vulnerable Marine Ecosystems (VMEs) that exist on and around the seafloor in these areas.

NAFO has continually been adapting and refining its VME approach since these areas were identified as having relevance to the organization's goals. The list of VME species has been expanded, the fishing footprint of the organization has been defined, and exploratory fisheries are now possible (Koen-Alonso, personal communication).

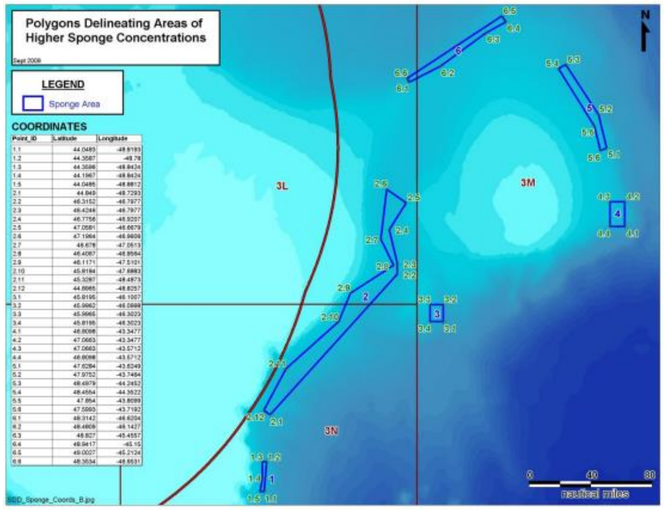


Figure 47 Areas in the Flemish Cap region closed to bottom fishing starting in 2012 (NAFO, 2012b). The closures are designed to protect Vulnerable Marine Ecosystems (VMEs) that exist on and around the seafloor in these areas.

7.7 Discussion

Summarizing NAFO's policy decisions over a defined timeframe indicates general trends in management approaches, but separating these developments from quotas and landings obscures their connectedness. To provide context for policy changes, quota and landings have been depicted in Figure 48, with major policy changes noted according to their year of implementation. This information includes TAC settings for 2013 but does not include landings, as this data is not available at the time of writing.

To align this summary with the goal of uncovering how environmental cues have influenced policy making, a climate indication bar is inserted at the top of the following figure, similar to how temperature was incorporated into Figure 39 and Figure 40. This bar is derived from the climate data presented in Table 12, but relative temperatures have been removed so that years with higher than average temperatures are not differentiated. Although this presentation omits the relative degree of temperature deviation from the norm, it is designed to demonstrate which years experienced environmental conditions promoting cod growth.

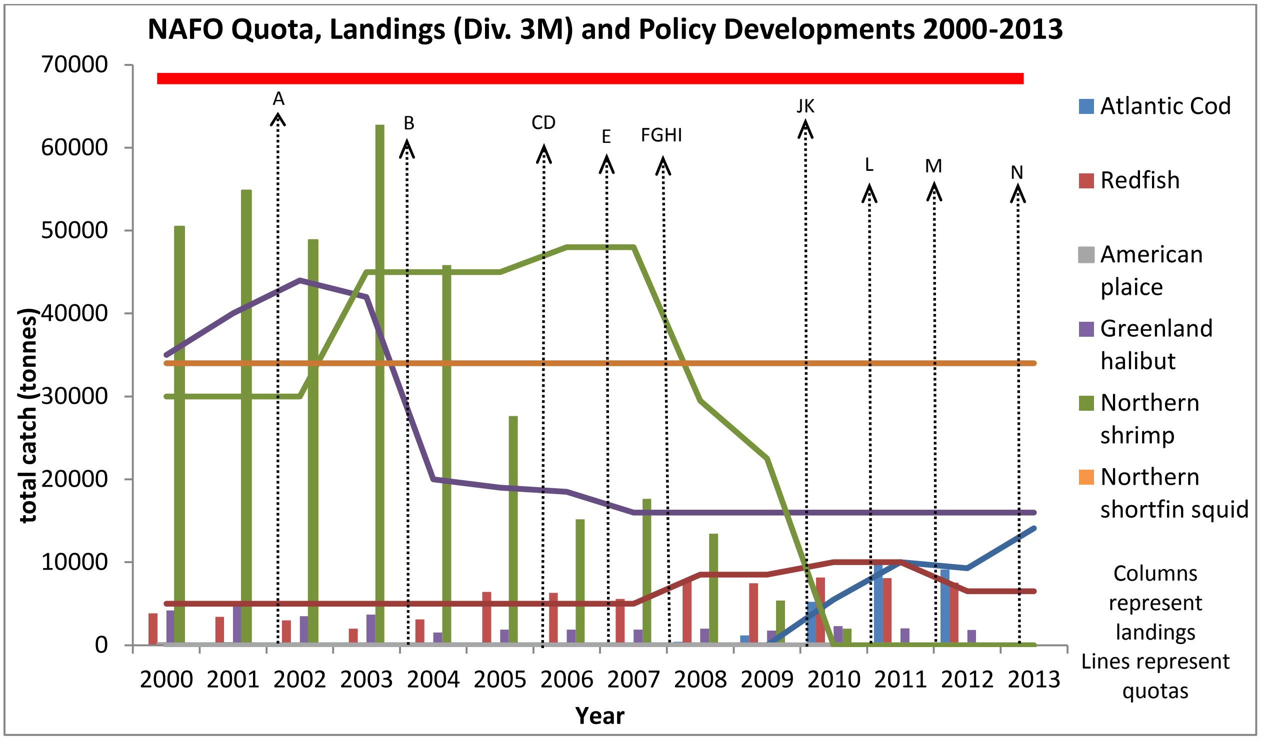


Figure 48 NAFO Quotas and Landings for Division 3M, with major policy developments noted. Letters correspond to policy changes described in Table 15. The red bar at the top of the figure denotes years where water temperature was above average; in this case, all years from 2000-2012 were warmer than the historical average.

Policy changes are represented on the graph as letters; a legend with corresponding explanations describing policy type, nature of the change and driving cause are provided in Table 15.

Table 15 Legend and description of NAFO policy changes noted in Figure 48.

Event	Year implemented	Policy	Root driver of policy	Source
A	2002	Skate fishery gear/mesh regulation	Ecosystem considerations	(NAFO, 2002)
B	2004	Precautionary approach	Species conservation	(NAFO, 1999)
C	2006	Resolution to Reduce Sea Turtle Mortality in NAFO Fishing Operations	Ecosystem considerations	(NAFO, 2006b)

D	2006	Area closures	Ecosystem considerations	(NAFO, 2006a)
E	2007	Redfish fishery gear/mesh regulation in Subarea 2 and Divisions 1F and 3K	Ecosystem considerations	(NAFO, 2007a)
F	2008	Resolution on the Interpretation and Implementation of the Convention on the Future Multilateral Cooperation in the Northwest Atlantic Fisheries	Ecosystem considerations	(NAFO, 2008b)
G*	2008	Major reduction of shrimp TAC	Species conservation	(NAFO, 2011b)
H	2008	Management strategy evaluations and harvest control mechanisms	Species conservation	(NAFO, 2012a)
I	2008	Ecosystem approach	Ecosystem considerations	(NAFO, 2007b)
J	2010	Conservation plans and rebuilding strategies	Species conservation	(NAFO, 2010a)
K*	2010	Cod moratorium lifted (3M)	Economic considerations	(NAFO, 2011b)
L*	2011	Shrimp moratorium (3M)	Species conservation	(NAFO, 2011b)
M	2012	Protection of Vulnerable Marine Ecosystems from Activities Other Than Fishing	Ecosystem considerations	(NAFO, 2007c)
N*	2013	Redfish gear/mesh regulations expanded to Division 3M	Ecosystem considerations	(NAFO, 2013c)

It is clear from these data that increased regulatory effort and policy design has coincided with decreased system productivity on the Flemish Cap in the contemporary era. Each year from 2009 to 2012, total landings on the Cap were lower than any year from 1960-2008. Policy reform since this time has focused on improving the state of the ecosystem as a whole, a different reaction to previous productivity declines which elicited a species-specific response from managers. A summary of policy implementations by climate context is included in Table 16. Relating previous policy events to temperature regimes may indicate the pace of future policy reform under different oceanographic scenarios.

Table 16 Summarizing NAFO policy events from 2000-2013.

Policy Characteristics		Number of implementations	
		In warm years	In cool years
Biological	Ecosystem Considerations	8	0
	Species Conservation	5	0
Social	Species/ecosystem conservation through international diplomacy	0	0
	Data/management improvement	0	0
	(primarily) economic considerations	1	0

A recent study by Gilman et al. (2013) provides insight into how well global RFMO's are functioning (relative to each other) in their attempts to improve ecosystem health through reducing bycatch and discards. Their composite index (combining several elements of management, including observer monitoring and data quality, bycatch data collection protocols, observer coverage rate, ecological risk assessment, etc.) indicated that NAFO has the third best performance record of the 13 RFMO's assessed (Gilman et al., 2013). NAFO performed strongest in regional observer coverage rates, observer data quality, and surveillance, enforcement and outcomes (Gilman et al., 2013). These findings, especially with respect to surveillance, enforcement and outcomes (where NAFO achieved a score of 95%) are especially interesting considering how they contrast with Day's (1995; 1997) comments on enforcement capacity. Gilman (et al., 2013)'s findings suggest that NAFO has made a strong turn around in this area, driven by the Institution's commitment to the ecosystem approach to fisheries management (see section 7.2.3-Ecosystem Approach).

While this turnaround is critical and should not be understated, management deficits remain.

7.8 Conclusion

Management of the Flemish Cap's marine resources in recent years has been complicated by declining production (assuming that shifts in landings reflect a shift in underlying productivity). NAFO responses has included minor reforms (gear, TAC change), and major reforms (moratoria, fundamental shifts to policy approaches) in order to increase long term resource stability and maximize economic outcomes. The majority of NAFO's initiatives in the 2000-2013 timeframe, whether the result of overarching international legislation or internal research and decision making, clearly shift focus from species-specific management to more integrated approaches designed around management of a wider scope of the ecosystem. In the past, resources received management support directly; this has shifted to include indirect support through protection of ecosystem components that contribute to not only fisheries yield, but overall system stability through the distribution and abundance of non-target species and early life stages (although these often go hand in hand).

This trend of shifting managerial ideology is accompanied by a noticeable increase in management response coinciding with decreased system productivity. This is reminiscent of previous instances where policy implementation occurred more often than usual rate following decreased landings (see Figures 39, 40, and 48).

CHAPTER 8. NORTHWEST ATLANTIC FISHERIES ORGANIZATION: A LEADER OR FOLLOWER OF ENVIRONMENTAL CHANGE?

8.1 INTRODUCTION

Previous chapters have presented important policy approaches and events during historical and contemporary fisheries management eras in the Northwest Atlantic. To describe the context in which these events occurred, environmental data and landings data have been included for the respective eras. Overlapping these data sets allows investigations into how management ideologies have evolved and responded to challenges of respective eras. These reviews facilitate determining the likelihood that future management routes employed by NAFO will address environmental variation. The conclusions drawn from these sections will be instrumental in trying to answer the question 'has NAFO been a leader or follower of fisheries management during environmental change?', and determining the Institution's capacity to integrate environmental context into management approaches. This question is mandated by the strength of the evidence linking fisheries production to environmental parameters, the invariable goals of improving resource stability and social welfare, and global climate forecasts.

Assessing whether NAFO policy will be influenced by environmental context in the future can be carried out by determining if previous decision making has been reactionary or proactive. Designing policy to meet goals based on expected environmental conditions would exemplify a proactive management behaviour- based on previous decision making trends, can this be expected?

8.2 TAC DESIGN AND RESPONSE

Of the management tools available to regulatory bodies, TACs have been widely used by in the Northwest Atlantic since the early 1970s, and all six commercial species on the Cap have been regulated by catch controls. Assessing how they have been implemented by NAFO in different production scenarios can be thought of as a type of indicator for how the Organization will likely respond to future shifts.

8.2.1 SHRIMP

Shrimp landings on the Flemish Cap were essentially zero until the early 1990s, when the biomass increased and a direct fishery formed. Recommendations for the 3M shrimp TAC were not made until 1999, and fishery closure occurred in 2011 (after being recommended for 2010). Quota recommendations did not quickly react to, or foresee the landings declines that the 3M shrimp fishery experienced in the late 2000s. As evident in Figure 48, shrimp landings decreased substantially before quota levels were redesigned to fit the new species production levels. This may have been the result of a management trade off, where heightened risk was accepted to meet other management goals.

8.2.2 REDFISH

A similar response is evident in NAFO TAC management of redfish in the 1990s. Total Allowable Catch levels were remarkably similar to landings totals the previous year, and failed to respond when landings decreased substantially in the second half of the decade. This is particularly noticeable in years 1995-1997 (see Figure 39 and Table 17).

Table 17 Landings and following year quotas for redfish in Div. 3M. Quota management appears to be reactionary until 1993, and unresponsive afterwards despite substantial declines in production

Year	Landings (tonnes)	Quota in following year
1989	47697	50 000
1990	66887	50 000
1991	41406	43 000
1992	31470	30 000
1993	21611	26 000
1994	9914	26 000
1995	6748	26 000
1996	1140	26 000
1997	424	20 000
1998	972	13 000
1999	795	

It appears as though the TAC levels for redfish in this era were particularly reactionary for the first half of the decade, and then totally unresponsive to production in later years. It seems that landings are determining quota here, instead of quota determining landings (the implied intent of TACs).

8.2.3 Northern shortfin squid

Total Allowable Catch for squid in 3M has been reactionary as well, in historical and contemporary eras. This is not due to quota adjustments, but rather a lack of adjustments. It has been noted several times in this discourse that squid productivity has been severely limited by environmental context on the Flemish Cap, but yet quota levels remain constant and elevated. Initially, squid quotas were implemented at a high level due to a lack of knowledge, presumably to be tailored as warranted by landings. This is another important example of how NAFO's TAC based management has been reactionary rather than proactive.

8.2.4 Greenland halibut

Greenland halibut quota management has recently (2011) changed to the harvest control rules method of determining TAC. The formula: TAC y+1 = TAC y (1 + λ * slope), explained in 7.2.3, provides a transparent mechanism for determining TAC and incorporates the most recent biomass trends as indicated by surveys.

8.3 NAFO Resolutions

Resolutions implemented by NAFO occur irregularly and, rationalized by the organization's goals, commitments and legislation, provide legal framework supporting new approaches or policies. Resolutions represent an important area to be assessed when determining institutional capacity for responding to climate change.

8.3.1 Resolutions 1979-1999

Resolutions implemented by NAFO from its formation until the end of the century were predominantly measures designed to react to challenges of the era. Illegal fishing and data transmission were addressed as events warranted, with all Resolutions in the era, with the exception of Resolution (2/99, on the precautionary principle) existing as reactive policy.

8.3.2 Resolutions 2000-2013

The Resolutions implemented in the contemporary period (see section 7.6) can all be thought of as proactive policy installations. In particular, 2008's Resolution on the Interpretation and Implementation of the Convention on the Future Multilateral Cooperation in the Northwest Atlantic Fisheries lays the framework for implementation of proactive policies, all which have been implemented to some extent in NAFO operations since its inception. The wide-reaching nature of the Resolution and its thoroughly proactive stance makes it among the most important single policy events in NAFO history (especially with respect to the likelihood of future proactive policies becoming implemented). Along with the other two Resolutions installed since 2000, the increasing dedication to creating proactive policy has resulted in the accumulation of institutional capacity to address challenges brought on by climate-driven productivity shifts.

NAFO Resolution 01/08 is an important step in NAFO's management evolution. This Resolution is an amendment to NAFO's convention, fundamentally changing NAFO's overall approach through immediate implementation of the organization's new convention.

8.4 Recent management approaches

8.4.1 Ecosystem approach

The installation of the Working Group on Ecosystem Science and Assessment is a decidedly proactive reform. The Group's goal is to incorporate the ecosystem approach into NAFO management through promoting conservation of fisheries resources indirectly through maintenance of important system components. The areas closed to bottom trawling noted in Chapter 7.5 are the manifestation of these efforts, as the VME's protected in these closures are not those targeted by capture fisheries.

This activity is an important example of proactive management, implemented not out of immediate necessity but to stabilize ecosystem health. However, the manner in which NAFO has included the ecosystem approach to management is not quite as integrated into policy as is warranted (see Chapter 7.2.3). To date, the ecosystem approach has been implemented through identification and protection of VME's and important system components, striving to achieve increased system stability through bottom-up pathways. Isolating the Organization's implementation of the ecosystem approach to this task overlooks the connectedness of which the approach is designed around. Implementing the ecosystem approach into a wider array of policy tools would be a prudent reform, and one that would increase the likelihood that NAFO attains its management goals under changing environmental conditions.

8.4.2 Precautionary approach

Integrating the precautionary approach into NAFO management is another example of how recent reforms have tended to be more proactive than reactive. The precautionary approach regulates management decisions so that future uncertainties do not impact management quality of the current period. Predicting complex systems, such as fisheries resources, that are influenced by countless social, biological and environmental drivers is difficult to the point where confidence in estimates may be low; limiting the impact that forecasting uncertainties have on management success is achieved through the use of the precautionary approach.

NAFO's development of a Precautionary Approach Framework started in the mid-1990's. The considerable reform that this framework entailed was developed by NAFO's Scientific

Council and debated by member states until 2008, when the framework was finalized. NAFO's has tried to develop an encompassing precautionary framework through their 'Roadmap to EAF', a strategy that encompasses VME management, MSE-based quota management while clarifying the role of the Scientific Council in the ecosystem approach framework.

8.5 Monitoring and enforcement

It has been noted that monitoring and enforcement weaknesses in NAFO's Convention Area have been an important reason why NAFO has not reached desired conservation outcomes. The Organization's ability to achieve future goals during changing environmental conditions, therefore, is partly reliant on its ability to effectively monitor effort and enforce its legislation.

The following figure (Figure 49) notes how fishing effort has decreased in the NAFO Convention Area from 2003-2011; Figure 50 shows how monitoring rates have progressed over the same period.

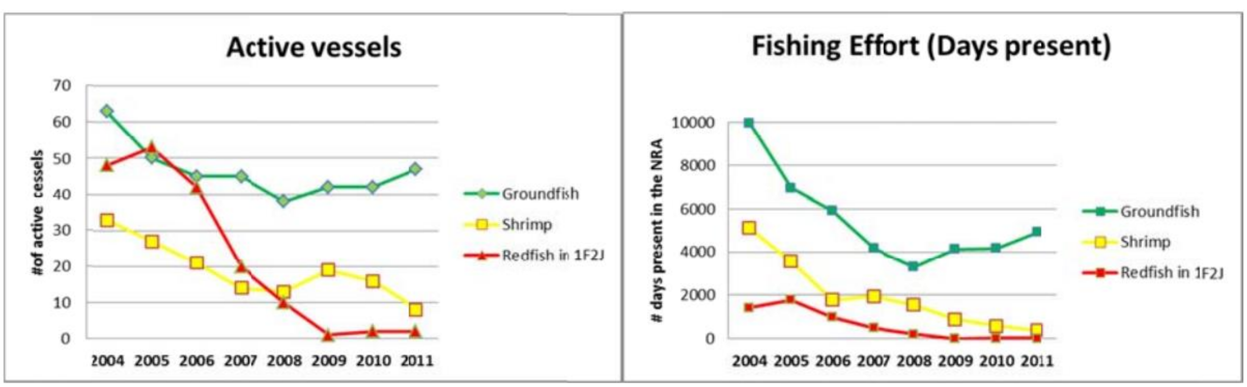


Figure 49 Number of active vessels and amount of fishing effort in the NAFO Convention Area, 2004-2011 (NAFO, 2012c). Substantial declines are evident in both graphs, owing to catch limitations and moratoria.

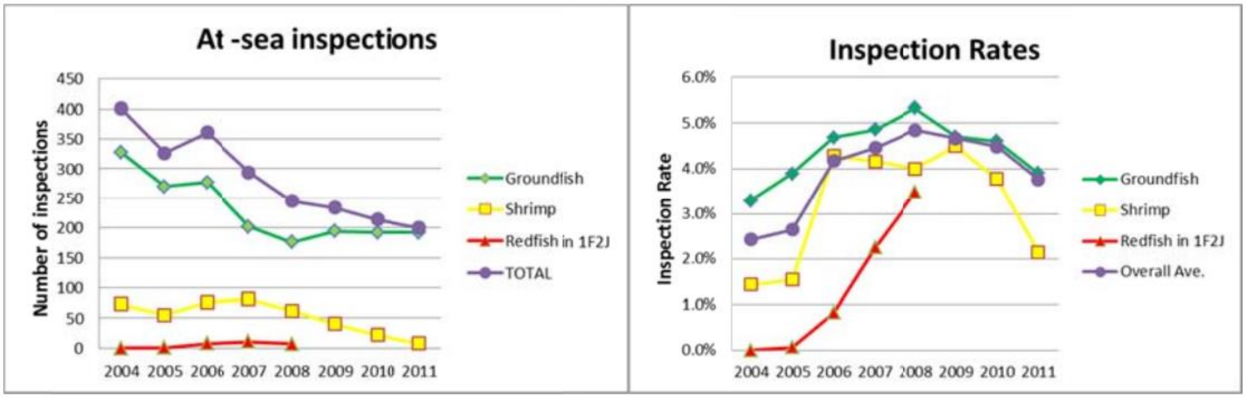


Figure 50 The number of at-sea inspections, and overall inspection rates in the NAFO Convention Area, 2004-2011 (NAFO, 2012c). While total inspections have decreased, the ratio of inspections to effort has increased in the period.

There is a clear decline in active vessels and effort over the period, and although inspection rates increased through the middle of the decade, the overall average declined each year after 2008.

The decline in inspection rates seems detrimental to NAFO's goal, but when adjusted for declining vessels and effort, inspection rates have actually risen from 2.4% of active vessels in 2004 to 3.8% in 2011 (NAFO, 2012c). Additionally, the at-sea citation rate has remained steady at around 4%, although citation rates for port inspections have decreased (NAFO, 2012c). These trends are noted in Figure 51.

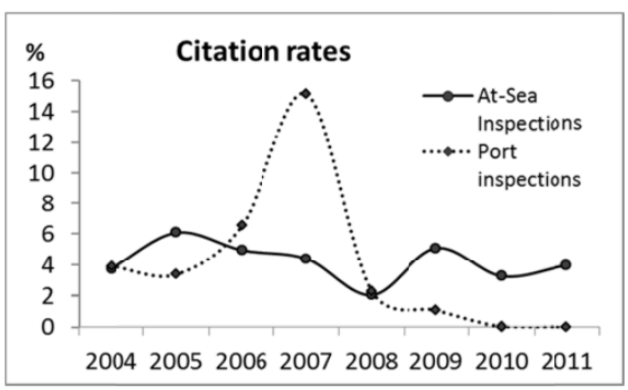


Figure 51 The percentage of inspections that resulted in citations in the NAFO Convention Area 2004-2011. Citation rates during at-sea inspections have remained fairly steady; citation rates for port inspections have fluctuated more aggressively (NAFO, 2012c).

These monitoring and citation trends are an improvement from the enforcement activities employed in the 1980s and 1990s. Continued improvement and dedication to enforcing

NAFO policies should be accompanied by continual strengthening of diplomatic channels to lower the likelihood of illegal fishing in the future. This combination should promote NAFO operations to be increasingly successful in managing its portfolio under changing environmental conditions.

Increased monitoring and enforcement will lower the likelihood of illegal fishing. The implicit assumption here is that if NAFO policies are more strictly adhered to, scientists and managers have better data from which to make decisions from, benefiting the sustainability of exploited species and ecosystem goods and services.

8.6 Conclusion

Fisheries management in the Northwest Atlantic has evolved along with biological trends and international legislation since ICNAF was founded. The policy events detailed in previous chapters (and summarized in Tables 7 and 15) start as predominantly reactive measures, but as understandings of species biology and system ecology have increased, major policy events have increasingly shifted from reactive to proactive. This shift is detailed in Figure 52.

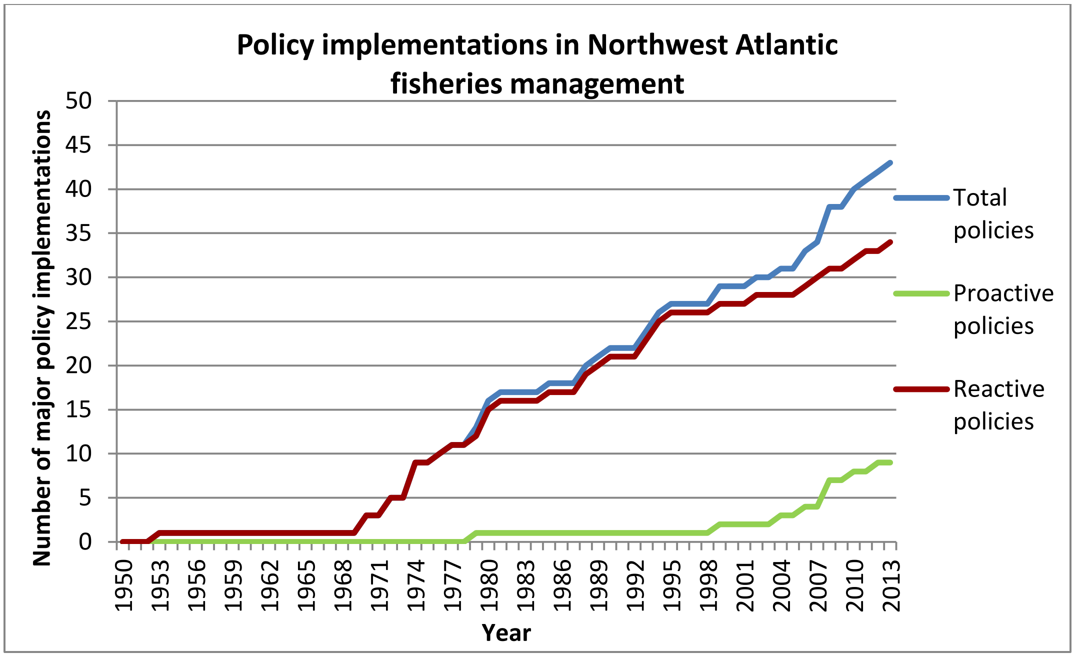


Figure 52 This figure notes how the fundamental policy characteristics have changed since fisheries management began in the northwest Atlantic. Proactive policies have accounted for an increasing share of policy developments, starting in the 2000s.

This is an important trend to recognize when assessing NAFO's institutional capacity for implementing proactive policy mechanisms in the future. Major commitments are required for proactive policies to be designed, monitored and implemented over long timeframes. Proactive policies require significant investment, persistence and dedication from government; NAFO's increasing use of proactive policies over the last 15 years is strong evidence that the organization possesses the resources and institutional characteristics required for designing proactive policies that incorporate environmental parameters.

Installing environmental parameters into TAC decision making is an intuitive method for improving management by fundamentally changing NAFO's pattern of setting catch levels reactively to approaches that set TACs through proactive mechanisms. Current NAFO context is conducive to this type of policy redesign, as the extensive management and scientific interest in the area since the late 1940s has resulted in the accumulation of detailed environmental records, intimate biological knowledge of the major species and functional groups, including system ecology. These sources of intellectual capital, when combined with strong institutional capacity and resolve, and increasing enforcement competence provides significant potential for management goals to be more readily achieved through the inclusion of environmental data into legal frameworks and policy mechanisms.

CONCLUSION

This report has identified the drivers of fisheries production, how environmental context has shaped the Flemish Cap's ecosystem, the extent to which environmental factors have been incorporated into NAFO management, and how management has reacted to declines in system yield. This investigative path has connected the oceanic environment to policy, and provided strong evidence supporting the inclusion of environmental information and dynamics into fisheries management contexts.

Further to this conclusion, the policy summary conducted above indicates that current NAFO frameworks restrict the Organization from effectively responding to climate-driven productivity declines. Proactive policies have recently been implemented much more frequently than in previous eras, but to date have omitted critically important environmental information despite its increasing availability and the prominence of the link to fisheries production.

Finally, this essay has determined that based on previous Organizational tendencies and trends, important policy reform (in this case, the inclusion of environmental data into policy) is promoted by NAFO's institutional characteristics. The shift to proactive policy, accompanied by improved monitoring and enforcement, suggests the likelihood of reform is substantial, and has been increasing in recent years.

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