THE BIOLOGY, ECOLOGY AND MANAGEMENT OF GREENLAND HALIBUT (Reinhardtius hippoglossoides) IN NAFO SUBAREA 0 + 1: A CASE FOR CONSERVATION AND CO-MANAGEMENT BY CANADA AND GREENLAND

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The Biology, Ecology and Management of Greenland Halibut (*Reinhardtius hippoglossoides*) in NAFO Subarea 0 + 1: A Case for Conservation and Co-management by Canada and Greenland.

by

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Abstract

Greenland halibut is a commercially important deep water fish in the Davis Strait shared between Canada and Greenland. The biology of Greenland halibut has been difficult to study as this fish lives in very deep waters and scientists have been unsuccessful to date in determining the specifics of the age, sexual maturity and spawning behavior of this fish, making the management of this species difficult. However, there is a bigger management problem than the uncertainties of the biology of this species and that is the lack of co-management between Canada and Greenland. There are as many as 1500 shared fisheries in the world however only about a handful of them are being managed effectively through co-management. This paper attempts to highlight the benefits of co-managing this shared fish stock and hopefully lays the foundation for what will be a great management relationship between Canada and Greenland.

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List of Abbreviations

CAN -	Canadian Dollar
CPUE -	Catch Per Unit of Effort
DFO -	Fisheries and Oceans Canada
DFHA -	Department of Fisheries, Hunting and Agriculture
DKK -	Danish Krone
EC –	European Community
EEZ -	Exclusive Economic Zone
GDR -	German Democratic Republic
GFLK -	Greenland Fishery License Kontrol
GINR -	Greenland Institute of Natural Resources
GRT -	Gross Registered Ton
IC -	Integration Committee
ICNAF -	International Commission for the Northwest Atlantic Fisheries
I.E. -	id est
NAFO -	Northwest Atlantic Fisheries Organization
TAC -	Total Allowable Catch
TMGC -	Transboundary Management Guidance Committee
TRAC -	Transboundary Resource Assessment Committee

Introduction

Greenland halibut (*Reinhardtius hippoglossoid*, is an arcto-boreal, deep water flatfish species from the family Pleuronectiforme (right eye flounders) that has become increasingly important in the commercial fisheries in the Northwest Atlantic in the last 20 years. Due to the drastic declines of economically important ground fish species such as cod (*Gadus morhua*), American plaice (*Hippoglossoides platessoides*), witch flounder (*Glyptocephalus cynoglossus*) and yellowtail flounder (*Pleuronectes ferruginia*), there has been an increasing interest in the Greenland halibut (G. halibut) fishery, which is now one of the major fisheries throughout the Northwest Atlantic in both Canada and Greenland (Bowering, 1999).

Greenland halibut is widely distributed in the western Atlantic ranging as far north as Smith Sound (78°) and as far south as the coast of New Jersey (42°), in the United States (USA) (Bowering, 1999). Their range also extends into Ungava Bay, the eastern North Atlantic, the Barents Sea, the Bering Sea and the North Pacific (Fairbairn, 1981). Furthermore, G. halibut are highly mobile and migrate great distances both in the larval and adult stages (Fairbairn, 1981; Riget and Boje, 1989; Morgan and Bowering, 1997). The broad migration pattern exhibited by G. halibut has led to the hypothesis that the northwest Atlantic populations are genetically homogeneous. This hypothesis is supported by studies using various stock separation methods such as: parasites as biological tags, protein electrophoresis, multivariate morphometrics, multivariate and univariate analysis of meristics and external tagging (Vis *et.al.*,1997; Boje *et.al.*, 1997; Bowering, 1999).

Little is known about the specifics of G. halibut reproduction. Although numerous studies have examined sexual maturity, spawning and age and growth in G. halibut, the age of sexual maturation is unknown. In addition there is a lack of knowledge concerning the location and boundaries of spawning areas (Simonsen and Gundersen, 2005). Researchers have also observed a trend from north to south in growth and size, where the bigger fish are further north in Davis Strait (Bowering, 1999). In Baffin Bay, the proportion of small fish in the catches increases (Treble and Jørgensen, 2002). Age determination of this species has also been under debate as it is very difficult to accurately determine the age using whole otoliths, and this method is believed to underestimate the age of older individuals (Albert *et.al.*, 2009, Treble *et.al.*, 2008). According to Bowering and Brodie (1991), G. halibut were believed to be the fastest growing fish among the four commercially important flatfish species in the Canadian Atlantic. However, recent studies indicate that G. halibut grow much slower than previously believed (ICES, 2011). All these factors make the management of this important flatfish species challenging, and management is further complicated by the fact that the stock is transboundary and shared between two countries.

The purpose of this paper is to give an overview of the ecology and fishery of G. halibut in the Northwest Atlantic Fisheries Organization (NAFO) Subarea 0 and Divisions 1A-1D and including Division 1A inshore (Figure 1). The implications of the fishery of both countries (Greenland and Canada) on the continued status of the stocks will also be discussed. The biology of this fish species will be described, a summary and description of the commercial fisheries will be presented, and an overview and considerations for the management of G. halibut by Canada and Greenland will be provided.

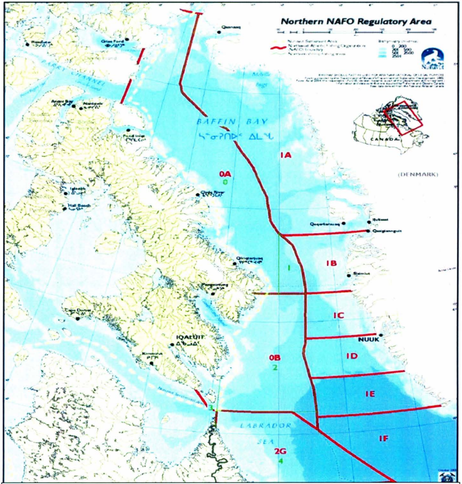

Figure 1: Northern NAFO Regulatory Area showing Subarea 0 and 1. (Source: Government of Nunavut in DFO. 2009).

Distribution

Geographic

Greenland halibut is the most widely distributed demersal fish species in the Western Atlantic (Bowering, 1999). Before the geographical distribution of G. halibut in NAFO Subareas 0 and 1 is discussed in detail, it is useful to consider the distribution of this species in other areas. The distribution of G. halibut in the Northwest Atlantic ranges as far north as Smith Sound (78°) and to the coast of New Jersey (42°) in the USA. They can also be found in the Northeast Atlantic and in the North Pacific Ocean (Morgan and Bowering, 1997).

Greenland halibut distribution on the Atlantic Canadian coast ranges from the deep waters of the continental slope in Baffin Bay and Davis Strait, along the deep waters and channels off the Labrador coast, continues around Newfoundland into the Gulf of St. Lawrence to the west and east to the Grand Bank and Flemish cap where an extensive commercial fishery has been conducted since 1990 by Canadian and foreign fleets (Bowering, 1999).

On the West Greenland coast, G. halibut is distributed in almost all of the fjords, on the slopes of the banks as far north as Thule and as far south as Cape Farewell at the southern tip of Greenland (Jørgensen, 1997a). G. halibut can also be found on the shelf region off East Greenland and eastward to Iceland (Riget and Boje, 1989).

Greenland halibut are relatively abundant off Baffin Island as far north as 76° and also in the inshore areas off of Baffin Island, mainly in Cumberland Sound (Bowering, 1999, Jørgensen, 2005). Bowering also reports that the distribution continues down to Hudson Strait at the edge of Division 0B. On the Greenland side of the Davis Strait, mainly Divisions 1A-1D, the most abundant G. halibut aggregations are found in the deepwater fjords, the offshore area north of 68°N (Store Hellefiske Bank) and around Disko Bay, which is believed to be an important nursery grounds for G. halibut (Atkinson *et.al.*, 1982; Riget and Boje, 1989; Jørgensen, 2005). Figure 2 shows the distribution of G. halibut in the northern most portion of the Northwest Atlantic (i.e. the portion of the stock occurring in NAFO Subareas 0 and 1) obtained during surveys conducted in 2001 and 2004 by Greenland and Canada.

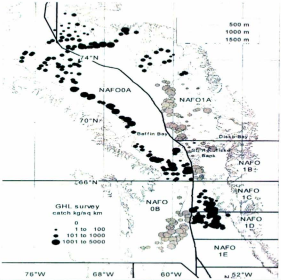

Figure 2: Distribution of catches in deep sea surveys conducted by Canada and Greenland in 2001 (grey) and 2004 (black). (Source: Jørgensen, 2005).

Depth and Temperature

The preferred habitat of G. halibut is deep water, and the species is reported to prefer deeper water than any other flatfish species in the Canadian Atlantic (Bowering and Brodie, 1991). The study of deep water fish species is difficult and often unsuccessful due to the low survival rates of fish brought to the surface, due to explosion of swim bladders and inversion of stomachs caused by the rapid change in pressure when fished are hauled up from deep waters. Interestingly, and fortunately for G. halibut researchers, their studies are facilitated by the fact that G. halibut lack a swim bladder, making it possible to use mark and recapture techniques to study this deep water fish (Simonsen and Treble, 2003).

Greenland halibut have been caught with longlines as deep as 2200m in West Greenland waters (Vis *et.al.,* 1997). Other studies conducted in Division 0A showed the highest densities were within the 751m to 1000m depth strata (DFO, 2009). Bowering and Chumakov (1989) also demonstrated the preferred depth of these fish differed seasonally, with the highest densities found in very deep water (>1000m) in the fall and winter surveys and at 750m-1000m in summer surveys (Bowering, 1999). This was corroborated by surveys conducted in West Greenland where the highest density of G. halibut occurred at more than 1100m in the spring, whereas in early summer highest densities were found in shallower waters at 900m-1100m (Jørgensen, 1997a). Morgan and Bowering (1997) suggest this is likely because G. halibut prepare for spawning in the late fall and winter, and start to move progressively into deeper water.

The water temperature range preferred by G. halibut in the Western Atlantic is between -1.0°C and 7.0°C, however, they are most commonly observed in temperatures between 0.0°C and 4.0°C (Bowering and Brodie, 1991). Riget and Boje (1989) reported that G. halibut spawn in temperatures between 3.0°C and 4.0°C. Hence, the preferred temperature may change according to season and life cycle. Jørgensen (1997a) found that temperature had no great significance on stock movement and distribution. However, the main distribution area had a temperature of 3.0°C to 4.0°C, which corresponds to the temperatures reported by Bowering and Brodie (1991). Figure 3 shows the bottom temperature distribution across Subarea 0 and 1.

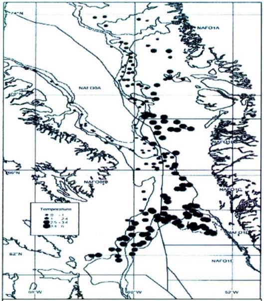

Figure 3: Bottom temperature (°C) for NAFO Subareas 0 and 1 sampled between 16 September and 15 September 2001. (Source: Treble and Jørgensen, 2002).

Vertical Migration

Studies show that G. halibut move up and down the water column according to the time of day, and also according to their lifecycle. Bowering and Parsons (1986) conducted the first study related to diel variability by using the data collected by research vessels off the coast of Labrador. They reported that catches were generally lower during dark periods, which can be attributed to the migration of G. halibut off the bottom and up into the water column during night. Jørgensen (1997a) found pelagic concentrations of small G. halibut in the Store Hellefisk Bank (Figure 2). The results showed G. halibut were most commonly found at the bottom during daylight hours, and were mostly evenly distributed in the water column around midnight, and also showed vertical distribution around sunset and sunrise. This study seems to very precisely describe the vertical migration patterns of this fish, but it was found that the pelagic occurrence was limited to one year old and to a lesser extend to two year old fish, thus suggesting that bigger fish tend to stay at the bottom of the water column at all times of the day. These observations were supported by a bottom trawl survey off Labrador where the analysis of length composition showed that the amount of smaller fish caught, mainly 1 year olds, decreased at night (Bowering, 1999). However, Vollen and Albert (2008) showed the size of fish caught in pelagic waters matched the size of the ones caught on the bottom.

Due to the morphological characteristics of G. halibut, scientists believe this fish is a fast swimmer and, therefore, display more bathypelagic behavior than other flatfish species. Scientists also believe this fish can act as a pelagic fish and migrate vertically in the water for feeding (Jørgensen, 1997b). However, a study by Albert *et. al.* (2003) using a camera attached to a trawl, showed that G. halibut swam horizontally to avoid being caught by the trawl. Albert *et.al.* (2003) concluded that the G. halibut exhibit more flatfish like behavior than previously thought. They also indicated that these results are restricted by the lack of coverage of the natural environment of G. halibut during the survey, and recommended that future trawl surveys should focus on behavior at higher abundance levels, be conducted during other time periods, and a higher emphasis should be put on pelagic occurrence (Albert *et.al.*, 2003).

Greenland halibut is occasionally caught at the surface in salmon nets off West Greenland, although accounts of these catches have become rare (Vollen and Albert, 2008). Feeding studies have also indicated pelagic behavior in G. halibut (Orr and Bowering, 1997).

Stock Delineation

Due to the high mobility of this species, it has been hypothesized that G. halibut in the Northwest Atlantic consists of one homogeneous and continuous stock. This is a particularly important question as this knowledge will assist in the proper management of the G. halibut fisheries. Different methods have been used to study this question, and the conclusion is that G. halibut in the Northwest Atlantic, within Canadian and Greenland and international waters, come from the same spawning stock. This presents huge implications for the management of the fisheries, with a number of problems to be addressed.

The first study to address this issue was Templeman in 1970, who found evidence that a separate stock exists in the Gulf of St Lawrence (Bowering, 1999). Fairbairn (1981) carried out biochemical genetic analysis of the G. halibut populations from the Northwest Atlantic, Gulf of St Lawrence and Bering Sea, and using specific electrophoretic protein loci in the G. halibut found that the Northwest Atlantic contains a single, interbreeding stock. He suggested that Gulf of St Lawrence stocks were separate, but not completely isolated, and that G. halibut in the Bering Sea were completely different from the two other stocks.

Methods to study homogeneous qualities of the Northwest Atlantic G. halibut stock have become increasingly more sophisticated. Studies using genetic analysis of mitochondrial DNA show that Northwest Atlantic G. halibut have extensive polymorphism and genetic diversity, but these differences are not significant enough to show that these fish originated from different stocks (Vis *et.al.,* 1997). The main conclusions were that there is intermixing between the northern and southern extremes of the commercial range in the Western Atlantic, and the G. halibut population is indeed composed of genetically homogeneous fish (Vis *et.al.,* 1997). These conclusions are supported by the fact that G. halibut is a highly migratory fish, as demonstrated by the results of numerous tagging experiments over the years where fish originally tagged in coastal areas of Newfoundland and West Greenland were recovered in Davis Strait and Iceland, respectively (Boje, 2002, Bowering, 1999).

It is believed that the genetic stock of G. halibut migrate to the deep waters of Davis Strait (Riget and Boje, 1989; Boje *et.al.,* 1997). It is also posited that G. halibut from Davis Strait move into deeper waters of the West Greenland fjords as they grow, and do not return to spawn (Riget and Boje, 1989). This is surmised from tagging experiments which showed that G. halibut within the northwestern Greenland fjords rarely move from their release sites and therefore are assumed to rarely participate in any spawning migrations (Boje 2002). Studies have shown G. halibut mature inside the fjords, although this happens at a slower rate, possibly due to the cold temperatures (Boje, 2002; Simonsen and Gundersen, 2005). The conclusion is that recruitment to these stocks originates from the Davis Strait spawning complex (Boje *et.al.,* 1997).

More recent research using microsatellite loci has shown a high level of genetic homogeneity among G. halibut living in the West Greenlandic fjords (Nygaard, 2008). This study concluded that G. halibut within the West Greenlandic fjords consist mainly of recruits from offshore areas. It is also suggested that spawning within the fjords of West Greenland is negligible, and that the fjords are in fact a "sink". Sink stocks are particularly sensitive to exploitation as they are dependent on migration from their source population in order to ensure the genetic variability and survival of the stock (Gaggiotti and Smouse, 1996). However, because the sink stocks in West Greenland completely rely on recruitment from the offshore stocks, the overall effect of the inshore fisheries on the offshore fisheries is negligible as the inshore fisheries are not adding to the recruitment in the offshore areas.

Another study published in 2008 provides a different view on the homogeneous nature of this species. Pomilla *et.al.* (2008) found evidence based on microsatellite markers that G. halibut may not be as homogeneous throughout the Northwest Atlantic as first thought. They found that there is a possible East-West differentiation within the Baffin Island and West Greenland area. The results are just preliminary, and the authors strongly recommend further studies be completed to fully understand the G. halibut stocks of the Northwest Atlantic.

Reproduction

Spawning

Reproduction of G. halibut has been difficult to study as sexually mature individuals are usually not abundant during surveys, and because fish in spawning condition can usually be detected all year round (Rideout *et.al.,* 1999). The detection of fish in spawning condition year round makes it difficult to determine a specific spawning period, which in turn complicates the management of this species. It is desirable to know the specifics about spawning seasons as well as fecundity in order to better predict the impact of the fisheries on future stock recruitment. One solution could be to conduct surveys year-round instead of collecting samples once a year, however this could be expensive and difficult in some areas (e.g. Baffin Bay) due to the presence of ice (Gunderson *et.al.,* 2004).

The Davis Strait area was believed to be the only major spawning site in the western Atlantic, however, recent studies have shown spawning occurs in the Gulf of St Lawrence, the Northern Flemish Pass, as well as in the deep waters of Uummannaq Fjord in West Greenland (Rideout et.al., 1999; Simonsen and Gunderson, 2005; Nygaard 2008). Spawning has also been observed in very deep waters along the continental slope of the entire distribution area (Bowering, 1999).

Peak spawning period of G. halibut is believed to be in the winter months, specifically between mid-December and April. Studies have shown these fish tend to release their oocytes in batches, which suggests that these fish spawn several times over a certain time frame (Jørgensen, 1997a; Morgan and Bowering, 1997; Rideout *et.al.,* 1999). Other studies show these fish have secondary spawning periods during some years, or suggest that they simply skip some spawning seasons (Morgan and Bowering, 1997). One study (Rideout *et.al.,* 1999) suggests that G. halibut are not determinate spawners like cod, further complicating the determination of the fecundity estimations of this fish. This study sampled G. halibut from all over the Northwest Atlantic and found fish sampled from the same area were not at the same stage of the reproduction cycle. The results showed some fish had oocytes that were ready to be spawned and at the same time had oocytes that were at a later stage of development. The researchers postulated that G. halibut must have some kind of cue during spawning time which allow the oocytes to quickly grow and mature as a means of increasing the fish's reproductive output (Rideout *et.al.,* 1999). This indicates G. halibut may be capable of growing and maturing oocytes in different stages and hence spawn indeterminately.

Some reports suggest, the main spawning area for G. halibut is in the Davis Strait near the submarine ridge between Baffin Island and Greenland at approximately 67°N (Smith, 1969; Bowering, 1999). Jørgensen (1997a) suggests otherwise, and says that the majority of the G. halibut stock is located at 64°N (between the NAFO Divisions 1C and 1D), making this area the main spawning area. Spawning is believed to take place in

3.0°C-4.0°C water at depths approximately 600m to 1200m (Riget and Boje, 1989; Jørgensen, 1997a).

After spawning in the Davis Strait, the pelagic larvae drift North with the Greenland current and South with the Canadian Polar Current to Labrador and East Newfoundland. There are several nursery areas where the G. halibut settle on the bottom in shallow water (200-250m). As they grow bigger, they start moving into the deeper waters offshore as well as into the inshore fjords and settle on the slopes of the banks (Jørgensen, 1997a; Bowering, 1999). The surface currents around Greenland and Canada can be seen in Figure 4.

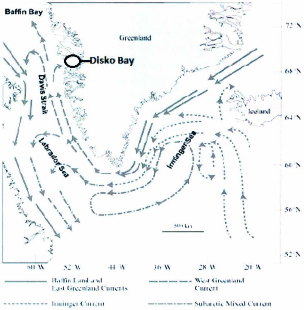

Figure 4: Surface currents around Greenland and Canada. (Source: Stenberg, 2007).

A G. halibut nursery is believed to be located west of Disko Bay (Figure 4) in West Greenland (Atkinson *et.al.,* 1982; Jørgensen, 1997a). This was evident when large numbers of juveniles, mainly one-year olds, were caught in the mouth of the fjords to the edge of the continental shelf of West Greenland during surveys conducted in this area

(Boje and Hjörleifsson, 2000). This area is believed to provide important recruitment to the fishery in Disko Bay, Uummannaq district and other districts further north in West Greenland (Atkinson et.al., 1982).

As mentioned, some G. halibut aggregations in West Greenland fjords stay isolated and do not participate in the Davis Strait spawning (Riget and Boje, 1989; Jørgensen, 1997a). Riget and Boje (1989) showed that the lack of recapture of tagged fish suggests that there is no spawning migration of G. halibut from the West Greenland fjords to the Davis Strait. However, they also cautioned that the lack of recapture of the tagged fish could be due to the lack of a commercial fishery for G. halibut immediately outside the fjords. The situation has changed now that an offshore fishery has developed in Baffin Bay. This presents an unfinished loop in the spawning cycle, where the fish that were spawned in Davis Strait do not return to add to the overall Northwest Atlantic stock. This presents, depending on the intensity of the fishery, another challenge in the management of the G. halibut fisheries.

Sexual Maturity

The determination of the age at which G. halibut reach sexual maturity has proved to be as difficult as the determination of its spawning behaviour. Studies conducted in the Canadian northwest have shown inconsistency in the length of mature males and females from Davis Strait to the Flemish Pass. The results showed that there was a high degree of geographic and temporal variability (Morgan and Bowering, 1997). During these surveys the size of mature males ranged from 51cm to 63cm and 63cm to 99cm for mature females. In some years no mature females were found despite 80cm to 90cm females being caught. The average age of mature males and females also had a wide range, from 8.2 to 11.6 years and 9.5 to 15.0 years, respectively. Other studies have proposed that G. halibut reach maturity after 6-11 years in males and 8-12 years in females (Boje *et.al.*, 1997). These inconsistencies are thought to be normal for this species as large immature fish are frequently encountered throughout the North Atlantic. These fish also have very irregular spawning behaviour, which leads scientists to conclude that this is a characteristic of G. halibut. The variation in size and age has been hypothesized to be linked to spawning migration, as more mature fish have been found in the main spawning area in Davis Strait (Morgan and Bowering, 1997). A similar increase in mature males and females from south to north to the main spawning area in Davis Strait has also been observed in the West Greenland waters, supporting the hypothesis that a northward migration occurs for spawning. In Greenland a north to south migration has also been observed from Disko Bay to the Davis Strait spawning area (Jørgensen, 1997a).

There have been few encounters with mature males and females, and during a series of surveys conducted in West Greenland by Riget and Boje (1989) only 9 ripe/running females were encountered out of 3,630, and only 49 mature males out of 1,488. Recent studies found that most mature male G. halibut were 38cm long and were 7 years in age, while the females were found to be 56cm long and were 8-9 years in age. However, this could be inaccurate as scientists have found that the methods of aging produce inaccurate results (ICES, 2011). The studies, conducted by Russian observers onboard commercial fishing vessels also concluded that spawning of G. halibut in the area of West Greenland takes place in winter. This was concluded through an analysis of the seasonal dynamics of the ratio of mature fish (Skryabin and Smirnov, 2008).

Age and Growth

The average life span of male G. halibut is believed to be 12 years of age whereas females have been estimated to be able to live over 20 years in Newfoundland and Labrador (Bowering and Nedreaas, 2001). The determination of age in these fish is problematic and error laden, and it is believed that the age of older G. halibut has been underestimated by up to 15 years (Albert *et.al.*, 2009). Studies conducted in Norway, Canada and the USA suggest G. halibut in the Northeast Atlantic reach an age of more than 30 years, and grow much slower than previously thought (Albert *et.al.*, 2009; Treble *et.al.*, 2008; Gregg *et.al.*, 2006). These studies highlight the importance of aging as a management tool for the development of sustainable fisheries, as accurate growth rates are essential to detect exploitation vulnerabilities (Albert *et.al.* 2009; Treble *et.al.*, 2008). Knowing the accurate growth rates is important in the determination of age at maturity, lifespan, natural mortality rate and population size (Treble *et.al.*, 2008). All these factors are used in stock assessment models and the determination of sustainable catch quotas. If the age of G. halibut is overestimated then that introduces an error in these models which in turn produces overly optimistic estimates of stock production. Overly optimistic estimates will translate into higher quotas and higher quotas will translate into overfishing.

The most recent study conducted in Greenlandic and Canadian waters derived growth rates of less than 2cm per year from ^{14}C ages of radiocarbon-dated fish (Treble *et.al.*, 2008). This study also concluded that the growth rates are significantly less than the growth rates of 5 cm per year previously reported for male and female G. halibut from the Northwest Atlantic, but were closer to the growth rates reported from other studies conducted in Iceland and the Barents Sea (Treble *et.al.*, 2008).

Food and Feeding

The examination of G. halibut caught during surveys reveals the variety of prey available to this species. This in turn provides information on fish interactions and the impacts that G. halibut have on other commercially important species such as capelin and northern shrimp.

Three studies have similar results in terms of the composition of prey as related to fish size (Orr and Bowering, 1997; Jørgensen, 1997b, Pedersen and Riget, 1993). In fish less than 15 cm it was found that the stomach contents consisted largely of pelagic crustaceans, with Hyperidae the most important, and Euphausiacea the second most important. In fish between 15 cm and 20 cm the preferred prey at shallower depths was again Euphausiacea. However, in deeper water Natantia (*Pandalus borealis* (shrimp)) was the preferred prey. In fish larger than 20 cm it was found that the preferred species besides Natantia included G. halibut, Redfish, (*Sebastes* sp.), snailfish (*Liparidae* spp.), northern alligator (*Leptoganus decagonus*) and shorthorn sculpin (*Myxocephalus* *scorpius*). Similar prey species were reported by Bowering (1999). However, other species such as Artic cod (*Boreogadus saida*) were identified. In very large fish (greater than 75 cm) empty stomachs were more frequently encountered (85.5%). However, in fish with full stomachs G. halibut and redfish were most abundant (Pedersen and Riget, 1993; Orr and Bowering, 1997; Jørgensen, 1997b). Capelin was also reported to be present in the stomachs of G. halibut, but mostly encountered in the fjords of West Greenland. Capelin has not been encountered in the stomachs of G. halibut from offshore areas of Davis Strait (Orr and Bowering, 1997). It could be capelin is not available in those areas.

Stock Assessment and Catch History

Management areas

The Davis Strait and West Greenland is divided into two Subareas (0 and 1) (Fig. 1). In 1994 the inshore of Division 1A became a separate management unit, based on scientific reports indicating the stocks there could be managed separately from the offshore (Bowering, 1999). Greenland continues to ask for scientific advice for the Division 1A inshore stocks from the NAFO scientific council with regards to Total Allowable Catch (TAC) and the setting of quotas (Nygaard *et.al.*, 2010).

In 1994, based on a more thorough scientific assessment and other information, NAFO scientific council recommended a decrease of the TAC for Subareas 0 and 1 from 25,000 tons to 11,000 tons (DFO, 2009). The significant decrease in TAC meant that the

TACs for Canada and West Greenland were reduced from 12,500 tons to 5,500 tons (Fig. 5). In the case of the offshore areas, Canada and Greenland jointly ask for advice from the NAFO Scientific Council and the two countries split the TACs.

The stock assessments are carried out by the respective countries within their EEZ's and the results from these assessments are then used by NAFO to determine the scientific advice for the different Subareas and Divisions.

Figure 5 shows the catches and the recommended TACs in the offshore and inshore fishery for Subarea 0 and Division 1A (offshore) and Division 1B-1F, from 1962 until 2012. The inshore area catches are not included in the Division 1A (offshore) catches. It is treated as a separate management area.

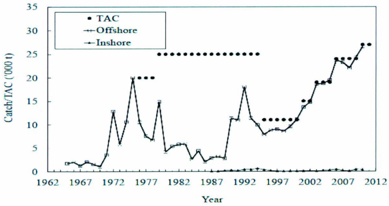

Figure 5: Catches in Subarea 0 and Division 1A offshore and Divisions 1B-1F and the recommended TAC. (Source: Jørgensen and Treble, 2011).

Canada

The Canadian fishery for G. halibut began in 1981 in Division 0B where at the time the majority of the quotas were allocated to foreign countries. This allocation was reduced over the years and was completely taken away in 1992, making the fishery exclusive to Canadian vessels. Due to the collapse of most major groundfish fisheries during the early 1990s, G. halibut became the most significant groundfish fishery in the region. The catches increased; with a concomitant decrease in the biomass and a shift in age structure (Bowering, 1999).

From 1996 to 2000 an exploratory fishery started in Division 0A. Before 1996 there had been no fishery for G. halibut in this area. The exploratory fishery was started to mainly benefit the inhabitants of Nunavut. The initial quota was set at 300 tons and remained at that level until 2001, when it was increased to 3,500 ton. The 300 tons was in addition to the Canadian quota of 5,500 tons for Division 0B. The TAC was further increased to 4,000 tons in 2002, and 4,400 tons for 2003-2005 (DFO, 2009). In 2010, following increasing trends in survey and CPUE indices, the TAC for 0B and 1 C-F was increased to 14,000 tons, which meant a TAC of 7,000 for each country (Jørgensen and Treble, 2011). Based on a more detailed assessment in new areas, NAFO increased its recommendation of the overall quota for Division 0A and Division 1A offshore + 1B to 13,000 tons in 2010.

Greenland

The Greenlandic history of G. halibut exploitation is similar to that of Canada. G. halibut was a less important fish in the commercial fishery until the collapse of the cod in the early 1990's. After the collapse of cod the G. halibut fishery came second to the shrimp fishery in economic importance (Nygaard, 2008).

The fishery was first developed as a longline fishery by Napoleon Andreasen in the fjords of Greenland in 1906 (Stenberg, 2007; Nygaard, 2008). It was originally a low impact fishery, but with the development of monofilament gillnets and the improvement of the technology in the trawler fleet, an offshore trawling fishery developed in the 1980's (Stenberg, 2007). This development significantly increased the fishing effort and raised concern in all management areas and led to efforts to increase fishing regulation. Regulatory measures included the introduction of maximum tonnage for fishing vessels, no introduction of new boats unless one is taken out of the fishery, and gear restrictions.

Inshore fisheries

The Division 1A inshore fishery has seen an increasing trend since the late 1980's. As mentioned previously, the inshore G. halibut fishery began in the early 1900's with longlines from small boats in the summer, and through the ice in the winter. The effort was small at first but has been increasing consistently in the past 15-20 years. The increase is in part due to the improvement of technology, but the main reason is the development of processing facilities in local communities that make it easier to sell and process fish. This increase has been especially profound in the Disko Bay (Ilulissat) area where the yearly total catch changed from less than 2,000 tons before the mid 1980's to more than 12,000 tons in the beginning of the 2000's (GINR, 2011a). This is an increase of 10,000 tons in 15-16 years. A similar trend was observed in the fishing communities in Ilulissat, Uummannaq and Upernavik. In these localities an increase from less than 2,000 tons per year to 5,000 - 6,000 has been observed in the last two decades (GINR, 2011a). Catches have remained stable or slightly increasing in these two communities since 2000, but a significant catch decrease has been seen in Disco Bay (Ilulissat) and is a cause for concern (Fig 6). In recent years, the annual catch decreased from over 12,000 tons to around 6,000 tons in 2009 and then increased to 8,458 tons in 2010 (Fig. 6) (GINR, 2011a and b). Catches have decreased by almost a third and this is believed to be evidence of overfishing.

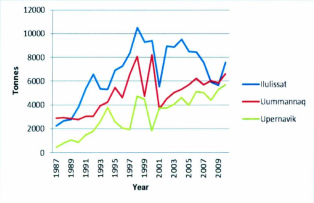

Figure 6: Trend of inshore catches in the areas of Disco Bay (Ilulissat), Uummannaq and Upernavik from 1987 to 2010. (Source: Statistic Greenland, 2011).

The concern for the stock is also heightened by the fact that the mean length of the fish has been decreasing, which could indicate that there is pressure on the stock by the fishery. Figure 7 shows the mean length trend from 1992-2007 for Disko Bay. It shows a decreasing trend since 2001.

The inshore total allowable catches are recommended by NAFO Scientific Council, and the quotas are set by the Government of Greenland. There were no quotas for the inshore G. halibut fishery until 2007. Since 2007, quotas have been set in the inshore fishery at three different areas: Disko Bay (Ilulissat), Uummannaq and Upernavik (DFHA, 2012). Table 1 shows the quotas for the inshore area.

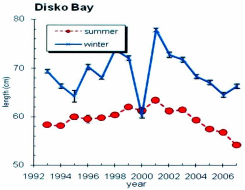

Figure 7: Mean length of Greenland halibut caught in the longline fishery from summer (lower) and winter (upper) catches from 1992-2007. (Source GINR, 2011b).

Table 1: Inshore fishery (NAFO Division 1A) quotas from 2007 to 2012 (Source: DFHA, 2012).

Tons	2007	2008	2009	2010	2011	2012
Disko Bay (Ilulissat)	12,500	12,500	8,800	8,800	8,000	8,000
Uummannaq	5,000	5,750	5,000	5,799	6,000	6,000
Upernavik	5,000	6,000	6,000	6,500	6,500	6,500

The quotas are set each year by the fisheries council based on scientific advice. The council consists of people from the industry, science (Greenland Institute of Natural Resources (GINR)) and management (Department of Fisheries, Hunting and Agriculture (DFHA)). The Minister of Fisheries has the right to change the quota and the conditions of the fishery at any point during the year after the setting of the quota. The fact the Minister can change his mind anytime is worrisome; it is not uncommon for the Minister to increase the quotas at the end of the fishing year and not necessarily just for G. halibut

but also for other fisheries. In the past the Minister has succumbed easily to pressure from the fishing community and increased the quotas.

Offshore Fisheries

The offshore fishery is not exclusive to the Greenland fleet, as the Greenlandic government has agreements with several other countries. The TAC is recommended by the NAFO Scientific Council and Greenland makes the decision on how it is distributed, but the majority of the TAC goes to the Greenlandic fleet. The countries fishing in Greenland waters include: Russia, Norway, Faroe Islands, Iceland and the European Union. In exchange for the G. halibut quotas Greenland is receiving approximately 300 million DKK (56 million CAN) a year (Fuglholt, personal communication, October 19^{th} 2011).

Assessments of Subarea 0, Div. 1A (offshore) and Div. 1B-1F

Surveys in Div. 1CD are carried out by Greenland every year, and Canadian surveys in Div. 0A are conducted every second year, although the whole Division is not always covered. Canada conducted surveys in Baffin Bay, in Division 0A in 1999, 2001, 2004, 2006, 2008 and 2010 (Jørgensen and Treble, 2011; Treble, 2011). In 2000 and 2001 Div. 0B was surveyed by DFO. The biomass estimates are included here to show the status of the stock and how the fishery has affected the stock over the years.

Division 0A and 1A (offshore) + 1B

In the deep sea surveys conducted by Canada it was determined that the biomass has increased gradually from 68,700 tons in 1999 to 86,200 tons in 2004 (Fig. 8) (DFO, 2009). A decrease in biomass to 52,271 tons was observed in 2006, but when adjustments were made for missing strata this estimate was considered comparable to 1999. The 2008 survey shows that the biomass had increased to 77,182 tons (Fig. 8). The overall length distribution in 2008 was 6cm to 99cm and is similar to what was seen during surveys conducted in 1999 and 2006 (Jørgensen and Treble, 2011). The length frequency has been stable in recent years and recruitment has also been good, although some year classes (2002-2005) have been showing a decline (Jørgensen and Treble, 2011). The most recent survey in Division 0A by DFO was conducted from October to November in 2010 and included areas north of 70° that have only been surveyed once before, in 2004. The biomass for Div. 0A south was estimated to be 74,272 tons, which was a drop from the 2008 survey (Fig. 8). The average length caught during this survey was 39cm which is similar to other survey years. The biomass for Div. 0A north was estimated to be 46,689 tons and is a slight

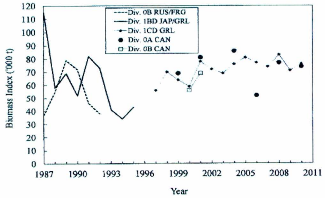

Figure 8: Biomass estimates from surveys conducted in Subarea 0+1 (excluding Division 1A inshore (from 1987 to 2010)). (Source: Jørgensen and Treble, 2011).

increase from the biomass estimated from the 2004 survey. The average length of fish was the same as for 0A south. (Treble, 2011).

Greenland has conducted surveys in Divisions 1A and 1B in 2001, 2004 and 2010. The 2010 biomass estimate was 79,332 tons, and the average fish length was 45 cm (Fig. 8). The same areas were not covered as in previous surveys but a comparison of the same areas that were covered in the 2001 and 2010 surveys, showed a small increase from 46,521 tons in 2001 to 52,248 tons in 2010. (Jørgensen, 2011a; Jørgensen and Treble, 2011).

The Greenland shrimp survey of Div. 1AB has shown inconsistencies in total trawlable biomass of young (< 3 yrs.) G. halibut during 1992-2007, with fluctuations between 9,258 tons and 31,000 tons. The biomass has fluctuated but has been increasing since 2007 (18,882 tons) and in 2010 it was slightly above average at 22,487 tons (Jørgensen and Treble, 2011). The biomass of the offshore area (not including Disko Bay) is now considered to be slightly above the average of the time series (1992-2010) (Jørgensen and Treble, 2011). In the inshore Disko Bay area, the biomass was estimated to be 12,193 tons in 2010, which is a slight increase from 9,456 tons in 2009. However, the biomass is still below the level seen in 2003-2006, which was 28,299 tons and 16,538 tons, respectively. (Jørgensen and Treble, 2011).

The length compositions, survey biomass and CPUE indices have been stable in recent years indicating that this stock is relatively stable (Jørgensen and Treble, 2011).

Division 0B and 1C-F

Surveys in Division 0B were last conducted by Canada in 2000 and 2001 with estimates of 56,212 tons to 68,917 tons, respectively (DFO, 2009). There have not been any surveys in recent years however, standardized CPUE rates from the commercial fishery have been available. The catches from Division 0B increased almost 1,000 tons in 2010 compared to 2009 due to an increase in TAC. The fish were caught by offshore trawlers and gillnetters and by a small inshore longline fishery (Jørgensen and Treble, 2011). The overall CPUE index increased to the highest levels seen in 2009 and then dropped again in 2010 to levels seen in the 1990s, however it is still among the highest levels seen in recent years (Jørgensen and Treble, 2011).

Surveys have been conducted annually by Greenland in Div. 1C-D since 1997. the G. halibut abundance has been relatively stable since 2002 and in recent years a slight increase in biomass has been observed. The biomass has fluctuated in recent years increasing from 74,357 tons in 2007, to 83,465 tons in 2008; then dropping to 70,966 tons in 2009 and increasing again to 75,522 in 2010 (Fig. 8) (Jørgensen, 2011b). The biomass is believed to be above the average for the time series. The length distribution was dominated by fish with lengths of 49cm (Jørgensen, 2011b). The mode of the length frequencies of the fish has been similar for many years and this indicates the stocks are stable.

Fisheries Management

Development of relationship between Canada and Greenland

Fisheries management is becoming a key component in the sustainability of the world fisheries. Fisheries management requires the integration of the biology and ecology of fish resources with the socio-economic, resource user, and institutional management factors that affect the behaviour of fishers and policy-makers (Defeo *et.al.*, 2007). Since the introduction of the 200 mile Exclusive Economic Zones (EEZ) in 1977 the management of natural resources has become more complicated, especially in cases where there are shared and straddling stocks, for example between the Greenlandic and Canadian fisheries.

On December 17, 1973, Canada and Greenland signed an *Agreement Relating to the Delimitation of the Continental Shelf between Greenland and Canada* (Parsons, 1993). This agreement was signed by Denmark on behalf of Greenland.

In 1973, Denmark joined the European Community (EC) despite great resistance from Greenland. The joining of the EC meant that all shares of TACs would be allocated between Greenland, Denmark and EC states. Denmark was able to create a policy whereby only Greenland and Denmark could fish within its 12 mile zone up until the end of 1977. From then until the end of 1982, the 12 mile zone was restricted to Greenlanders only. Since Denmark (and therefore Greenland) was a member of EC, the EC was in charge of the management of the different stocks. This meant that Canada had to communicate and negotiate with the EC for solutions over shared stocks. This was done by seeking advice from the NAFO Scientific Council, which is still the procedure today. The fishing areas between Greenland and Canada were originally treated as global and Canada freely gave TACs to EC ships from the German Democratic Republic (GDR) and the Union of Soviet Socialist Republics up until 1978 (Parsons, 1993). From 1978 to 1980 Canada and the EC held annual bilateral meetings where the setting of TACs for G. halibut, roundnose grenadier and shrimp were discussed. There were negotiations for percentage based splits of quotas, where Canada was mostly interested in shrimp. However, negotiations broke down because there was not an agreed scientific starting point for such a sharing arrangement at the time (Parsons, 1993). There was a continued effort to establish a joint management regime of the shared stocks however, the tension created due to the disagreements over shrimp TACs prevented the two countries from reaching an agreement. Towards the end of 1981, it was obvious that an agreement between Canada and the EC was becoming less likely, due to the approaching EC referendum in February 1982. Greenland was expected to vote to withdraw from the EC at the referendum which they did, putting a stop to any EC treaties. (Parsons, 1993).

The terms for the withdrawal were settled in February of 1984 and on January 1st, 1985 Greenland officially withdrew from the EC (Parsons, 1993). The main reason for Greenland's withdrawal was to obtain more control over the fisheries. The resentment towards the EC was largely due to the fact that the EC had been taking Greenland quotas to distribute to other EC states, literally preventing Greenland fleets from fishing in their own waters (Parsons, 1993). The withdrawal from the European Community meant that Greenland now had the responsibility to manage the fisheries within its waters and

Canada now had to communicate and negotiate with Greenland. The first official negotiations between Greenland and Canada took place in November, 1986, when Canadian officials travelled to Nuuk to discuss the shared fisheries. Despite good relations between Greenland and Canada, no joint management regimes have existed since 1981 for G. halibut, although there has been an informal understanding or agreement to share the TAC's equally.

An interest in bilateral agreements sparked in the early 1990s. However, no formal agreement was developed. During these meetings, scientific data and information on management measures and catches were exchanged and discussed. According to M. Treble, (personal communication, August 12th, 2011) there has been no bilateral meeting between the two countries in a few years. However, there will be a bilateral meeting in the beginning of 2012 where officials from both countries will attend (R. Fuglholt, personal communication, October 19, 2011). There appears to be some tension between the two countries as Canada feels the historical catches should entitle them to more than a 50% share of the offshore TAC and Greenland disagrees (Steinbock, 2001). This could be one of the causes for the lack of co-management between the two countries. In the present, there appears to be no concrete obstacle preventing the two countries from coming together and constructing a shared management plan.

Management measures

In Canada Development of the major enforcement measures and management of the fishery in Divisions 0A and 0B are the responsibility of Fisheries and Oceans Canada (DFO) (see Table 2).

In Greenland, the management measures are different as the G. halibut fisheries are not operated with multi-year management plans. The fishery is regulated based on the 1996 Fisheries Act, and additions to the Act in subsequent years. The fishery has been subject to licensing since 1998.

Table 2: The current management enforcement measures of Canada. Source: DFO (2009).

Dockside Monitors	• 100% dockside monitoring is required. • In Nunavut, industry funded onboard observers act as dockside monitors. • Outside Nunavut, industry funds 100% dockside monitoring of all catches. • When offloading in Greenland ports, and onboard observers are not present, industry funds the services of Lloyds of London agents who conduct dockside monitoring.
Observer coverage	• 100% observer coverage in 0A • 100% observer coverage January to April inclusive for all vessels in 0B. • 100% observer coverage for mobile gear in 0B. • 20% observer coverage on fixed gear in 0B. • Observer sea day costs funded by industry. • Vessels must notify Observer Company six hours prior to sailing.
Hails	• Daily hails of position, activity and catches must be sent to licensing office for all vessels.
Logbooks	• Accurate fishing and production logbooks are required to be submitted to the appropriate area office for all vessels.

Licenses are only given to people who list the commercial fishery as their main occupation. There is also a restriction on the size of the vessel in the inshore fishery; no vessel larger than 5 Gross Registered Tonnes (GRT) can enter the fishery unless an equal tonnage is taken out of the fishery. The use of gillnets is forbidden in the offshore and inshore fishery. However, some exceptions exist in Disko Bay (Ilulissat), Uummannaq and Upernavik during specific times of the year. The minimum mesh size allowed for gillnets is 110mm (Nygaard *et.al.*, 2010). All fish are landed to onshore processing facilities and it is the responsibility of the processing facility to record and report the amount of fish caught to the Grønlands Fiskeri Licens Kontrol (GFLK). Therefore, there are no records of any discarding that happens on the boat. The processing facility is obligated to report any discarding that occurs at the facility and this is taken from the overall quota (GFLK, 2010). There is no direct monitoring of the inshore fishery besides the random dockside monitoring, and there are no observers onboard any fishing vessel.

In the offshore fishery, 29mm grates were introduced to the shrimp fishery in December 2002, as a means to protect juvenile fish, including G. halibut (Nygaard, 2008). This was thought to be necessary as the main shrimp fishery of Greenland occurs in and around G. halibut nursery areas. Surveillance of the offshore fishery is handled by the Royal Danish Navy and onboard observers, as well as random dockside monitoring. Every commercial fishing vessel in Greenland waters, including the offshore and inshore fishery is obliged to keep a log book and must report the weekly catches to the GFLK.

Canada and Greenland have both taken steps to manage their fisheries within their own EEZ's and their respective management measures are similar to each other. The next step is to find a management scheme that involves both countries and works to co-manage the straddling stocks of the Davis Strait and Baffin Bay. Below are two examples where coastal states with straddling stocks are successfully co-managing their fisheries.

Coastal States With Transboundary Fish Stocks

Russia and Norway

There are as many as 1500 transboundary fish stocks in the world but only a small number of these fish stocks are being managed effectively through co-management (Munro *et.al.*, 2004a). This demonstrates how difficult it is to reach an agreement between two or more states on how to manage and protect a natural resource. Even though there are more failures than successes with regards to the history of co-management there are some cases where co-management is thriving due to the effort and commitment given by the involved coastal states. An example is the co-management of shared fish stocks in the Barents Sea, where Norway and Russia are involved. Norway was confronted with a tough situation with the extension of the coastal zones in the mid-1970s. There were issues with regards to the settlement of the maritime boundary, establishment of management rules and other subjects such as illegal fishing, all these problems had to be solved with Russia, which had an ever changing political scene. This made solving the matters extremely delicate (Stokke, 2002).

These two coastal states have solved most of their differences and the methods used in coming to an agreement on the management of the fisheries can serve as a good example to other coastal states having similar issues. The three important aspects that were used to resolve the management problems between Norway and Russia are: (1) generation of adequate knowledge about the health of the ecosystem and the impact of harvesting of various stocks; (2) ensuring that available scientific knowledge is applied in the establishment of adequate regulations; (3) and compliance control including; monitoring in order to assess adherence to the regulations as well as imposition of sanctions on violators (Stokke, 2002). To ensure high quality scientific knowledge that allows for accurate assessments of the stocks, Norway and Russia cooperate to execute survey programmes every year and take into consideration the ecosystem of the entire area of the Barents Sea (Stokke, 2002). By doing this, the two countries have minimized any deficiencies in their scientific methods and the stock assessments are more reliable and accurate. The adoption of the joint-effort in the assessment of the different fish stocks have also helped evolve the science of the assessments as the two states have contributed with their own strong points in different areas, enhancing the efficiency of the policy-relevant knowledge (Stokke, 2002).

The conservation and management measures applied by the two coastal states have also ensured a good cooperative relationship. The decision to open up their respective EEZs in a mutual access agreement ensured no tension would develop between the two countries, this decision greatly assisted in maintaining a good relationship in a very delicate political environment. Ensuring both countries can move freely within the two seas ensured more transparency, giving each country an opportunity to ensure rules are being followed and no overfishing takes place. As part of the deal to have the ability to fish in each other's EEZs, an exchange of information on landings and inspection reports would be done on a regular basis. The two states abilities to monitor who is fishing and how much they are fishing within their EEZs was beneficial and provided them with more trust and less secrecy. The third aspect mentioned is the compliance control. Even though both countries had problems ensuring regulations were followed they have somewhat managed to iron out their differences. Most importantly the compliance control has made the fisheries in the Barents Sea more accountable and has assisted in a way to draw political attention when inadequate actions are taken towards overfishing and other illegal fishing. It has been harder for both of the coastal states to ignore the need for adequate management and enforcement measures. The increased transparency has also introduced embarrassment (moral persuasion) by directing more political attention towards the state that is less likely to cooperate. Having increased transparency and accountability makes it easier to put political pressure on the state that is refusing to cooperate or that may be more inclined to perform illegal fishing. If every move made by the coastal states is watched then it makes it more difficult to perform illegal fishing, have inadequate enforcement or management measures and to be generally against working towards the greater good for all parties involved.

The most important achievements by this cooperation has been the agreement signed between the two countries that require routine exchange of information on landings and inspection reports, direct lines of communication between inspection vessels of the two states, and collaboration on the development of a positional tracking system for the entire Barents Sea (Stokke, 2002). All these steps taken by Russia and Norway, although not without problems, have ensured a fairly stable relationship between the two countries. The decision to open up their respective EEZs to the other state has proven to be advantageous and has shown that both states are willing to be flexible in the setting of the different fish quotas. The quota exchanges allow both parties to fish for what they consider to be the most valuable product, and have also provided both states with better means to optimally utilize both existing capital and the fisheries resources (Stokke, 2002). The two countries adapted to their new situation and through hard work managed to achieve something that most countries with transboundary stocks have failed to achieve. The success of Norway and Russia shows that it is possible to achieve co-management even in a delicate political environment.

Canada and USA

Another situation involving stocks shared between Canada and the USA arose in the 1970s due to the implementation of the 200 mile limit (EEZ). Due to the extension of their offshore jurisdiction both countries now had to deal with transboundary stocks on their respective east and west coasts. The east coast of George's Bank came into dispute, and the groundfish stocks suffered due to the lack of co-management. The disputed stocks included cod, haddock and yellowtail flounder (Pudden and VanderZwaag, 2007). On the west coast, pacific salmon and pacific halibut came into dispute, along with other transboundary fish stocks (McDorman, 2009).

The international boundary on George's Bank was established in October 1984 by the International Court of Justice (Pudden and VanderZwaag, 2007). Even though the international boundary was set and both countries had their respective sides of George's Bank, the coastal states could not reach an agreement regarding the shared stocks. The lack of a co-agreement on the management of the shared stocks created a problem of overfishing of the groundfish stocks, and could have led to disastrous results, such as a collapse of fish stocks (McDorman, 2009; Pudden and VanderZwaag, 2007). However, due to a successful and quick collaboration between the two countries the stocks have exceeded the numbers of previous highs in some cases (Peacock and Peters, 2006). This type of quick response to develop solutions is desirable in all situations where shared fisheries exist. Unfortunately this is more an exception than the rule.

The two coastal states started their cooperation by establishing a Steering Committee in 1995. The Steering committee oversees the work of a number of sub-committees and working groups which deal with transboundary management issues. The Canada and USA Fisheries Enforcement Agreement, which was established in 1990, ensures the co-management measures developed by the Steering Committee are enforced and no illegal fishing occurs within the waters of either state. Since the establishment of the Steering Committee and the signing of the Fisheries Enforcement Agreement there has been a significant decrease in illegal fishing (Pudden and VanderZwaag, 2007).

The Steering Committee has representatives from the maritime region of the DFO, USA National Marine Fisheries Service, New England Management Council, Canadian Gulf of Maine Advisory Committee and industry representatives from both countries (Pudden and VanderZwaag, 2007). The committee meets bi-annually to discuss the transboundary management issues and what measures are needed to solve them. Canada and the USA also established the Transboundary Management Guidance Committee (TMGC) in 2000 and the TMGC works with the Transboundary Resource Assessment Committee (TRAC) which was formed in 1998. The main purpose of the TMGC is to provide viable management and harvesting strategies that ensure the health of the fisheries in the Gulf of Maine. The TRAC is a committee established to conduct joint stock assessments of haddock, cod and yellowtail flounder and to provide yearly stock assessment reports to the TMGC. The work of TRAC and the TMGC is also expanding into other commercially important fish stocks found in the Gulf of Maine (Peacock and Peters, 2006).

The newest addition to the vast cooperation agreement between Canada and USA is the Canada-USA Integration Committee (IC), which is a pilot project aimed to institutionalize ecosystem based management. In 2003 Canada and the US reached an agreement on a 10 year sharing program, which takes into account historical catches and resource distribution and moves forward to more consistent management of the shared stocks in the Gulf of Maine (Peacock and Peters, 2006).

The joint stock assessments done by the two states, where peer review is a very important aspect of the committees that oversee these surveys, ensure accountability and transparency. Both states have agreed upon every process and the setting of TACs is amicable. The structures of the committees does not allow for any secrecy and the websites of TRAC, TMGC and the IC are filled with information about the stock assessments and the data used to determine the recommendations (Peacock and Peters, 2006). Allowing the outside viewer to look at the data and see what the process is for the determination of the recommendations and the setting of the TACs is important. By doing this they have made themselves accountable and more transparent to the public, thus allowing themselves no room to do anything irresponsible or detrimental to the fisheries.

The quick response as well as the successful cooperation between the two states shows how well they adapted to a difficult situation that involved important natural resources. The establishment of the Steering Committee that involves officials, scientists and managers also shows how efficient and invested the two coastal states were in solving the problems at hand. They have continued to better the committees and the work that they do by including an ecosystem based management approach. It is a testament to their flexibility and adaptability to ever changing environmental issues.

The successful cooperation and establishment of the committees was fairly easy, this could be due to the two countries having such similar fisheries cultures and fisheries management histories which facilitated the move to a joint management system. However, other factors have also ensured the success of the arrangements; these factors are very similar to the Russia/Norway arrangement where emphasis was placed on transparency, accountability, adaptability, flexibility and efficiency (Peacock and Peters, 2006).

There is no denying that Canada and the USA have a good arrangement which successfully deflated any tensions that existed due to the conflicts over the transboundary stocks in the Gulf of Maine. These two countries are making a sound effort to correct the deficiencies within the already established committees and continually work to include more species that are shared within the Gulf of Maine.

Game Theory

Game theory is a management tool used mostly in academic circles. The game theory fits well with fisheries management as fishers and/or managers seek to maximize the benefits from a given fishery (Bailey *et.al.*, 2010). Game theory can be used where there are two or more participants in a fishery but becomes more complicated as the number of participants increase. In game theory, participants are known as players. One of the very first applications of game theory occurred in 1954 and was applied in a political science situation (Grønbæk, 2000). The first real application to fisheries management came when a paper entitled "The optimal management of transboundary renewable resources ", was published by Munro (1979). The argument was that co-management needs to be utilized in cases where there are transboundary fish stocks that travel across the EEZs of two or more countries. Game theory is proposed as a possible solution to the problem (Munro, 1979).

Game theory players are all assumed to be rational and have options to take action when needed; these forms of actions are called strategies. The rationality assumption is utilized to predict the preferred outcomes of the players, among a set of outcomes (Bailey *et.al.*, 2010. The players expect a return for their actions and this return is referred to as a payoff. The payoff is in all cases the motivation to enter a fishery. When the game is between two countries, the payoff can mean two different things to them, depending on how much value they put on the fishery. The interaction among the players is in response to the different strategies being used and is the game. The strategies between the countries can differ, depending on how much money is put into the development of the fishery. The best case scenario for any game is a stable outcome and if this stable outcome exists then the game is solved (Munro *et.al.,* 2004a).

There are always two possible scenarios when it comes to game theory, there is a non-cooperative game where there is no communication between the players and there is a cooperative game where communication is open and two or more players are willing to openly cooperate to manage their fisheries (Munro *et.al.,* 2004a).

A non-cooperative game is explained as the default position of fisheries management, where the two players are unwilling to communicate but interact through their strategic games within the fishery; so one player makes a move and the other player counteracts with their own move (Bjørndal and Munro, 2007; Grønbæk, 2000). In other words, when one player makes a move the other player will be affected and vice versa. In the case of non-cooperative games, the resource will more than likely be overexploited, making both players worse off than they were to begin with (Bjørndal and Munro, 2007).

A cooperative game is when both players have open lines of communication and are willing to work together to achieve the best results. Even though, the players are assumed to be motivated by self-interest only, this is the most desirable situation or game, as both players are willing to cooperate to create the best sharing solutions for the fisheries (Munro *et.al.,* 2004a).

In order to have a successful cooperative game, there are two conditions that must be fulfilled. The first is that 'Pareto Optimality' must be achieved, in which there exists no other outcome or payoff that does not decrease the outcome or payoff of the other player. In other words, Pareto Optimality strives to achieve a situation where equal payoffs or outcomes will occur for both players (Bailey *et.al.*, 2010; Munro *et.al.*, 2004a, Munro *et.al.*, 2004b). The second condition is that 'The Individual Rationality Constraint' must apply, in which with cooperation all the players are at least as well off as they would be without cooperation. In other words the payoff to the players during cooperation must be equal or greater than the payoff they would receive by not having cooperation (Bailey *etl.al.*, 2010; Munro *et.al.*, 2004a). The motivation to have a cooperative game will be higher when the payoff is greater than it would be without cooperation.

In the case of a cooperative game, there are two different ways in which the players can cooperate. The first one is scientific, where the players can share their scientific findings regarding the stock within their EEZ. However, Munro *et.al.*, (2004a) describe a case where one player could take advantage of that knowledge and use it against the other player. The possibility of this happening makes it less desirable for the players to have scientific cooperation. The second way in which players can cooperate is with co-management. In order to succeed players are required to create a co-management strategy that will ensure optimal harvesting over time, players are also required to allocate harvest shares between them, and lastly but most importantly players are required to implement and enforce any management measure determined through their co-management (Munro *et.al.*, 2004a).

If the management measures of both the players were the same, a co-management programme could be easily obtained. However, more than likely the players have different management goals, and chances are it will be difficult to reach an agreement. In cases like this, a possible solution to the problem is side payments. Side payments are types of transfers that are monetary or non-monetary in nature (Munro *et.al.*, 2004a). Side payments are beneficial if one of the players places a higher value on the fishery than the other player, this way the player which places a higher value on the fishery can receive a greater allocation and provide the other player with side payments (Thébaud, 1997). The side payment can be in the form of another species of fish, where the player with a greater allocation of a specific fish can give the other player quota for another species such as shrimp or marine mammals. An example of this type of side payment happened in the 1970s and 1980s between Canada and Greenland (European Community) where Canada provided quotas of G. halibut in exchange for shrimp quota (Parsons, 1993). In order for the exchange of quotas to occur, the countries need to open up their EEZs to each other, as Norway and Russia did in the case of the Barents Sea.

All the requirements of cooperation should ensure a solution is found to the game if common sense is used. However, history of the world's fisheries show common sense is rarely used when it comes to the exploitation of any natural resource. Game theory is an interesting concept that helps us understand interaction between players, but achieving a true solution to the problems caused by transboundary stocks will need all the parties to cooperate fully. This will be hard to achieve if the management goals and values of the fishery are different for each coastal state. Nevertheless, it is possible to create a co-management program using the elements of game theory but it requires hard work and commitment from both parties involved.

Conservation and Co-management of Canada and Greenland

In the case of Greenland and Canada, Game Theory is a plausible solution to the existing absence of co-management. A bilateral scientific relationship exists, where scientific knowledge of the stock has been exchanged (R. Fuglholt, personal communication, October 12th, 2011). DFO and GINR also have an agreement to conduct surveys in Division 0A and 0B, using the Greenlandic research ship M/S Pâmiut and its crew (GINR, 2012). Hence, a good scientific relationship appears to exist between the two countries. The open communications will allow for a cooperative game.

The next step for the two countries, if game theory is going to work, is to create a co-management strategy. This should be fairly easy as the two countries appear to have similar strategies and measures to manage their respective fisheries. However, in any case where there are discrepancies, a solution could be side payments. As explained before, the side payments can either be monetary or non-monetary in nature. A form of side payment could be to exchange quotas for species that are more valuable for one state and which will optimally utilize the existing capital and fisheries resource. The different transboundary species have different values to both countries. In the case of the northern shrimp and G.halibut, Greenland appears to put more value in shrimp than G. halibut so an idea could be for Canada to decrease its share of shrimp quotas in exchange for G.

halibut quotas in offshore Div. 1A, where the importance of G. halibut is increasing for the Nunavut Inuit (R. Coombs, personal communication, October 13, 2011).

The USA and Canada joint management relationship succeeded due to the creation of the Steering Committee; hence it would be a good idea to create a Canadian and Greenlandic joint committee. This committee would have to have representatives from governments, DFO from Canada and the Department of Fishery, Hunting and Agriculture from Greenland. NAFO could still provide advice on the TACs and the two coastal states could work together to allocate portions to the fisheries in their waters. Subcommittees could also be formed. Having these subcommittees could allow the responsibility of the scientific advice to be shifted from NAFO to the two countries. By allowing the respective countries to form bi-national subcommittees could encourage the formation of a co-management of the fisheries in their waters. The subcommittees will be there to ensure that the research and management of the shared stock is consistent. The Subcommittees could include representatives from the industry groups to allow for inclusion in the decision making and planning process. The purpose of this is to make the stakeholders more inclined to assist in the co-management of the shared stocks and to make the industry more inclined to work towards a sustainable fishery of the transboundary stocks.

There are several different transboundary species (roundnose grenadier, shrimp, Atlantic salmon, Greenland halibut, narwhal, beluga and bowhead whales). If a shared fisheries management is developed, it would be a good idea to develop a multispecies agreement where all transboundary species are incorporated. Hopefully steps can be taken towards achieving this during the next bilateral meeting which will occur in the beginning of 2012.

The success of the Canada/US and Norway/Russia relationships are based on transparency, accountability, adaptability, flexibility and efficiency. To obtain a successful co-management of the G. halibut fisheries between Canada and Greenland in the Davis Strait and Baffin Bay, the two countries must adapt these principles and adhere to them. If the right tools are used, Canada and Greenland can be successful in keeping the G. halibut fisheries and other transboundary stocks healthy and thriving for many years to come.

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