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from 1950 to 2010**

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MARINE FISHERIES CATCH RECONSTRUCTION FROM 1950 TO 2010**

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ABSTRACT

Total marine catches in Eastern Canada’s Exclusive Economic Zone (EEZ) were reconstructed to include catches of the small-scale subsistence and recreational fisheries, as well as illegal and unreported commercial catches and their discards, both domestic and foreign. Additionally, a ‘baseline’ of reported FAO landings was established by regionally disaggregating domestic and foreign data reported to FAO, in essence separating landings caught inside the Canadian EEZ to those caught outside. The reconstructed catch was over two times the ‘baseline’ FAO reported landings deemed as having been caught in the Canadian EEZ (or EEZ-equivalent waters) from 1950 to 2010. The bulk of unreported catch was taken prior to the establishment of the EEZ in 1977 (treated as EEZ-equivalent waters), due to high discards by the domestic and foreign groundfish trawl fleets at that time. This study also includes an analysis of the biomass, catch, and exploitation levels of the post-moratorium Atlantic cod (*Gadus morhua*) stocks in Eastern Canada, with insights as to its sluggish recovery in the post-moratorium era.

INTRODUCTION

Fisheries in Eastern Canada date back over 11,000 years, since people entered the North American continent via the Bering land bridge, and moved east to inhabit the modern Canadian provinces of New Brunswick, Nova Scotia, Prince Edward Island, Québec, Newfoundland, Labrador, and the south eastern coast of Baffin Bay (Nunavut). The diverse range of coastlines, bays, and islands provided ideal conditions for marine life, and the elaborate cultures of the Mi’kmaq, Beothuk, Innu, and Inuit, among others, relied on the seasonal bounty of fisheries for thousands of years (Canadian Museum of History 2014).

However, it was the cod fisheries of Eastern Canada, initiated by Basque fishers as early as the 15th century which were crucial in shaping modern Canada. Throughout the next several centuries, the French, English, Portuguese, and Spanish Basque flooded into the New Found Lands and developed seasonal fishing outposts. Cod, which was dried and salted directly on the pebble beaches of Newfoundland before being sent back across the Atlantic, gained immense popularity in Europe as a cheap alternative to meat, as well as fueled an enormous boost in the European economy (Harris 1998). Indeed, the competition in the 17th and 18th centuries between France and Britain over the North American continent was largely about access to the abundant fish stock off what is now Eastern Canada. Over time, outposts turned into permanent settlements, and a unique maritime culture developed. During this time and up until the early twentieth century, annual landings of cod off of Newfoundland oscillated between 200,000 and 300,000 t (Hutchings and Myers 1994).

Nevertheless, the entire dynamic of fishing in Atlantic Canada changed when the first foreign factory freezer trawlers arrived in the 1950s. Fleets of this gear practiced pulse fishing, i.e., fishing areas heavily until depletion, as well as heavy discarding where virtually all the fish returned to the water were dead, either “crushed by the changes in temperature as they were pulled up from the depths, or by the weight of fish in the net, or suffocated in the cod end of the trawl when their gills were squeezed shut” (Harris 1998). According to data reported to FAO, by 1968, catches of cod off Newfoundland more than tripled, while all cod catches in Atlantic Canada reached a maximum level of which 80% were landed by foreign trawl fleets.

Indeed, while the cod was the predominant target species, especially for foreign fleets, many other groundfish species were caught and landed besides the Atlantic cod, i.e. American plaice (*Hippoglossoides platessoides*), haddock (*Melanogrammus aeglefinus*), redfish (*Sebastes fasciatus*), etc. Additionally, many other fisheries existed, notably those targeting pelagic species, i.e. herring (*Clupea harengus*), mackerel (*Scomber scombru*), and alewife (*Alosa pseudoharengus*), as well as crustaceans like American lobster (*Homarus americanus*), snow crab (*Chionoecetes opilio*), and Atlantic surf clam (*Spisula solidissima*).

Many of these species were significant in the recreational fisheries of Canada, notably the Atlantic salmon (*Salmo salar*) which was a popular and thriving target for recreational fishers as early as the 19th century (Gough 2007). Likewise, these species were vital for subsistence, for both native and non-native peoples. Although many native peoples had been marginalized, excluded from key resources, or driven extinct, like the Beothuk of Newfoundland, the late 20th century was a time of great change for these cultures. In the 1990s, the Canadian government recognized treaty rights of many aboriginal groups, who were given priority in fishing for food, social, and ceremonial purposes (DFO 2011a).

Many changes also took place in the commercial fishery during the time period of interest for the present paper, 1950 to 2010. In 1977, Canada declared its Exclusive Economic Zone (EEZ), and thus extended national jurisdiction over resource use from 12 nm to 200 nm. This legislation forced foreign fleets to leave the rich resources of the Grand Banks (Figure 1) that they had traditionally fished for groundfish. Although foreign presence was still teeming on the high seas, just outside the EEZ (as well as on the ‘nose’ and ‘tail’ of the banks), the domestic Canadian fishery was hopeful that this legislation would help boost employment for the small fishing villages bound by the boom and bust cycle of catches (Parsons 1993). Moreover, even though stocks had been heavily exploited after the “killer spike” of catches in 1968, stock assessment scientists kept pointing to optimistic estimates of stock recovery (McCay and Finlayson 1995). Although the fishing industry already had excess capacity, there was a broad domestic expansion of the fishery sector and fleet (Harris 1998; Schrank 2005).



Figure 1. The Exclusive Economic Zone (EEZ) of east Canada with the continental shelf, major banks (Grand Banks and Georges Banks), and provinces labelled.

In the 1980s, fishers knew something was wrong when they noticed that the cod were getting smaller, and fewer of them were showing up on traditional fishing grounds (Neis 1992). However, it was only in the early 1990s that the administration admitted that the Total Allowable Catch (TAC) had been set twice as high as sustainable due to incorrect stock assessments (Parsons 1993). A moratorium was placed on the cod in 1992, which confirmed the collapse of what was once the greatest and most abundant cod fishery in the world (Hutchings 1999). The president of the Fish Food, and Allied Workers Union called it, “*the most wrenching societal upheaval since the Great Depression*” (Harris 1998). After this, things got worse. Other groundfish collapsed as well, leaving 40,000 former fishers and plant workers unemployed throughout Atlantic Canada (Gough 2007). Catches of all species fell by half in the domestic fishery.

Between then and 2010, the fisheries of Eastern Canada underwent dramatic changes. In some places, the unique maritime culture disintegrated, especially in Newfoundland where population decreased due to lack of viable employment options (Schrank 2005; Gough 2007). Of the few groundfish fisheries still viable, fishing effort shifted to turbot and redfish and was relocated to previously unexploited areas like the east coast of Baffin Island. Fishing for shrimp (*Pandalus borealis*), which began in the late 1970s began to greatly expand, as did the valuable snow crab and lobster fishery whose high value replaced the traditional groundfish fishery. Lobster, which now became a “*fancy meal*” used to be fed to prisoners in the earlier times. This is consistent with a worldwide trend of fishing down the food web, as the mean trophic level of fish landed on the east and west coasts of Canada is declining by $0.03\text{-}0.10\cdot\text{decade}^{-1}$ (Pauly *et al.* 2001).

In the present paper, we performed a ‘catch reconstruction’ (following Zeller *et al.* 2007) for the period 1950 to 2010 for the above mentioned Canadian provinces, excluding the French territories of St Pierre and Miquelon, the area outside the limits of Canadian Exclusive Economic Zone (EEZ), and the eastern part of the Canadian Arctic (FAO area 18), which was previously covered by Zeller *et al.* (2011). We recall that catch reconstructions are performed for a variety of reasons, notably:

1. To gain a correct appreciation of the role of small-scale fisheries (including subsistence and recreational), often neglected in official fisheries statistics;
2. To provide, via the inclusion of all withdrawals from an ecosystem, one of the elements required for an ecosystem-based assessment of the fisheries;
3. To allow, by including discards as well as landings, the quantification of the wasteful practice of discarding unwanted bycatch;
4. To provide a basis for an economic valuation of the fisheries as a whole, and not only of industrial fisheries, their privileged part.

We present, in the following, the datasets and methods used for our reconstruction, which proceeds by fishing sector.

Methods

Reported ‘baseline’

There are two publicly available landings statistics data sets for Eastern Canada: FAO (Food and Agriculture Organization; UN) and NAFO (Northwest Atlantic Fisheries Organization). We considered FAO landings statistics in Area 21 as the baseline for this catch reconstruction (1950 – 2010). Although FAO data included key information (i.e., year fished, species, country fishing, and catch amount), they did not include any spatial indication of where the catch was taken within the broad FAO area 21, thus limiting these data for any detailed regional analysis.

For this reason, NAFO landings statistics (1960 – 2010) were used to supplement FAO data. NAFO data and FAO data have comparable landings (with NAFO landings being on average 0.3% lower than FAO), however NAFO data also include finer spatial resolution of where catches were taken. As seen in Figure 2, NAFO area is divided into Subareas (0-6) along with more precise Divisions within the Subareas. This extra detail enabled us to disaggregate FAO data (for each species and year) by region.

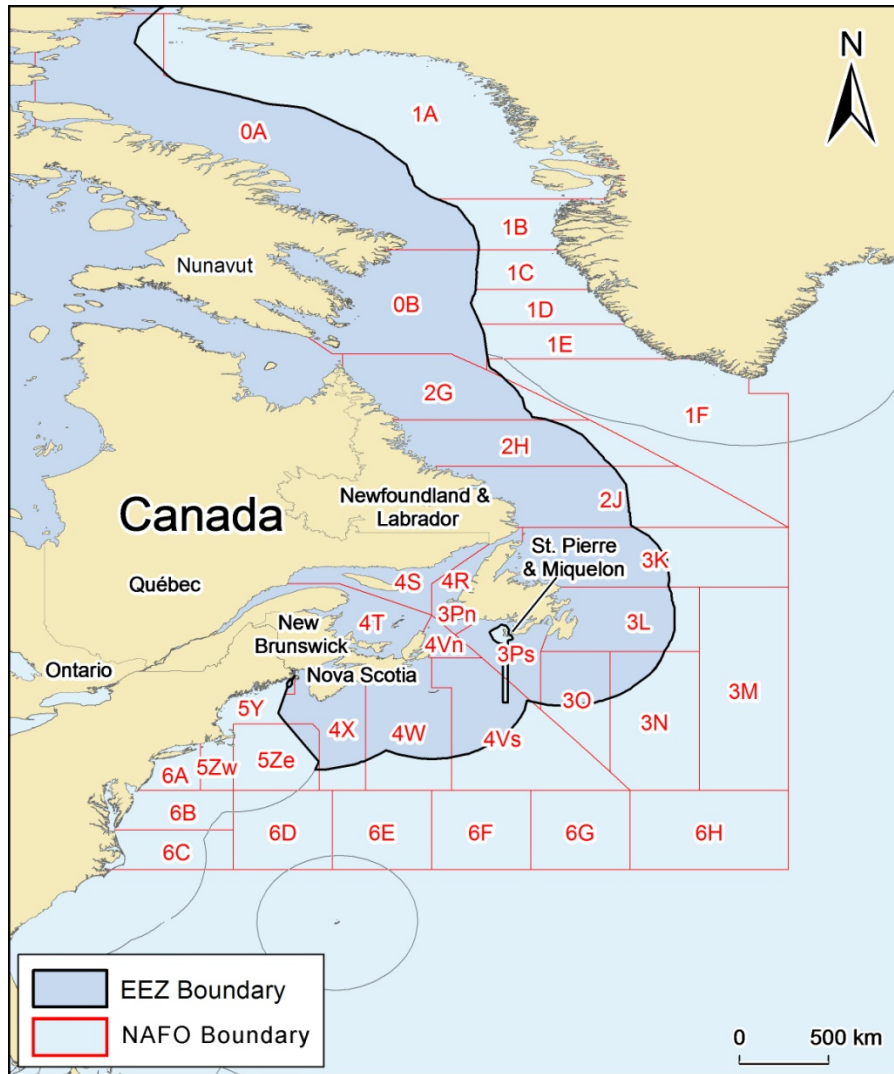


Figure 2. Eastern Canada's EEZ with NAFO Subareas and Divisions overlaid.

Regional disaggregation

In order to disaggregate FAO data by region, FAO and NAFO landings for each country were compared by species. The complication that arose from a species by species comparison was that the species classifications were inconsistent between the two data sets. For example, for Canadian landings, FAO had 77 species classifications while NAFO had 105. Thus, some adjustments had to be made before the data were comparable. Each species was coded by major species group, e.g., groundfish, pelagic fish, other finfish, shrimp, scallop, lobster, and other invertebrates. For each country and species group, the percentage of NAFO landings attributed to each region was applied to FAO data. For the years 1950 to 1959, NAFO data were not available and the regional NAFO breakdown from 1960 was used.

The NAFO data were coded by Division, but there were also three additional designations: "Unreported", "Outside NAFO Area", and "Unknown." For most species, these designations only began appearing in 1994, and at times the catch in these categories were quite large. Since this amount was fairly constant but the designation varied from year to year, we assumed that this amount was simply coded differently each year, but essentially represented a portion of the catch where there was uncertainty as to where it was taken from. In these cases, we dealt with the data as follows:

1. If this unknown amount was small for a given year, then the NAFO Division disaggregation was done without considering this unknown amount.

2. If this amount was large for a given (or consecutive) year(s), the percentage breakdown from a previous year was used (or an interpolation between several years). Without this adjustment the percentages would have significantly skewed the data.

Allocation of 'baseline' reported catch within Canada's EEZ

It is clear that NAFO Divisions (Figure 2), which provided the highest level of detail available, do not discriminate between what is taken within the EEZ and on the high-seas. This posed a problem for the reconstruction of total foreign removals within the Canadian EEZ. Moreover, this issue is even more severe for FAO data, which does not show catches by or within the Canadian EEZ, rather what is taken by Canada regardless of which region or EEZ it has been taken from. Nevertheless, we utilized the disaggregated FAO catch and made certain assumptions. For domestic catches by the Canadian fleet, we assumed all catch in Subareas 0, 2, 3, 4 and 5ZC, 5Y, and 5Z were within the Canadian EEZ for the entire time period.

For catch by foreign vessels (except St. Pierre and Miquelon) we made two separate sets of assumptions for the time periods prior to and after the establishment of the Canadian EEZ. From 1950 to 1976, we assumed that foreign catches in Subareas 0, 2, 3, and 4, but excluding Division 3M, were taken within the Canadian EEZ-equivalent waters for two reasons: (i) foreign catches in these areas declined sharply after the EEZ was declared in 1977, and (ii) the abundant Grand Banks groundfish stocks are primarily within the Canadian EEZ (except the 'Nose' and 'Tail') and the area within the EEZ is considerably more productive (Garcia-Orellan 2010). These assumptions are conservative because Canada also has jurisdiction for a small area of the northern Georges Banks, which straddles the U.S. – Canadian maritime frontier in Division 5ZE and in 5Y (Parsons 1993). Foreign landings in this region were not considered in our reconstruction.

For the period after the declaration of the Canadian EEZ in 1977, we only considered foreign landings within Subarea 0 and Divisions 4RST, 4Vn, and 3P for this reconstruction, as they lie primarily, if not completely, within the Canadian EEZ. We made the same general assumptions for St. Pierre and Miquelon except for catch within Divisions 3Ps and 4Vs, which includes the St. Pierre and Miquelon EEZ and thus we assumed any catch in these regions was in the French, rather than Canadian jurisdiction.

These assumptions resulted in a 'baseline' database of reported FAO catch by region along with an indicator as to whether the catch was taken inside or outside the Canadian EEZ (or EEZ-equivalent waters). In the following sections, we describe the methodology for reconstructing unreported catches in the commercial sector and their discards, as well as small-scale subsistence and recreational catches.

Unreported commercial catches

"Law at sea is more a fiction than a reality" (McMullan and Perrier 2002).

Although this quote refers to the poaching in the Canadian lobster fishery, there are numerous cases of unreported commercial catches documented from 1950 to 2010, including poaching by the domestic fleet, unreported foreign catch, and illegal foreign catch. Canada, which has full jurisdiction over its waters and relatively good monitoring capability, still struggles to enforce laws in the open terrain the sea.

Domestic fisheries

Unreported catches refer to what is otherwise known as poaching. Misreporting was very common in the Canadian fishery (Palmer and Sinclair 1996; Metuzals *et al.* 2008). According to a Newfoundland fisher, pre-moratorium *"landings were never written down and misreporting happened all the time"* (Metuzals *et al.* 2008). Although the full extent of unreported catch may never be known, we present conservative methods for reconstructing catches by species for the domestic fleets. Additionally, we include estimates of misreporting by foreign commercial fleets before the declaration of the 200-nm EEZ.

Lobster

Up until the mid-19th century, lobster fisheries were under a 'laissez-faire' policy, governed by informal property rights. However once technology and markets expanded in the late 19th century, the opening of canneries resulted in privatization of a resource that was once public. Thereafter, the federal government attempted to *"establish itself as*

the sole manager of the resource” via legislation and regulations (McMullan and Perrier 2002). This was the beginning of the tense relationship between government and lobster fishers that colored the 20th century.

In addition to increasing regulations, in the 1950s the government launched various state-supported financial and social welfare schemes to encourage capitalization in the industry. This left many lobster fishers in debt to the government, yet paradoxically facing increasing regulations that limited their ability to pay off their loans. The seasonality of the fishery imposed high price elasticity, as tourists arrived (and therefore demand increased) right before the fishery closed, which didn’t help fishers. The result was hostility, where out-of-season poaching became *“a routine form of everyday resistance”* (McMullan and Perrier 2002).

The Atlantic lobster fishery was one of the most troublesome fisheries to monitor (McMullan *et al.* 1997; Gough 2007). Not only were a small number of enforcers dispersed over thousands of kilometers of coastline, but as one fishery officer explained, *“our equipment is still in the dark ages”* (McMullan *et al.* 1989; McMullan and Perrier 2002). Three distinct types of lobster poachers were described in the literature: the communal poacher, outlaw poacher, and the commercial poacher. The communal poachers were those who poach lobster for subsistence, rather than for profit. These lobster poachers were often supported by the community, as they posed no threat, and we included these catches in the small-scale subsistence sector (see below). The second type of poaching was commercial poaching, which is poaching by registered fishers who concurrently report legal catches as well. This category of poachers was also supported within the community, as the memory of informal property rights was retained within the psyche of the people. In contrast to the first two types of poachers, outlaw poachers posed a threat to the community and were considered outsiders. In fact, enforcers believed that most cases of leaked information about the whereabouts of outlaw poachers was by commercial poachers (McMullan *et al.* 1989). Rough estimates of outlaw lobster poaching in the Scotia-Fundy region range from 17% to 35% of reported lobster catch, averaging almost 3,000 t·year⁻¹ from 1968 to 1987. However, to avoid double counting, we did not reconstruct this segment here.

Thus, this reconstruction for lobster poaching only accounted for catches by the commercial poacher, since the *“organization of business poaching [was] larger in scale and more complex and continuous”* than outlaw poaching (McMullan *et al.* 1989; McMullan and Perrier 2002). Unregulated commercial lobster fishing included high trap usage, out-of-season catches, and poaching undersized lobster. However, only high trap usage was included in our analysis. Additionally, commercial poaching left no paper trails, as is seen by the following excerpts:

- Poachers *“entered into alliances with hotels, restaurants, community groups, private citizens to dispose of illegal catch”* (McMullan and Perrier 2002)
- *“Lobster pounds and fish companies purchase[d] lobsters from business poachers on a cash only basis without providing official receipts”* (McMullan *et al.* 1997)
- *“Buyers tend[ed] to overlook the illegal activities of fisher[s] because they [had] nothing to lose by being caught with lobsters that were caught in untagged lobster traps. Once lobsters [were] in the plant, who is to know”* (McMullan and Perrier 2002)

To calculate unreported catches in the lobster fishery, we used the sub-sample of southwest Nova Scotia in the mid-1980s, for which there was abundant descriptive literature and some media coverage of the *“piscatorial piracy”* (DeWolf 1974). Thereafter, we extended our estimates to encompass other regions with reported cases of lobster poaching as well as adjust catches to trends in lobster poaching for the entire time period 1950 to 2010.

McMullan and Perrier (2002) state that non-compliance in the southwest Nova Scotia lobster fisheries is consistent with that of the Massachusetts lobster fishery (Gauvin 1988) and the Rhode Island clam fisheries (Bean 1990), where it was estimated that 10% of fishers were frequent violators and 30-40% were occasional violators. We believe these estimates are strict minimums for the lobster fishery due to the deeply entrenched history and social acceptance of poaching.

Case in point, within the fisheries studied by Gauvin (1988) and Bean (1990), fishers who comply with regulations cited their main reason as the need to *“do the right thing”* (Kuperan and Sutinen 1998). In contrast, the lobster poachers of Nova Scotia do not share the same morale. As a fishery officer aptly put it, *“overfishing has a lot to do with the culture of the area”* and in Nova Scotia *“the people who are held up as heroes in their community are the people who catch the most fish”* (McMullan and Perrier 2002). Even though this points to higher noncompliance is

in the lobster fisheries of Atlantic Canada than what was estimated by Gauvin (1988) and Bean (1990), we conservatively assumed the same compliance: 10% of commercial lobster fishers were frequent violators and 35% were occasional violators.

To reconstruct high trap usage over the allowable limit, we referred to cases of high trap usage in literature. The highest appraisal of trap usage was from an article in the Atlantic Fisherman in 1986, which stated that approximately 20% of southwest Nova Scotia lobster fishers “*set up to 700 traps*” (McMullan *et al.* 1997). Since the maximum trap limit in southwest Nova Scotia was 375, we assumed that this quote referred to the ‘frequent violators’. T_{frequent} denotes the number of traps used over the trap limit for these violators, which is 325 traps. T_{limit} denotes the maximum trap limit, which is 375 traps.

Another account stated that it is common to see “*trap usage that is on average 100 to 200 traps above the 400 trap limit*” (Kearney 1988). We applied this level of trap usage to occasional violators and conservatively assumed that 100 traps were set over the limit, which means $T_{\text{occasional}} = 100$. The following formula results in the average value of unreported landings as a percentage of reported landings:

$$\text{Unreported catch (\% of reported lobster catch)} = \frac{10\% * T_{\text{frequent}} + 35\% * T_{\text{occasional}}}{T_{\text{limit}}}$$

The result is unreported catch at 18% of reported catch. We extended this estimate of illegality to all other lobster landings for several reasons. First, the Maritimes (Nova Scotia, New Brunswick, and Prince Edward Island) and Quebec had a comparable reputation for misreporting lobster catches according to Gough (2007), where lobster poaching was an “*old tradition*.” Second, literature on the perceived gains and penalties of lobster poaching indicated that the net return on lobster poaching in the Scotia/Fundy region is actually negative at -\$7, while in the Gulf and Newfoundland the net return was positive, \$19 and \$9, respectively (Blewett *et al.* 1987) This implies that lobster poaching should actually be less common in the region we estimated than in other Atlantic provinces. Thus, we believe 18% is a conservative estimate of unregulated catches in the mid-1980s for all lobster landings in Atlantic Canada.

We varied the rate of unreported catches over time due to perceived changes in poaching. Between 1968 and 1984, Gough (2007) stated that lobster “*poaching seemed to begin a slow decline even though it remained common*.” Therefore, the unregulated catch was assumed to be slightly higher at 21% in 1968 and then linearly decline to 18% by 1984. Prior to 1968, we assumed that poaching stayed constant at 21%. From 1984 to 2000, poaching was still present, but “*many observers believe it has diminished*” (Gough 2007). Thus we assumed that poaching declined by half from 1984 until 2010, from 18% to 9%. As stated before, these rates were applied to total lobster landings.

Atlantic Cod

Cod poaching began in 1983 due to the introduction of quotas for the Newfoundland trawl fleet. Underreporting of catches was rampant until the cod moratorium, along with excessive use of liners and discarding (Palmer and Sinclair 1996). It was stated that “*most buyers cooperated by paying for about 25% more fish than they officially reported having purchased*”. This implies that unreported catches in Newfoundland are in the order of 25% higher than what is officially in the records for those years. In order to be conservative, we assumed that this claim was only true for 60% of the buyers, thus making the unregulated catch 15% higher than reported landings. This rate was applied to all domestic landings of Atlantic cod from 1983 to 1993.

According to responses by fishers, misreporting of cod landings post-moratorium was still “*extremely high*” (Metuzals *et al.* 2008). For the few fisheries still open for Atlantic cod, particularly the Sentinel and Index fisheries, fishers stated that underreporting was “*rampant*” and that unreported catches totaled as much as 30%. Additionally, since there was legally no quota for bycaught cod, 30% of these cod were never reported. In brief, regardless of whether cod was caught as a directed species or as bycatch, 30% of the true catch was not reported. This translates to unreported catches at 43% of reported cod landings, which was applied to all cod landings in the post-moratorium period (1994 – 2010). The growth in poaching from 15% to 43% in the post moratorium period is consistent with the claim by a fisher that the amount of cod sold illegally has increased since the moratorium (Metuzals *et al.* 2008).

Other species

According to Metuzals *et al.* (2008), fishers cited the fisheries of Atlantic mackerel, Atlantic herring, capelin (*Mallotus villosus*), turbot (*Reinhardtius hippoglossoides*), and redfish as known for misreporting or lack of surveillance by officials. For these fisheries, we assumed unreported catches are 10% of landings. This is very conservative because the theoretical model for these fisheries estimates a concealment rate of nearly 58%, which translates to unreported catches at 138% of landings (Metuzals *et al.* 2008).

Foreign fisheries

In eastern Canada, Spain and Portugal were consistently known as the “*bad boys of the international fishing community*” (Harris 1998). Whether this was due to actual overfishing or that “*Canada was not prepared to take action against either the Soviets*” or other militarily and economically strong states, as international relations theory would predict, is beyond the scope of the present paper (Garcia-Orellan 2010). Since most accounts focus on Spain and Portugal, we only estimated unreported catch from these two countries.¹

Unreported catch by Spain and Portugal

Prior to the establishment of the EEZ, when foreign fishers legally fished in water outside the 12 nm territorial seas, Losa (2001) stated that declared landings should be increased by about 20 - 25% in Spanish fisheries. We used 20% of landings to estimate unreported Spanish catches.

Although there was no evidence of misreporting by Portugal in the early 1950s, increased competition and lower catch rates starting in 1957 likely incentivized Portuguese fleets to underreport catches (Coelho and Stobberup 2001). Although a direct estimate isn't given, we assumed a rate of 5% misreporting from 1957 to 1976. There was also evidence of overfishing by Spain within the EEZ after the declaration of the EEZ, but these catches are no longer considered unregulated, rather illegal (see below).

In addition to estimating true illegal catch from Spain, we also estimated overfishing by countries outside of the EEZ on the high seas. While the latter portion will not be included in the reconstruction of catches, we nonetheless included these estimates of unreported catch in order to have a more meaningful and complete discussion on the management of fish stocks.

Illegal catch by Spain

From 1977 to 1992, there was evidence of illegal fishing by the Spanish fleet within the Canadian EEZ. This first began after the establishment of the EEZ in 1977, when foreign fleets were forced to leave the abundant Grand Banks off Newfoundland. The tension is clearly seen through the nickname given to the red Coast Guard boats of Canada: “*veine el demonio*” or “*ven o demo*” (here comes the devil) by Spanish and Portuguese boats.

A crew member of Terranova, the Spanish fleet on the Grand Banks, revealed that they “*took every risk in the book*,” they “*all fished inside the 200 miles. If [they] saw someone coming, [they'd] cut the warps, warn the others, and get the hell out of there. If you stayed outside of the limit like you were supposed to, you might be hauling up one “camasto” (100 kg, 220 pounds) per tow, which is nothing. And so, as time goes on and the hold is still half empty, you start taking risks, crossing the line.*”

Many more accounts like this existed. In order to be consistent with previous estimates of under-reporting by Spain, we estimated that illegal catches were 20% of reported Spanish landings from 1977 to 1985. During this period, fishers admitted to heavy overfishing because fines were relatively low due to the inability of Canadian surveillance to truly prove the vessel's position (Garcia-Orellan 2010). From 1985 to 1992, Canadian surveillance became more advanced and crossing the line became less common, although a skipper stated that “*the line is still not completely delimited, even early in the twenty first century*” (Garcia-Orellan 2010). Since there was an account leading into the 21st century, we assumed that illegal catches linearly decreased from 20% in 1985 to 2% in 1992, thereafter staying constant at 2%.

Although Portugal was often grouped with Spain as countries with a reputation for overfishing, evidence revealed that Portugal fished right along the border of the EEZ while Spain fished passed it, often entangling their nets with

¹ Future investigations should extend this approach to other foreign fishing entities fishing in these waters.

Portugal while hurrying to return beyond the 200-mile limit when the red patrol boat was spotted (Garcia-Orellan 2010). Thus, illegality for Portugal was not reconstructed in the present analysis.

Catch outside the EEZ, on the Nose and Tail

“We are not stealing, these are nobody’s waters”
Spanish crew member, Manuel Nogueira (Harris 1998)

NAFO considers catches made by non-member vessels on the high-seas to be illegal. However, this was not considered illegal catch for the purposes of our reconstruction because it was outside the EEZ delineation (it may be deemed ‘unregulated’). Thus, these estimates were not included in our final reconstructed catch, yet included for purposes of a stock analysis of Atlantic cod, as the EEZ cuts through the Grand Banks cod stock.

We estimated unreported catches just outside the EEZ based on Canadian detailed air and sea surveillance that stated that, *“there was a quadrupling of effort by non-member vessels in the Regulatory Area between 1984 and 1990 and that this was accompanied by a catch increase to an estimated 46,800 tonnes by 1990... Canada estimated that 95.5% of this catch comprised cod, flounder, and redfish taken on the Tail”* (Day 1995). The ‘Nose’ and ‘Tail’ are portions of the Grand Banks that are located outside the Canadian EEZ, and since fish are not aware of the EEZ boundary, these catches are important to consider in the management of stocks. Of the total amount reconstructed, we assumed that all specific species of cod, flounder, and redfish were caught on the Tail, 90% of which was designated as Division 3N and 10% as 3O. The miscellaneous species (which amounted to about 4.5% - 6% of total catch) were designated as being caught on the Nose, in NAFO Area 3L.

Effort data of non-member vessels cited outside the EEZ were available from various sources (Rayfuse 2004; Rosenberg *et al.* 2005; NAFO 2013). Particularly in 1990, 44 non-member vessels were cited, which results in a catch per unit effort (CPUE) of 1,064 t·vessel⁻¹. We assumed that the CPUE stayed constant, as after the cod moratorium, other abundant species were targeted, e.g., turbot and redfish (Rosenberg *et al.* 2005). This CPUE was applied to the number of boats from 1977 to 2010. As mentioned previously, nearly all of these catches were composed of Atlantic cod, turbot, and redfish. Post-moratorium, turbot was heavily targeted in the mid-1990s, out of which arose the Turbot War and capture of the *Estai*. By 2000, most sources cited non-member countries fishing for redfish, of which Atlantic Cod was 6.4% of the bycatch (Rosenberg *et al.* 2005).

To determine which countries were responsible for the unreported catches, we used the same effort data of non-member vessels cited, which often included names of countries. For each year, we attributed an equal proportion of catches to each country listed, and interpolated between years. Furthermore, the allocated unreported catches for each non-member country was cross-checked with official reported data by FAO and NAFO to ensure that there was no double-counting. For the following countries, there was no reported data in the FAO database, which means that the catches were indeed unreported: Venezuela, Panama, Chile, Cayman Islands, Mauritania, St Vincent’s, Sierra Leone, Honduras, New Zealand, Sao Tome, Principe, Dominica, Belize, Cyprus, Guinea Conakry, Ghana, Russia (Georgia). On the other hand, Mexico, Spain, Korea, and USA, did report landings to FAO and NAFO for the years where these estimates were allocated. Thus, these ‘unreported catches’ may have been reported and we exclude them from our estimates for the years that there were data. The only exception is Mexico from 1980 to 1987, where there were no reported landings. The final breakdown of unreported catch by country can be seen in Appendix I.

Discards

Discards were calculated for the groundfish, shrimp, scallop, lobster, and swordfish fisheries. Local observer studies and publications were used to calculate a variable discard rate for each gear. A majority of authors state that the figures from observer studies are strict minimums.

Additionally, based on observer studies from 1978 to 2002 for the Gulf of St. Lawrence, there is strong evidence of an observer effect, i.e., a fisher’s behavior changes in the presence of an observer. The results show that in the cod-fixed fisheries, discards are underestimated by 16%, while in the mobile-gear fisheries discards are underestimated by 9% (Benoit and Allard 2009). Furthermore, even estimates by an observer may be biased downward, as seen by a

study where visual estimates by *experienced* observers were always underestimated, at times more than ten times lower (STACTIC 2000). An insightful example is the reaction of Nova Scotia-based crew members after finding out that an observer was deployed to their vessels: they said they were pleased, as they were not asked to discard fish (Angel 1994).

However, regardless of the tendency of observer studies to underestimate discards, observer studies are the best window we have into discarding at sea, and will be used in this reconstruction (Kelleher 2005). The last step for calculating discards will be disaggregating the lump sum amount of discards (for each gear in a fishery) by species.

Groundfish-directed discards

We calculated discards for the groundfish fishery by segmenting all groundfish landing data by gear caught from 1950 to 2010 using FAO disaggregated landings. We utilized three anchor points for the gear breakdown, compiled from various sources, e.g., years 1950, 1981, and 2010. We linearly interpolated the gear breakdown from 1981 to 2010. Between 1950 and 1981, however, we used a progressive adjustment in order to be consistent with historical accounts of gear changes. For foreign landings, we assumed all landings were landed by trawlers. Below is the methodology for the (i) anchor point for gear-based landings, (ii) progressive adjustments between the anchor points from 1950 to 1981, and (iii) discard rates by groundfish gear.

(i) Anchor points for gear-based landings

1950:

In 1950, a clear breakdown of the Atlantic groundfishery by gear was not available. While NAFO data were available from 1960 onward, the gear used was only present 10% of the time from 1960-1969. Therefore, the gear breakdown for 1950 was derived. Atlantic cod landings were used as a proxy for groundfish as a whole because in 1950, Atlantic cod landings accounted for 78% of total groundfish landings. We also assumed that available data for the Gulf of St. Lawrence Estuary (NAFO sub-Area 4T) in the 1950s and Newfoundland & Labrador (NAFO sub-Area 2J3LK) starting in 1959 were representative of the Atlantic cod fishery (Jean 1963; Bratley *et al.* 2008).

We weighed the gear composition evenly for these two areas as they were simply sub-samples of the groundfish fleet at large. According to Jean (1963), 16% of Atlantic cod landings were made by trawlers in 1950, while the rest (84%) were split between trap and handline, although the specific proportion was not stated. In Newfoundland, trawlers accounted for 3% of the cod landings in 1959. For 1950, we assumed that gear taken by Newfoundland trawlers was 0%. Averaging the two anchor points, we obtain 8% as groundfish landings attributed to landings by trawlers.

The other 92% is attributed to fixed-gear landings. Jean (1963) and various historical accounts of Newfoundland depicted line and trap as the mainstays of the fixed gear (Gough 2007; CDLI 2014). We assumed an equal split between trap and handline landings, and thus estimated 46% of landings attributed to trap gear and 46% of landings attributed to handline gear.

1981:

In 1981, 44% of the Atlantic Canada groundfish landings were taken by trawlers (large and medium sized), while the rest were taken by other gear (Gough 2007). Although there were no concrete estimates for the gear composition of the other 56%, Quebec, New Brunswick, and PEI took only 7, 3, and 2% of the groundfish landings in that year (Gough 2007). Therefore, we looked to Newfoundland and Nova Scotia to understand the gear breakdown.

Gough (2007) described that for Newfoundland, with the exception of trawlers, “*most craft used gillnets and cod traps,*” while in the Scotia-Fundy region, most boats that were not trawlers used “*longlines, gillnets, and handlines.*” Since gillnet was present in both fisheries as a major gear, we assumed that the gillnet gear accounted for 45% of non-trawl landings. Trap gear is also very common in Newfoundland, but not used in Nova Scotia, therefore we will assume that trap gear accounted for 30% of landings. The less common gears like longline and handline were assumed to account for 15% and 10% of non-trawl landings, respectively, since longline was considered more “*popular*” (Gough 2007). These rough estimates of fixed gear landings were applied to the 56% fixed-gear landings. The final breakdown for gear-based landings in 1981 was 44% trawlers, 25% gillnet, 17% trap, 8% longline, and 6% handline.

2010:

Data were available for 2009 and 2010 with groundfish landing caught by gear (Chadwick 2012). In 2009, 63% of landings were caught by trawlers, 22% by gillnet, 13% by long-line, and 2% by handline. Trap gear was 0% in 2010, as it was heavily tied to the Atlantic cod, and trap fishing declined post-moratorium (Bratley *et al.* 2008).

(ii) Progressive adjustment of gear-based landings from 1950 to 1981

Rather than linearly interpolating between the anchor points for 1950 and 1981, there was strong evidence that the gear distribution in 1981 was actually a shift that happened earlier, in the late 1950s and early 1960s. For example, in 4T, landings by trawlers in the early 1960's were ranging anywhere from 45% to 39% of the Atlantic cod catch, which is similar to that of the groundfish distribution in 1981. Trawl discard rates were not as high for Newfoundland (only about 4% by 1960) however at this time new fisheries were being targeted that could only be reached offshore through trawling, e.g., redfish (Parsons 1993).

Regarding other gear, by 1960 in Newfoundland, the gillnet had begun to “*grow rapidly*” in popularity, while the hook and line and trap fishery became “*less effective as the proportion of large fish declined*” (Gough 2007; CDLI 2014). This description of the early 1960's matched the estimates of gear breakdown in 1981. Therefore, we linearly interpolated between the gear breakdown in 1950 and 1962 and assumed that the values in 1981 were representative of the values in 1962. From 1962 to 1981 the gear breakdown was assumed to be constant.

(iii) Discard rate by groundfish gear

For the groundfish directed fishery, discard rates varied by gear (trawl, gillnet, longline, trap, and handline). All discard rates are a percentage of landings by weight, unless otherwise stated.

Trawl discard rate:

Numerous discard surveys were done for cod and American plaice in the 1950s, 1960s, and 1970s averaging 6% for cod and 56% for American Plaice as a percentage of groundfish landed (Jean 1963; Belzile 1978; Cliche 1981; Halliday *et al.* 1989). However, Jean (1963) was the only source to include discards of other commercially targeted species (accounting for approximately 200%) as well as non-commercial species in the analysis (95% of groundfish landings). Estimates of discards by Jean (1963) for Atlantic cod and American Plaice were 6% and 40%, respectively. Since these discard rates are less than or equal to other studies done in this time period, we used the discard rates given by Jean (1963) as representative. The total discard rate estimated by this study amounted to 343% discarded as a percentage of landings (75% as a percentage of total removals from the ocean).

Kulka (1982, 1984, 1985, 1986a, 1986b) calculated discard rates for Newfoundland offshore, domestic trawlers. Discards of all species increased from 7.71% in 1982 to 10.99% in 1985, the change being attributed to the cod-directed fishery off Newfoundland and Labrador in NAFO Divisions 2J3KL. A line of best fit was calculated between the discard rates of 1956 to those of the 1980s. For the years prior to 1956, the geometric mean of the discard rates between 1956 and 1961 was used, which was 343%.

The rate of 10.99% was assumed to be constant from 1985 until the cod-moratorium in 1992, at which point it was assumed that the rate returned to the 7.71% rate due to the cod 2J3KL fishery being absolved. Species were disaggregated by interpolating the species breakdown in Jean (1963) and Kulka (1986a, 1986b). Comparable studies after the moratorium were not available, so we used the most recent source of data as representative for the post-moratorium period, except we adjusted the proportion of cod in order to account for the stock collapse. We used the data from the shrimp trawl as representative for the region 2GH and 2J3LK, which each showed a particular pattern. Starting in 1993, the proportion of cod to total catch composition declined to 40% its 1992 amount. Since the predominant region for groundfish trawl catch was in the Grand Banks in regions 2J3LK we used this region as representative for all other areas. This resulted in cod as bycatch declining from 40.3% in 1992 to 16.1% from 1993 - 2010. The other species were adjusted proportionally to account for this change.

We assumed all foreign trawlers had comparable discards to that of Canadian trawlers. This is conservative because foreign factory freezer trawlers were known to be far more detrimental to fish stocks than older models of trawlers used by the domestic fleet, as well as their tendency to discard all bycaught species except cod, while domestic fleets landed some non-target species (Jean 1963; Harris 1998). Additionally, a rough guideline of amount discarded to retained by foreign trawlers is 3:1, which corresponds to a discard rate of approximately 300% (Harris 1998). This is comparable to the discard of Jean (1963) whose discard rate is slightly higher at 343%.

Longline discard rate:

Benoît and Hurlbut (2010) evaluated the catch and discards in fixed-gear groundfish fisheries in the Estuary and Gulf of St. Lawrence from 1991 to 2008. We used a weighted average of the discard rates for all longline gear fisheries, i.e. targeting cod and Atlantic halibut (*Hippoglossus hippoglossus*), which placed discards at 10.5%. Other studies for the Atlantic coast were limited for bottom longline fisheries. However, this discard rate is consistent with the estimates of the global FAO discard study by Kelleher (2005), who estimated that the discard rate of groundfish longline was in the range between 9% and 41%. It is also consistent with fisher's logbook data for 2005 in Pacific Canada where minimum discard rates were between 0% to 18% by weight (Fuller *et al.* 2008). We assumed a constant rate of 10.5% throughout the time period due to no significant changes in gear or fisher behavior.

Handline discard rate:

Benoît and Hurlbut (2010) reported discards for the cod handline fishery, a very small fishery in the Gulf of St. Lawrence. Since the sample size was so small, we used the discard rate of 2% provided by Kelleher (2005). The species disaggregation, however, was taken from Benoît and Hurlbut (2010).

Gillnet discard rate:

The discard rate for groundfish gillnet gear was also taken from Benoît and Hurlbut (2010). We used a weighted average of the discard rates for the gillnet fisheries targeting Atlantic cod, turbot, American plaice, and winter flounder (*Pseudopleuronectes americanus*), which resulted in a discard rate of 14.7%. This is consistent with estimates of 1 - 25% by Kelleher (2005) and lower than the estimates of Alverson (1994) at 25 - 43%.

In the late 1980s effort increased significantly for the inshore groundfish gillnet gear directed at cod, as cod became smaller and less frequent (Neis 1992). Along with a tripling in effort, the discard rate also increased by this magnitude (Hutchings and Ferguson 2000). We assumed that the discard rate doubled, rather than tripled in order to remain conservative, as there are other gillnet fisheries as well, e.g., for turbot. The discard rate of 29.4% is still lower than the maximum limit of 43% in Alverson (1994).

We interpolated linearly from 14.7% in 1985 to 29.4% in 1988 and assumed that the discard rate remained constant at 29.4% between 1988 and 1992. After the moratorium, we inferred that the effort, and thus the discard rate, decreased. From 1994 to 2010 we applied a discard rate of 14.7% for the groundfish gillnet gear and an intermediate value for 1993.

Trap discard rate:

Most pot and trap fisheries in Canada did not have observer coverage (Fuller *et al.* 2008). However, Stevenson (1986) used the discrepancy between landed and sampled size of cod in the inshore cod trap fishery of Newfoundland to derive a discard rate of 5.2%, which is composed of undersize cod. According to Hutchings and Ferguson (2000), after the mid-1980s when the previous study took place, there was a trebling of effort, and discards, in the trap fisheries as the number and size of cod began to significantly diminish. Other sources state that dumping may have been as high as 50% by weight due to rejection of undersize fish by plants (Harris 1998; Metzals *et al.* 2008). Some fishers described how the, "water was white with small fish" and "the harbour looked like it was covered with ice" (Metzals *et al.* 2008). We conservatively used the anchor point of discards tripling to 15.6% rather than 50%. By the early 1990s, fishers reported that no more dumping took place, so we interpolated the rate of discarding from 15.6% in 1989 to 5.21% in 1991, thereafter remaining constant.

We interpolated linearly from 5.2% in 1985 to 15.6% in 1988 and assumed that the discard rate remained constant at 15.6% between 1988 and 1993. After the moratorium, we inferred that the effort, and thus the discard rate, decreased. From 1994 to 2010 we returned the discard rate to 5.2% for the groundfish trap gear.

Shrimp-directed discards

Discards for shrimp fisheries were estimated by compiling the discard rate anchor points for nine different NAFO Divisions, from seven different independent sources on observer coverage from 1977 to 2010 (Minet *et al.* 1978; Howell and Langan 1992; Kulka 1995; Kulka 1999; Koeller *et al.* 2006; Savard *et al.* 2012) This coverage was appropriate, since shrimp fishing mostly began in the late 1970s and landings only expanded in the mid-1980s. For years when there was more than one discard rate, a geometric mean was taken. The geometric mean is preferred to averages, since it always leads to an equal or smaller average, which for the purposes of this reconstruction is more conservative.

These values were then plotted, and a clear trend was seen in the data across all of the regions. This trend also matched the historical gear changes. Between the late 1970s and mid-1980s, discard rates ranged between 20% to 100% of landings and were on a decline, perhaps due in part to changes in minimum mesh size (Savard *et al.* 2012). Rates continued to decline until the early 1990s when the discard rate dropped tenfold with the introduction of the Nordmore gate gear attachment, which significantly reduced bycatch (Kulka 1995; Kulka 1999; Koeller *et al.* 2006; Savard *et al.* 2012). The Nordmore gate is a device that places a guiding tunnel for larger fish to escape from if they are caught in a codend of a shrimp trawl (DFO 2013a). Starting in the mid-1990s the discard rate stabilized to a very low amount, averaging 2.5%.

From 1977 to 1992, a line of best fit was used to estimate the declining discard rate. This line was fairly steep, and since data were not available prior to 1977, we used the discard rate from 1977, 60%, as the maximum discard rate for this fishery. Thus, from 1950 to 1973 the discard rate was 60%, and then decreased linearly to 24% in 1990. The Nordmore gate was introduced in 1991, and we linearly interpolated from 24% in 1990 to 2.5% in 1994 and then kept the discard rate constant at 2.5%.

We disaggregated catches taxonomically by taking the unique species breakdown in each NAFO Division and applying it to the disaggregated landings of all shrimp in their respective NAFO Divisions. For Divisions 2GH and 2J3LK, there was a dramatic difference in the contribution of Atlantic cod to discards before and after the moratorium. This was incorporated by varying the discard distribution of species to account for these changes. This is the only fishery where there was enough detail to vary the species disaggregation based on landing site.

Swordfish-directed discards

According to Campana *et al.* (2009), most shark bycatch and discards were a result of pelagic longlining in the tuna and swordfish (*Xiphias gladius*) fisheries. Although we were not able to find the proportion of tuna landings caught by longliners, we were able to dissect swordfish landings by gear in order to apply the discard rate of 94% to the appropriate base of landings.

The Atlantic swordfish fishery began in the late 1880s, dominated by harpoon sailing vessels, until the early 1960s, when the fishery shifted from a harpoon to primarily a longline fishery. Thus we assumed that longliner landings were 0% until 1961 and then increased to 70% by 1962.

Landings data by gear (harpoon versus longlining) were available from 1987 to 2003. Between 1962 and 1987, we performed a linear interpolation. After 2003, the harpoon fleet was allocated 10% of the Canadian swordfish quota, while the predominant longline fishery accounted for 90% of the annual harvest. Thus we used the 90% to 10% breakdown from 2004 to 2010. Swordfish longliner landings were multiplied by the discard rate of 95% from 1950 to 2010 to obtain discards of shark. The harpoon gear had very minimal to no discards.

Scallop-directed discards

Duthie (1996) estimated the discard rate of the scallop (*Placopecten magellanicus*) dredge in Atlantic Canada at 20%, which we applied to all years from 1950 to 2010. Discards consisted of 59% molluscs and echinoderms, 38% crustaceans, and 5% fish (Chadwick 2012). We divided the 59% for molluscs and echinoderms evenly so that 29.5% of discards were attributed to marine molluscs and the other 29.5% to echinoderms. The echinoderm taxon classification consisted of primarily starfish and sea urchins. In order to be more specific, we classified this taxon as sea urchins and other echinoderms because other studies in Atlantic Canada have also shown high discard rates of sea urchins, but limited discards for starfishes (Jean 1963; Kulka 1986b; Benoît and Hurlbut 2010). Additionally, we classified the 5% discards of fish as marine fishes not identified.

Lobster-directed discards

Gendron and Duluc (2012) compiled data on discard rates in the trap lobster fisheries of Gaspé-Nord, Gaspé-Sud, and Îles-de-la-Madeleine. We estimated a weighted average of the discards in these areas at 24.4%. Of this amount, over half of discards by weight were various crab species, while the rest were finfish and other marine species. Since crab species have a traditionally low mortality rate, we excluded these discards from our analysis and arrived at a discard rate of 11.1% for all lobster landings from 1950 to 2010.

Small-scale catches

Small-scale catches include those caught in artisanal (i.e., small-scale commercial) and subsistence (small-scale non-commercial) fisheries. Unreported artisanal fisheries were not evaluated in this analysis to avoid double counting, as we assumed conservatively that the above estimated unreported commercial catches may include unreported artisanal catches. However, we were able to disaggregate reported FAO landings by gear (see discards section for methods). The gear type was used as a proxy for industrial or small-scale fishing.

Every country has its own definition of artisanal fisheries. For Canada, the definition of inshore versus offshore sector is often used, especially in the division of quotas. Offshore gear is generally defined as trawlers greater than or equal to 100 feet, while inshore vessels are less than or equal to 65 feet (Kirby 1982; Parsons 1993; Gough 2007). The reason these terms are “*misleading*” is that there are boats in the inshore category, notably, 65-foot Nova Scotia draggers, “*capable of fishing most of the year and harvesting most of the species available on the Scotian Shelf*” (Parsons 1993). Another example is the trap lobster fishery, which by this definition qualifies as an inshore fishery, but is heavily capitalized and far from ‘small-scale.’

Thus, for the purpose of this report, we used the distinction of mobile-gear versus fixed-gear for the groundfishery to differentiate small-scale versus commercial. This gear differentiation has already been done (see section on groundfish-directed discards). For the swordfish fishery, harpoon gear was considered small-scale and the longline gear industrial. For the shrimp fishery, the predominant bulk of the landings was taken by trawlers, regardless if they are commercial offshore trawlers or inshore trawlers between 45 – 65 feet in length (Foley 2012). Thus all shrimp landings were considered commercial landings. For other fisheries where there was less information, we assumed that FAO reported landings were industrial landings.

Subsistence catch

Subsistence catches were estimated by adding the estimated subsistence catch of two distinct population segments of eastern Canada; i) coastal aboriginal reserves or communities, including arctic subsistence catch for FAO Area 21, previously calculated by Zeller *et al.* (2011), and ii) small, rural fishing villages. For both population segments the yearly per capita consumption of fish was multiplied by the population.

i) Subsistence catches in coastal aboriginal reserves or communities

Berkes (1990) undertook a synthesis of harvest studies in Canada for native subsistence fisheries. The Canada-wide estimate was 60 kg of whole fish per capita per year. In our region of interest, the other relevant anchor points were 83 kg·capita⁻¹·year⁻¹ for the Labrador Inuit (Usher 1982), 54 kg·capita⁻¹·year⁻¹ for the Baffin Island Inuit (Donaldson 1984) subdivided into three distinct areas: Clyde River with 49 kg·capita⁻¹·year⁻¹, Pangnirtung with 53 kg·capita⁻¹·year⁻¹, and Pond Inlet with 50 kg·capita⁻¹·year⁻¹. We assumed 27 kg·capita⁻¹·year⁻¹ for the capital city Iqaluit, which is half of Baffin Island per capita consumption.

For the regions where no harvest study was undertaken, the Canada-wide estimate of 60 kg·capita⁻¹·year⁻¹ was used. Since these studies took place in the late 70’s and early 80’s, we assumed that per capita consumption changed over time. We assumed that in 1950, the per capita consumption was 20% higher, and that in 2010 it was 20% lower. Various independent sources confirmed that for aboriginal, and especially northern communities, subsistence provisioning remains vital for survival and still has vital cultural significance (Statistics Canada 2001; DFO 2011b; Natcher *et al.* 2012).

Next, we gathered population data for 44 reserves and aboriginal communities. For the 1950s, the 1951 census was used for population data on communities in Newfoundland and Labrador and New Brunswick (Canada Dominion Bureau of Statistics 1951). For recent population data figures, data were compiled from various sources: Secrétariat aux affaires autochtones (2007, 2013) for Quebec; Nova Scotia Aboriginal Affairs (2006) for Nova Scotia; Statistics Canada (2011a, 2011b, 2013) and Indian and Northern Affairs Canada (2011) for the provinces of New Brunswick, Prince Edward Island, and Newfoundland and Labrador. For the Inuit, Usher (1982) provided data for the Nunatsiavut region in Labrador in 1979 and population data for Iqaluit were from Statistics Canada (2012). Figure 3 depicts which communities of Atlantic Canada were used in the present analysis and which were not used. The communities that were not used were excluded either because their fishing area was not in FAO Area 21 or it was a significant distance from shore and hence unlikely its people would fish at sea.

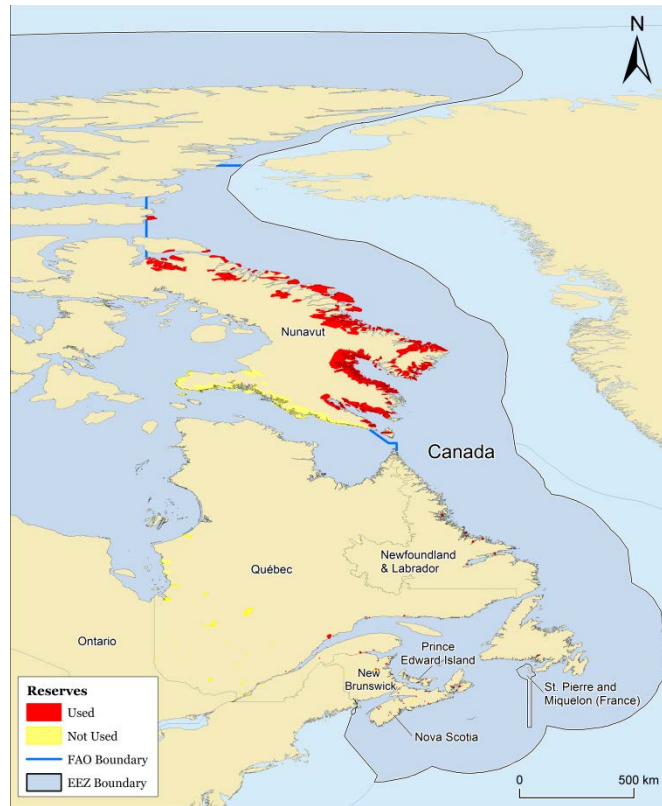


Figure 3. Aboriginal coastal communities used for the subsistence catch reconstruction of Atlantic Canada from 1950 to 2010

When gathering anchor points for the population of all relevant coastal communities from 1950 – 2010, it became evident that the population statistics for all reserves were not present in the 1951 census, most likely due to lack of coverage at the time (Statistics Canada 2002). There were only nine reserves with population data available in the 1951 census and these anchor points indicated the average rate of growth at 7.5% per year, approximately 450% growth from 1950 to 2010 (Figure 4). Census data indicate that between 1951 and 2001, the Aboriginal ancestry population grew sevenfold, while the Canadian population as a whole only doubled. (Statistics Canada 2002). Thus, our estimate falls somewhere in between these two growth rates.

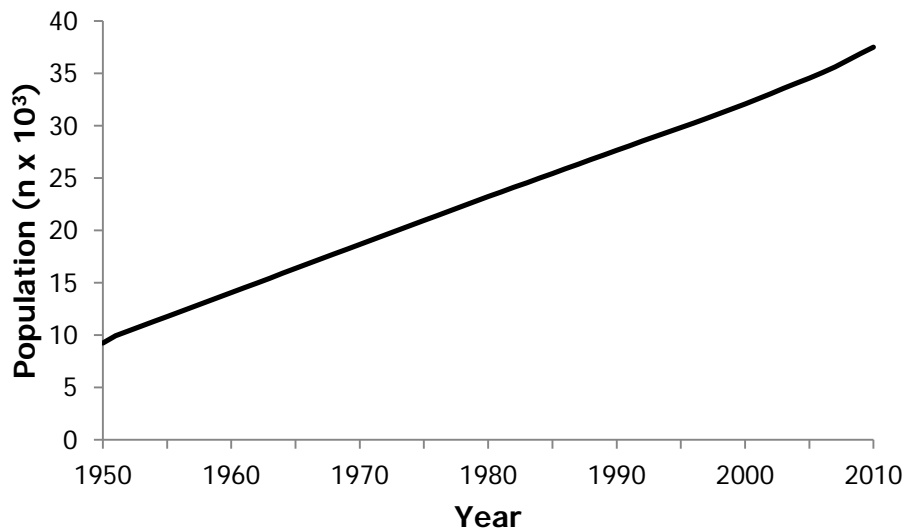


Figure 4. Aboriginal population in the Maritime region of Atlantic Canada from 1950 to 2010

It is reasonable that the annual rate of 7.5% is over double that of Canada as a whole because Aboriginal people have a higher natural fertility than non-Aboriginal people on average (Statistics Canada 2002). It is also reasonable that our estimate is smaller than the rate of growth for Aboriginals in Canada as a whole because this high rate was due in part to the dramatic population increase of the Métis, who are not regionally located in the areas of our study as nearly 9 in 10 Métis live in the western provinces and Ontario (Badets 2012). From 1996 to 2006 the growth of the Métis was more than three times higher than those with First Nations and Inuit identity. This has not been a result of natural increase, but hypothesized to be representative of the trend of increased reporting of Aboriginal origins or identity due to increased awareness of Aboriginal issues (Statistics Canada 2002).

Thus, we have assumed that the average rate of growth for our sub-sample of nine communities was representative of the entire sample of 44 communities. Since these nine communities were dispersed geographically, we used their respective rate of growth in neighboring communities. If neighboring communities were not available, then the annual estimate of 7.5% was used. Once the population estimates were complete, respective per capita consumption of fish was applied to each community.

The subsistence consumption for various Arctic communities was previously calculated by Zeller *et al.* (2011) and included catch from both FAO Area 18 and 21. Thus, we took the total estimates of subsistence harvest from 1950 to 2010 and subtracted the harvest attributed to FAO Area 18. The communities for FAO Area 21 that were covered in this analysis were: Killiniq, Pond Inlet, Qikiqtarjuaq. The other communities of Nunavut that were included in the population estimates of this analysis were Clyde River, Iqaluit, and Pangnirtung.

The last step was to disaggregate the consumption by species. We performed a literature review of traditionally consumed species, with adjustments through time if needed. For the Nunavut fisheries, Atlantic salmon, Arctic char (*Salvelinus alpinus*), and trout species were traditionally consumed, while for the Inuit in Labrador, their main species were Atlantic salmon, Arctic char, and Atlantic cod (Torngat Secretariat 2010). We assumed an equal proportion of consumption for these popular species.

The Mi'kmaq, the aboriginal people dispersed through what is now known as the Maritime Provinces and Quebec, represent the majority of the non-Inuit aboriginal groups covered in this report. Traditionally, the Mi'kmaq relied upon the sea for 90% of their available food (Mi'kmaq Spirit 2013). They would fish seasonally, and would commonly fish species such as eel (*Anguilla rostrata*), flounders, smelt (*Osmerus mordax*), herring, sturgeon (*Acipenser oxyrinchus*), striped bass (*Morone saxatilis*), alewife, herring, Atlantic salmon, and invertebrates like shellfish and molluscs (Mi'kmaq Spirit 2013; Canadian Museum of History 2014). Historically, the 'favorite fish' was the eel, available year-round and one with special cultural and spiritual significance (Weiler 2011; Mi'kmaq Spirit 2013; Canadian Museum of History 2014). However, as time went on, a decline of the eel fishery prevented Aboriginals from fishing. First, with the construction of dams and large-scale industrial logging in the early 1900s, the migration of eels was altered. Then, as large scale commercial harvesting began, abundance dropped significantly in the 1970s, and to very low levels since the late 1990s (Weiler 2011).

This is reflected in the species disaggregation. We assumed that in 1950, 20% of subsistence fishing (by weight) was for eels, while the rest was divided between the other species listed. From 1979 to 1998, the percentage of eel subsistence fishing linearly decreased from 20% to 2% and remained at that level until 2010. The other species increased in percentage in accordance with this trend.

ii) Subsistence catches in small, rural fishing villages

Data were available on the percentage of people living in small fishing communities for each Atlantic province except Quebec in 1982: 53% for Newfoundland, 11.5% for New Brunswick, 25.8% for Prince Edward Island, and 14.3% for Nova Scotia (Parsons 1993). In 1951 we assumed that there were 5% more people living in these communities, and in 2010 it was assumed that 5% less people were living in these small communities.

These percentages were then applied to the population by province from 1950 to 2010 to obtain estimates of people living in small fishing villages, which can be seen in Figure 5 (Statistics Canada 1951, 2013). Population estimates were multiplied by the per capita consumption found in Berkes (1990) of 60 kg for native subsistence. Much like for aboriginal subsistence, in 1950 this amount was assumed to be 20% higher. However, in 2010 we assumed that per

capita subsistence was 50% lower because non-aboriginals have more access and incentive to eat store bought fish than aboriginals, who are still highly dependent on harvesting fish for both cultural reasons as well as subsistence (Statistics Canada 2001; DFO 2011b; Natcher *et al.* 2012).

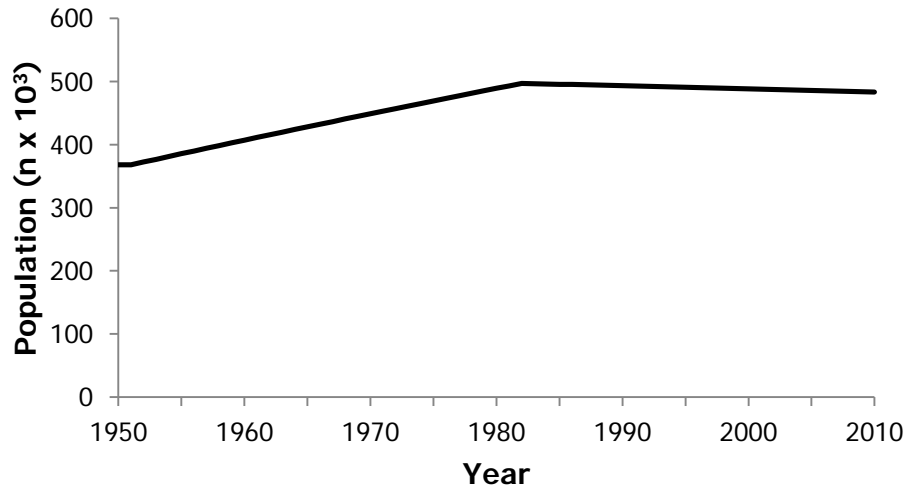


Figure 5. Non-Aboriginal population in small fishing communities of Atlantic Canada from 1950 to 2010

Finally, the sum amount of subsistence by province, by year, was disaggregated by specie. In Newfoundland, we assumed that 50% of catch was Atlantic cod, while 50% was Atlantic salmon. For the Maritimes, a species composition similar to the Mi'kmaq was used, except eel was substituted with lobster due to knowledge of a large lobster subsistence fishery in the Maritimes (McMullan *et al.* 1989; McMullan *et al.* 1997; McMullan and Perrier 2002). The breakdown follows: 20% American lobster and the remaining equally divided by flounders, smelt, Atlantic herring, sturgeon, Atlantic salmon, striped bass, alewife, capelin, and miscellaneous marine molluscs.

Recreational catch

Unreported catches from the recreational sector were reconstructed by compiling anchor points for several years and interpolating between them. The most detailed data on catches were from 1990 to 2010 in the Surveys of Recreational Fishing in Canada (DFO 1990, 1995, 2000, 2005; BriLev Consulting Inc. 2008; DFO 2010). The surveys were given to a representative sample of anglers, and then extrapolated to the population at large.

The data were available as the number of fish harvested by specie by province. Only the provinces in scope were included in the analysis, e.g., Newfoundland & Labrador, Quebec, New Brunswick, Nova Scotia, Prince Edward Island, Nunavut, and the North West Territories (NWT), prior to 2000. Since both freshwater and marine recreational fishing was included in the survey, we excluded freshwater species from the analysis. Moreover, since catches were given by the number of fish harvested instead of the weight of fish harvested, we transformed the data by plugging in the average length into the Length-Weight function in FishBase (www.fishbase.org). The outcome was an average weight for each taxon, which we then multiplied by the number of fish caught.

Additionally, several adjustments were made to the data for the present paper. First, since Nunavut was part of NWT in 1990 and 1995, we averaged the percentage of Nunavut landings to NWT landings (by species for 2000, 2005, and 2010). These percentages were used for 1990 and 1995. Additionally, East Baffin Island is geographically approximately 25% of the entire Nunavut Area, so to obtain catches for this region we multiplied Nunavut catch by 25%. Second, after 2000, data on catches by non-resident anglers in Quebec was no longer available. However, it was stated that non-resident license sales fell at an average annual rate of 2% since 2000. We applied this trend to the data, estimating that non-resident angler catches in 2005 and 2010 were 90% and 82% of the catch in 2000, respectively.

Prior to 1990, Mitchell (1980) provided data on number of resident adult anglers in 1975. We assumed the change in the number of anglers from 1975 to 1990 was proportional to the change in catch. From 1975 to 1990, the number of

anglers increased by 72% for the Atlantic (from 246,900 to 424,375 anglers) and by 226% for Quebec (from 484,600 to 1,578,237 anglers). Catch was adjusted commensurate with these changes.

Prior to 1975, data were not available on the number of anglers or recreational catches. Thus, we used the change in the Canadian population from 1950 to 1975 as a proxy for the change in the number of active resident anglers (www.worldbank.org, Statistics Canada 1951). To be conservative, we assumed that active resident participation in 1950 was half that of 1975.

Thus, by compiling all the anchor points and interpolating between them, we reconstructed catches from the recreational fisheries in Eastern Canada. The last adjustments to the data were from additional sources indicating recreational catches of tuna and shark. Between 1967 to 1985, there was a significant bluefin tuna (*Thunnus thynnus*) fishery in North Lake, Prince Edward Island (Island Narratives Program 1995). Data were available from various historical sources, each confirming that the fishery peaked from 1974 to 1976 with 1,000 tons of tuna landed (ASE Consultants 1993; Island Narratives Program 1995; Sutton 2002). These catches were added, along with the recreational catches of blue shark (*Prionace glauca*) from derbies and recreational fishing between 1993 and 2003 (Campana *et al.* 2006). After 2003, data were also publicly available, but we only considered landings until 2006 due to new rules for derbies where blue sharks are to be released alive after tagging (Canadian Shark Research Laboratory 2014). As in Campana *et al.* (2006), we assumed that from 2004 to 2006 recreational catch was 66% of derby catch.

Atlantic cod analysis

In order to more accurately access the state of cod stocks post-moratorium, we generated a time series of cod biomass from 1950 to 2010. Generally stock assessments for Atlantic cod are done by NAFO Divisions, which were originally suggested to enclose the movement of distinct groundfish stocks, primarily cod (Halliday and Pinhorn 1990). Since the mid-1980s, all assessments are done by these regions and thus are highly divisive. This is the first publicly available attempt to synthesize the data and offer a portrait of the state of cod stocks and exploitation in the post-moratorium in comparison with the pre-moratorium years.

Stock assessment models are done based on Division, and hence make no distinction between the stock inside or outside the Canadian EEZ, as we have done for the present catch reconstruction. Similarly, we have compiled cod biomass estimates disregarding the Canadian EEZ, as this limit is a political-economic division, not a biological one. Since catch data are also available at the level of Division, biomass and exploitation level per stock can be compared, a result not available in any other analysis.

Cod biomass was reconstructed for NAFO management regions 2 – 4, which include NAFO Divisions that represent unique stocks: 2GH, 2J3LK, 3NO, 3M, 3Ps, 3Pn4RS, 4TVn, 4VsW, and 4X. The first available data source on cod biomass from management regions 2 – 4 was available in Parsons (1993), who presented biomass of Atlantic cod exploited age groups from 1961 – 1986. Prior to this we assumed biomass remained constant from 1950 – 1960 at the 1961 level of biomass. From 1987 – 2010, all data were available by individual stock, as can be seen in Table 1.

Table 1. Data sources of biomass estimates by NAFO management region, Eastern Canada 1950 – 2010.

NAFO management region	Source
2 - 4	(Parsons 1993)
2GH	(COSEWIC 2010)
2J3LK	(DFO 2013b)
3NO	(Power <i>et al.</i> 2010)
3M	(Gavaris 1980; NAFO 2011)
3Ps	(DFO 2012b)
3Pn4RS	(DFO 2012a)
4TVn	(DFO 2007)
4VsW	(Mohn and Rowe 2011)
4X	(DFO 2009)

A few data adjustments were necessary to standardize the data across numerous disparate sources. For example, some of the biomass estimates were not performed in consecutive years, so any years with gaps in biomass estimates were assumed to be an average of the years directly prior and after it. In some cases, data from recent years, e.g., 2009, 2010, were missing. In these cases we assumed the most current biomass estimate remained constant for the following years. Additionally, for Divisions 3Pn4RS, the data were not presented as biomass (t) but as population numbers ages 3+ (DFO 2012a). To circumvent this and keep data standardized with other sources, we used the average weight of fish annually to convert to biomass, using data from 2J3LK due to its proximity (DFO 2013b). Finally, in management region 4TVn, there were results presented for two different population models. Since the results were similar in trend and magnitude, we took an average of the two models for a representative estimate of biomass. Results of this biomass analysis and the level of exploitation can be seen in Appendix II.

RESULTS

Unreported commercial catches

Poaching by the domestic fisheries increased from 23,000 t in 1950 to a peak of 125,000 t in 1988 due to high poaching of Atlantic cod, followed by a sharp decline in cod poaching due to its stock collapse in the mid-1990s. Unreported catch for all species remained fairly constant thereafter, averaging 44,000 t·year⁻¹ in the 2000s (Figure 6a).

Unreported catches by foreign fisheries increased from 20,000 t·year⁻¹ in the early 1950s to a peak of 68,000 t of catch in 1968. This peak coincided with the highest landings ever reported in Atlantic Canada, after which both reported landings and unreported foreign catch declined, the latter dropping nearly six fold by 1976. When the Canadian EEZ was established in 1977, any unreported foreign catches with the Canadian EEZ were classified as illegal. Illegal catches began at 7,000 t in 1977, peaked in 1986 at 13,000 t, and then decreased over tenfold to 800 t in 1992. Afterwards, illegal catches by Spain averaged 440 t·year⁻¹ until 2010 (Figure 6b).

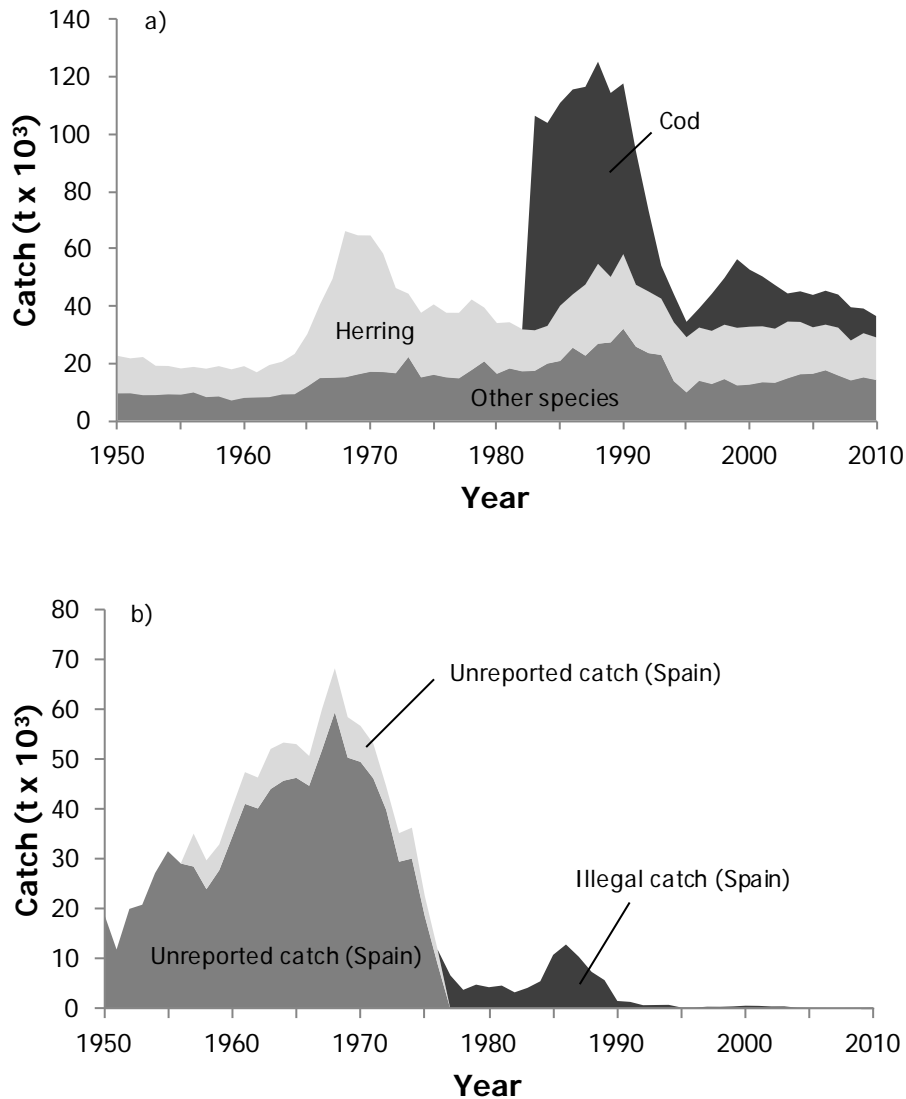


Figure 6. Unreported commercial catches within the Canadian EEZ from 1950 to 2010 for **a)** domestic fisheries **b)** foreign fisheries.

Discards

Total discards were 1.5 million t in 1950, peaking in 1961 and 1968 with 3.7 million t and 3.9 million t, respectively. From there, discards sharply dropped over tenfold to 240,000 t by 1977, and then continued to decline to 46,000 t in 1994. Thereafter, discards stayed relatively constant until 2010, averaging 37,000 t·year⁻¹ of discards (Figure 7a).

In 1950, Canadian discards were approximately 111,000 t, peaking in 1963 with 792,000 t. Discards declined throughout the 1960s and 1970s, reaching 34,000 t in 1981, remaining at a low level of about 43,000 t·year⁻¹ in the 1980s, 1990s, and 2000s.

Foreign discards began at 1.4 million t·year⁻¹ in 1950, reached their peak in 1968 at 3.2 million t, and then declined to 520,000 t in 1976. Starting in 1977, the EEZ was declared and foreign fleets were forced to fish beyond 200 nautical miles from the coast of Canada. Hence, foreign discards in the Canadian EEZ decreased to 26,000 t in 1977 and continued to decline, averaging just over 400 t·year⁻¹ from 1994 to 2010.

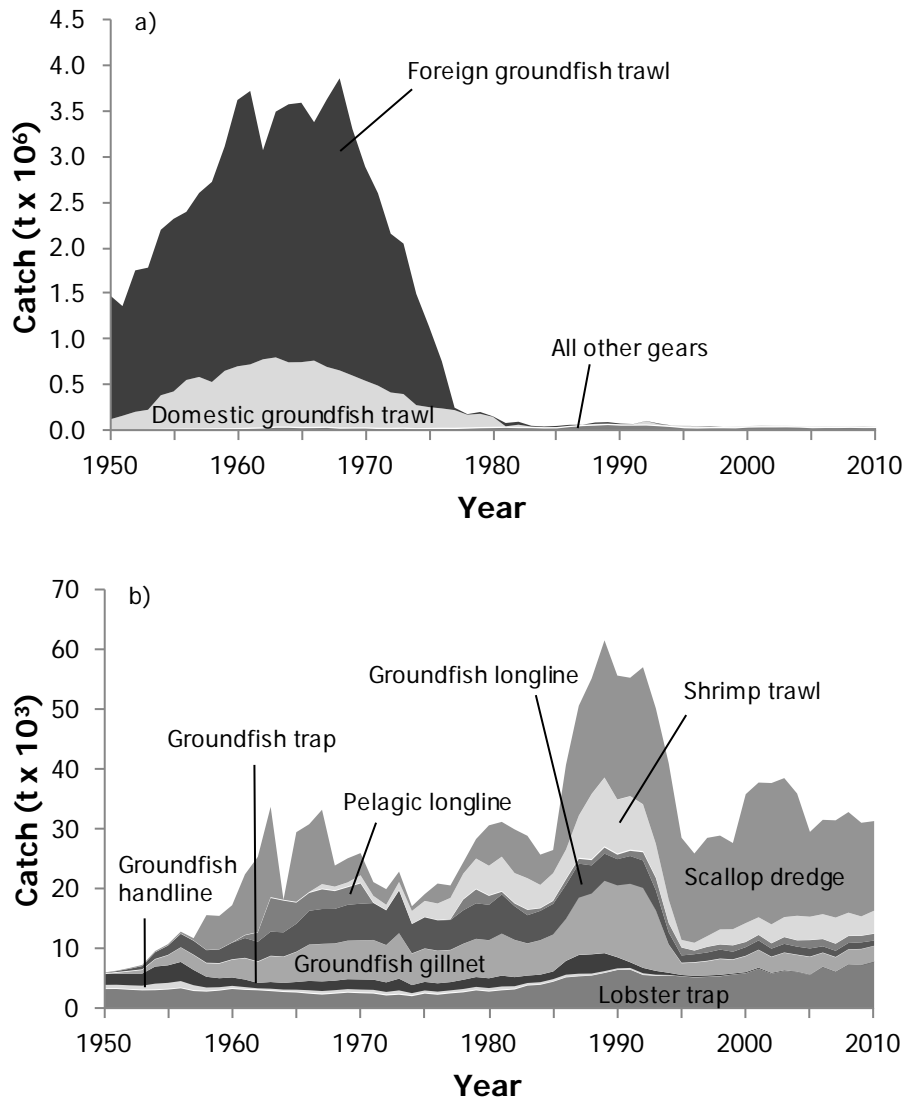


Figure 7. Discards within Canadian EEZ from 1950 to 2010 by **a)** all gears **b)** gears other than groundfish trawl

Groundfish trawling gear had both the highest discard rates and landings in the 1950s, 1960s, and 1970s, which resulted in very high discards (Figure 7a). Besides the discards from groundfish trawl, the two gears with highest discards were the groundfish gillnet and the scallop dredge (Figure 7b). For the groundfish gillnet, discards were minimal in the 1950s, increased to 13,000 t·year⁻¹ in the early 1990s before plummeting to 2,000 t in 1995. After the cod moratorium, the amount of discards attributed to this gear were about 2,500 t·year⁻¹.

Subsistence catch

Subsistence catch averaged 22,000 t·year⁻¹ in 1950s until the 1970s, and then steadily declined to 12,700 t in 2010. The vast majority of this was taken by non-Aboriginal small fishing communities (Figure 8).

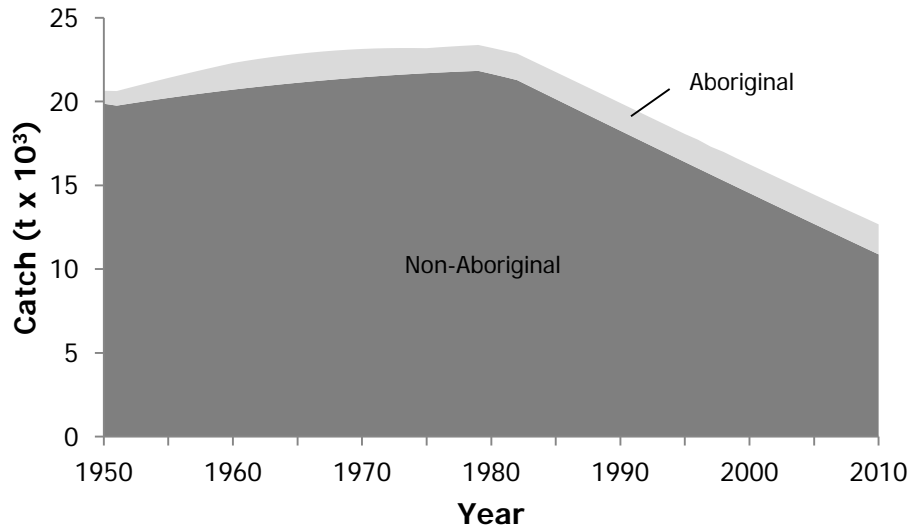


Figure 8. Subsistence catch in Eastern Canada, 1950-2010.

Recreational catch

Recreational catches increased from 8,200 t in 1950 to 74,000 t in 1990 and then decreased to half the pre-moratorium level at about 23,000 t·year⁻¹ from 1995 to 2010 (Figure 9). Most of this catch was from the Newfoundland & Labrador recreational fisheries, followed by Quebec, Nova Scotia, New Brunswick, and Prince Edward Island. Nunavut recreational catches were almost insignificant, ranging from 1- 3 t·year⁻¹, which is explained by the relatively few anglers that frequent Nunavut and the even fewer varieties of species. Cod represented the largest portion of the catch with 46%. Trouts were the second most important with 35% of the total recreational catch.

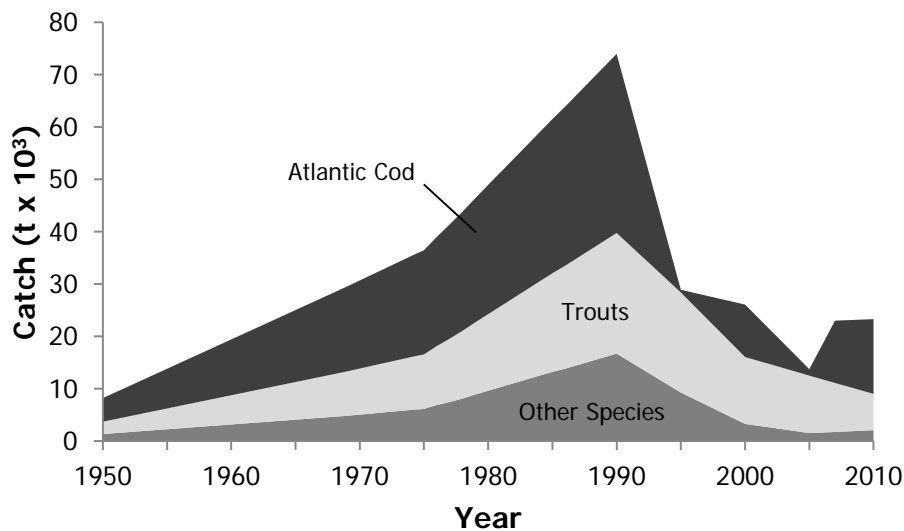


Figure 9. Recreational catch in Eastern Canada, 1950-2010.

Total reconstructed catch

The total reconstructed catch in the Eastern Canada's EEZ (from both domestic and foreign fleets) was estimated at 2.6 million t in 1950, peaking at 6.6 million t in 1968, declining dramatically in 1977 to 1.2 million t due to the withdrawal of foreign fisheries from Canada's newly declared EEZ, and then remained relatively constant at 1.1 million t-year⁻¹ for the following decades until 2010.

Overall, total reconstructed catch was twice the data reported by FAO, however the unreported portion is heavily skewed to the early years, when foreign vessels were fishing freely in the Canadian EEZ-equivalent waters and as a result producing significant discards (Figure 10a). During this early time period, the majority of catch was of Atlantic cod, redfish, hake, American plaice, and skates and rays. After the majority of the groundfisheries collapse in the late 21st century, species such as Atlantic herring, scallop, lobster, shrimp, and crab composed the majority of catch (Figure 10b).

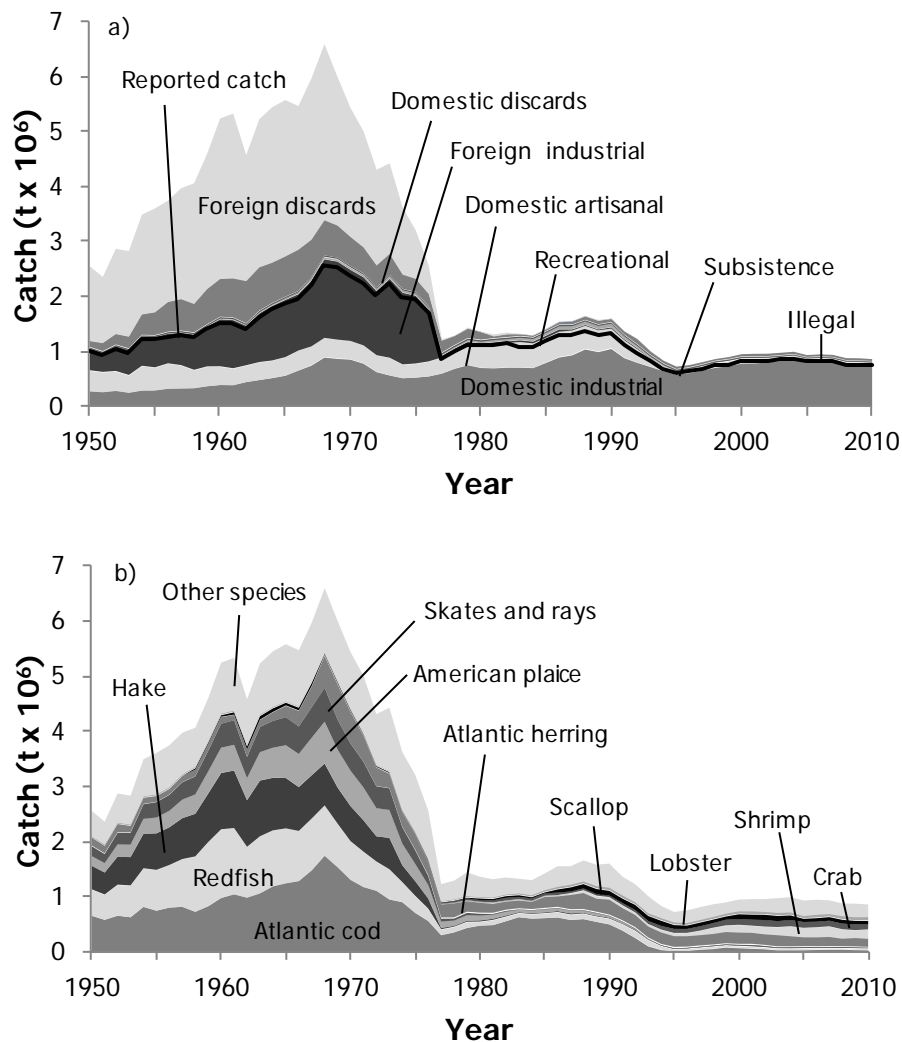


Figure 10. Total reconstructed fisheries catch within the Canadian EEZ from 1950 to 2010 **a)** by sector compared to reported catch **b)** by species

DISCUSSION

Total catches in the Canadian EEZ and EEZ-equivalent waters were estimated to be twice the data supplied to FAO for both domestic and foreign fishing fleets within between 1950 and 2010. The under-reported component was mainly composed of foreign and domestic discards, with a far lesser contribution from the recreational sector, subsistence sector, and unreported catches from the commercial sector. The discrepancy between reconstructed catch and reported landings was much higher prior to the establishment of the 200-mile EEZ in 1977 (Figure 10a). This is predominantly due to discards by foreign trawlers. Although the foreign and domestic discard rate for trawlers was assumed to be the same, reported foreign landings were over double that of domestic landings.

Fishing by trawlers was at unsustainable levels in the 1960s due to high landings and discards. This was especially visible through the collapse of the Atlantic cod. Evidence from tagging data, survey, and catch data all point to the same outcome: that overfishing is the predominant cause of the cod collapse (Myers *et al.* 1996; Shelton and Lilly 2000). Indeed, far before the cod moratorium, in 1963 a captain on a foreign trawler stated that “*there was already less cod in Newfoundland*” (Garcia-Orellan 2010). Other theories such as increased natural mortality due to seal predation and cold water temperatures have largely been disproven (Hutchings 1999; Rose 2004). For example, studies with respect to colder water temperature show that Atlantic cod “*showed no pronounced preference or avoidance with respect to temperature... This is not surprising, since cod, as a northern species, has been around for some ten million years and has therefore lived through the recent ages and certainly through much colder eras before that*” (Villagarcia *et al.* 1999).

Since our reconstruction shows that catches of cod, and other species, were even higher than reported data, it further reinforces the effects of overfishing. The maximum sustainable yield (MSY) for the cod stock corresponds to an allowance of 18% of harvestable biomass caught by commercial vessels annually, which was maintained by setting TAC (Hutchings 1999). However, it is clear that much more than this was fished prior to the moratorium, when exploitation rates reached over 45% in 1968 and 1992, averaging almost 30% for this period (Appendix II). In the post-moratorium period, the comparison of reconstructed catch with assessed biomass yields an average exploitation rate of over 19%, which is still above the maximum recommendable exploitation rate of 18%, a fact which may be a major contributor to the sluggish recovery of the Atlantic cod stocks.

The reliability of stock assessments is inextricably linked with the reliability of catch data. Underreporting of catches causes stocks to appear healthier than they really are which in turn causes quotas to be set too high and accelerates overfishing (Metuzals *et al.* 2008). This is what happened in the case of Atlantic cod prior to the moratorium. Besides misreporting, several other factors limit the accuracy of stock assessments. First, is the lack of communication between those who generate guidelines for fishers as to the TAC and the fishers themselves (Neis 1992). According to Neis (1992), fishers were aware of dwindling cod stocks far before fishery scientists were, yet stock analysis continued to depict that the health of the stocks was fine and policy makers continued to set TAC at a high level. A second barrier to accurate stock assessments is political, as well as arbitrary, boundaries used for data collection and management of stocks. With respect to data collection, the most detailed data available are from NAFO, yet even these Divisions do not always comply with actual stocks (nor with the EEZ), which makes it difficult to reconcile the catch with the stock from which it was taken.

With respect to political designations, the delineation of the EEZ takes precedence to the management of stocks. Historically, the ‘Nose’ and ‘Tail’ of the Grand Banks have been known as the “*Achilles heel*” of NAFO (Day 1995). Canada was designated the sole manager of the Grand Banks stock, however it technically has no control over fishing beyond its EEZ. From 1977 to 2010, an estimated half a million tonnes of unreported catch was taken by ‘non-member’ countries, 27% of which was Atlantic cod. There was potentially even more unreported catch taken by ‘member’ countries on the Grand Banks, as much as 79% of reported catch in 1990 according to Canadian surveillance (Parsons 1993). While these estimates were not within the EEZ, and thus not included in the reconstruction, unreported catch beyond the EEZ posed a problem for the entire Grand Banks stock. This is still an issue, as unreported foreign groundfish catch outside the EEZ increased in the late 1990s after the cod moratorium (Preikshot 2001).

The third problem for stock assessment science is less related to the assessment, and more to do with political and behavioral realities. Once stock assessment science finally confirmed that cod was severely depleted in the early 1990s, a moratorium was not set immediately because of underlying political denial. For example, from 1991 to 1993 a new multi-year Groundfish Plan set annual fishing mortality at 45%, purposely (even though the recommended strategy was 25% and the maximum sustainable yield point was 52%) because it was built upon the expectation that the stocks would rebuild (Parsons 1993). Furthermore, since the 1980s, politicians knew that with limited employment options outside of the fishery, TACs had to be held at economical levels, and thus they “*tended to let a bad situation get even worse*” (Harris 1998).

The collapse in the early 1990s of many ground-fisheries also had a profound effect on the recreational fisheries, as can be seen in the trend of increasing catch until 1990, and then a sharp decline thereafter (Figure 9). While the commercial fishery could recover by targeting other species, generally of lower trophic level (Figure 10b), recreational fishers generally use rod, line, and hook to target finfish, the bigger the better. Indeed, a collapse in the recreational fisheries of Canada is supported by Post *et al.* (2002) who calls this the “*invisible collapse*”. It is invisible because there were only “*13 papers that refer to declines or collapses of recreational fisheries out of a total of 4,904 papers published in the 1990s,*” which is why the collapse has largely gone unseen. However, this trend was confirmed by recreational fishery experts as well as fishers, who when asked about the recreational fisheries proclaimed, “*It ain't as good as it used to be!*” (Post *et al.* 2002).

Moreover, it is surprising that even in the post-moratorium era, the landings of Atlantic cod comprise the majority of all species landed in the recreational fishery. The quality of recreational survey data was very high, in particular for the cod fishery, as a special post-season survey of catch and effort was released after the recreational fishery was reopened in 2007 (BriLev Consulting Inc. 2008). However, the estimates from these surveys are not included in official reported landings. For example, in 2008, reported recreational catches were 67 t, while herein we estimated total recreational catch at 12,693 t·year⁻¹, which is a very large discrepancy. Given the sluggish recovery of the Atlantic cod, this is disconcerting in the post-moratorium period.

Recently, there is a worldwide trend of increased unreported catch as “*harvesters try to avoid the stricter fishing rules that follow declining catches*” (Metuzals *et al.* 2008). According to observer evidence, unregulated catches seem to be increasing for the Newfoundland fleet due to “*introduction of property at the enterprise level*” (Metuzals *et al.* 2008). Ultimately, as fishers are forced to fend for themselves at the individual level (IQs), there are more incentives for illegal fishing. This draws a parallel to the Atlantic lobster fishery, where a community model becomes privatized and heavily regulated. This problem is systemic in nature, and forces fishers to be involved in increasingly secretive practices. Another parallel between poaching of Atlantic cod to the Atlantic lobster fishery is the attitude of the fishers and social acceptance of the act. In Newfoundland, “*poaching for food is not considered morally wrong,*” as is indicated by the selling of undersize cod from door to door (Metuzals *et al.* 2008).

Furthermore, increasingly secretive practices may shed light on discarding at sea. Our reconstruction showed that discards decreased drastically from 1950 to 2010. This was likely due to several factors, including but not limited to gear changes and changes in fisher behavior over time. However, our estimates did not include the practice of high-grading, which remains common in a quota fishery like that of Newfoundland, and involves discarding small, unmarketable fish repeatedly until the quota is filled with larger, more marketable species. A theoretical model of high-grading in the Newfoundland fisheries by Metuzals *et al.* (2008) estimated that the high-grading data fouling factor is 56%, which means only 44% of catch is actually reported, while the rest is dumped or discarded. However besides this model there are no data available on the practice of high-grading, as obviously fishers would never practice high-grading in front of observers. Therefore, while discards have been decreasing, according to a single haul seen by an observer, the true amount of discarding from high-grading can only be gauged through greater knowledge of fishers' behavior, a ripe area for future research.

The history of Atlantic Canada is complex and understanding the true culprit for a fishery collapse like that of the cod is difficult to pinpoint. There have been many attempts to assign blame, and this tendency to point fingers invariably led to many conflicts, like that between foreign fleets and domestic ones, as is seen by the *Estai* capture (Pélissac 2003). However as satisfying as it would be to assign blame to one single party, “*everyone who made their living from the sea knew there were no clean hands in the fishery*” (Harris 1998). A single culprit cannot be found, rather, to blame is the entire network of fragmented and complex interactions between fishers, government, and

science. Indeed, with such a diverse and opposing array of disunified interests, sound management choices cannot be made (Pauly 1999).

Although the image of water “*boiling*” from the sheer number of cod is no more than a nostalgic memory (Garcia-Orellan 2010), there is still a thriving fishery in Eastern Canada. Small fishing enterprises are working towards building a community and strive for greater communication. With greater transparency, the current fragmentation and isolation of the three mentioned parties could become integrated, allowing for sound management. That is, of course, only if the lessons of the past are internalized and learned from.

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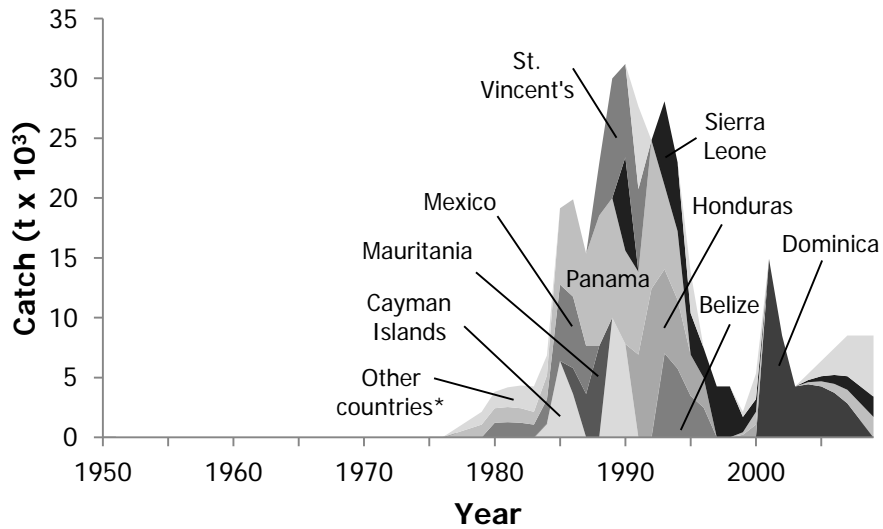
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APPENDICES

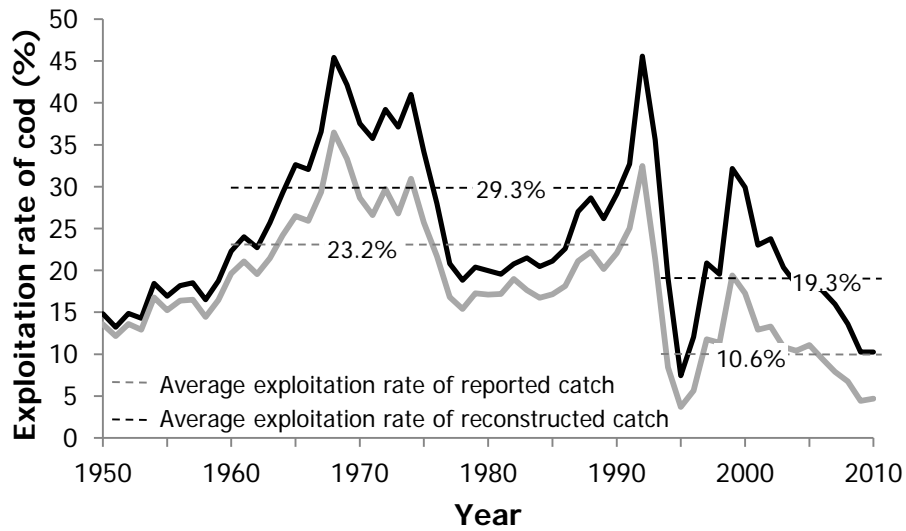
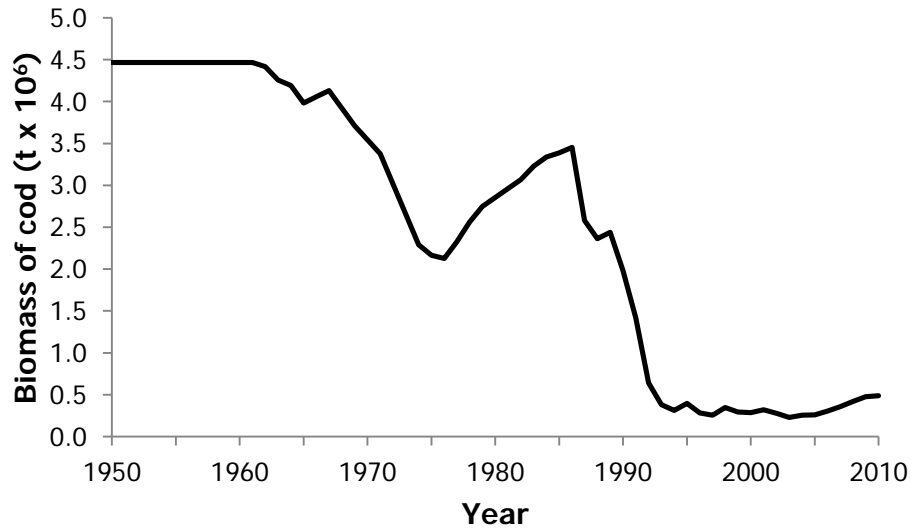
Appendix I. Unreported catches taken on the Nose and Tail of the Grand Banks by over a dozen countries* from 1950 to 2010.



*Countries represented here include vessels flying flags of convenience, and thus the true country is obscured.

**Other countries include Chile, Georgia, Ghana, Guinea Conakry, Morocco, New Zealand, Principe, Sao Tome, and Venezuela.

Appendix II. a) Biomass of Atlantic cod in NAFO Areas 2 – 4 from 1950 to 2010 and b) reported and reconstructed exploitation rate of Atlantic cod in NAFO Areas 2 - 4 in the pre-moratorium period (1961 – 1991) and in the post moratorium period (1993 – 2010)



Appendix III. Total reported and reconstructed catch of the domestic and foreign fisheries catch in Eastern Canada's EEZ from 1950 - 2010, delineated by sector.

Year	FAO landings			Reconstructed catch									Total
	Domestic	Foreign	Total	Domestic					Foreign				
				Industrial	Artisanal	Recreational	Subsistence	Discards	Industrial	Illegal	Discards		
1950	629,632	378,841	1,008,473	288,000	365,000	8,200	20,600	112,000	398,000	0	1,360,000	2,550,000	
1951	600,789	339,218	940,007	273,000	350,000	9,320	20,600	152,000	351,000	0	1,200,000	2,360,000	
1952	617,058	432,346	1,049,404	296,000	344,000	10,400	20,800	195,000	452,000	0	1,550,000	2,870,000	
1953	546,682	434,257	980,939	263,000	304,000	11,600	21,000	218,000	455,000	0	1,560,000	2,830,000	
1954	715,545	502,721	1,218,267	301,000	434,000	12,700	21,200	377,000	530,000	0	1,810,000	3,490,000	
1955	687,593	521,515	1,209,108	303,000	403,000	13,800	21,400	419,000	553,000	0	1,890,000	3,610,000	
1956	761,001	510,620	1,271,621	335,000	445,000	14,900	21,600	544,000	540,000	0	1,840,000	3,740,000	
1957	728,897	555,787	1,284,684	339,000	408,000	16,000	21,800	578,000	591,000	0	2,020,000	3,970,000	
1958	641,378	614,311	1,255,689	344,000	317,000	17,200	22,000	522,000	644,000	0	2,190,000	4,060,000	
1959	705,223	694,734	1,399,957	379,000	344,000	18,300	22,100	645,000	728,000	0	2,460,000	4,600,000	
1960	706,067	818,718	1,524,785	401,000	324,000	19,400	22,300	694,000	859,000	0	2,920,000	5,240,000	
1961	672,440	833,922	1,506,362	398,000	292,000	20,500	22,400	716,000	881,000	0	3,000,000	5,330,000	
1962	724,875	675,618	1,400,493	454,000	291,000	21,700	22,500	771,000	722,000	0	2,290,000	4,570,000	
1963	782,372	837,763	1,620,135	490,000	313,000	22,800	22,700	792,000	890,000	0	2,690,000	5,230,000	
1964	808,815	945,921	1,754,737	527,000	306,000	23,900	22,800	738,000	999,000	0	2,830,000	5,450,000	
1965	863,268	995,021	1,858,289	569,000	325,000	25,000	22,800	740,000	1,050,000	0	2,840,000	5,570,000	
1966	973,781	980,715	1,954,496	663,000	351,000	26,100	22,900	757,000	1,030,000	0	2,610,000	5,470,000	
1967	1,041,151	1,144,098	2,185,248	753,000	337,000	27,300	23,000	688,000	1,200,000	0	2,930,000	5,970,000	
1968	1,181,131	1,371,047	2,552,178	902,000	345,000	28,400	23,100	649,000	1,440,000	0	3,200,000	6,590,000	
1969	1,150,304	1,371,417	2,521,721	878,000	337,000	29,500	23,100	594,000	1,430,000	0	2,700,000	5,990,000	
1970	1,125,673	1,245,670	2,371,343	863,000	327,000	30,700	23,100	537,000	1,300,000	0	2,350,000	5,430,000	
1971	1,050,213	1,195,152	2,245,365	789,000	320,000	31,800	23,200	483,000	1,250,000	0	2,110,000	5,000,000	
1972	882,461	1,129,704	2,012,165	635,000	294,000	33,000	23,200	407,000	1,170,000	0	1,740,000	4,310,000	
1973	837,682	1,410,658	2,248,340	574,000	308,000	34,200	23,200	390,000	1,450,000	0	1,650,000	4,430,000	
1974	721,618	1,276,316	1,997,935	524,000	236,000	35,300	23,200	269,000	1,310,000	0	1,220,000	3,620,000	
1975	736,132	1,217,335	1,953,467	535,000	242,000	36,500	23,200	247,000	1,240,000	0	884,000	3,210,000	
1976	777,591	924,876	1,702,467	556,000	259,000	39,000	23,200	232,000	937,000	0	517,000	2,560,000	
1977	850,571	26,988	877,559	608,000	280,000	41,400	23,300	214,000	27,000	6,750	26,200	1,230,000	
1978	983,910	23,656	1,007,565	697,000	329,000	43,800	23,300	164,000	23,700	3,860	5,870	1,290,000	
1979	1,106,961	24,772	1,131,733	762,000	385,000	46,400	23,400	173,000	24,800	4,910	20,300	1,440,000	
1980	1,079,444	25,849	1,105,293	711,000	403,000	48,900	23,200	140,000	25,800	4,390	5,760	1,360,000	
1981	1,095,467	33,913	1,129,380	704,000	426,000	51,400	23,000	34,300	33,900	4,720	38,300	1,320,000	
1982	1,121,972	26,692	1,148,664	717,000	437,000	53,900	22,900	53,500	26,700	3,360	32,600	1,350,000	
1983	1,064,138	29,935	1,094,073	717,000	454,000	56,500	22,500	31,800	29,900	4,260	10,400	1,330,000	
1984	1,042,460	30,683	1,073,144	709,000	437,000	59,000	22,100	27,100	30,700	5,580	7,170	1,300,000	
1985	1,137,605	37,648	1,175,253	805,000	444,000	61,500	21,800	27,500	37,600	10,870	12,800	1,420,000	
1986	1,244,943	39,534	1,284,476	902,000	458,000	63,900	21,400	41,600	39,500	12,940	11,200	1,550,000	
1987	1,266,291	17,552	1,283,842	943,000	440,000	66,400	21,000	52,200	17,600	10,480	839	1,550,000	
1988	1,343,042	13,649	1,356,691	1,050,000	418,000	68,900	20,700	62,000	13,600	7,460	15,700	1,660,000	
1989	1,271,855	13,104	1,284,958	1,000,000	384,000	71,400	20,300	64,700	13,100	5,810	17,500	1,580,000	
1990	1,299,425	20,530	1,319,956	1,060,000	358,000	74,000	19,900	59,400	20,500	1,630	6,710	1,600,000	
1991	1,107,683	16,790	1,124,473	891,000	311,000	64,900	19,500	58,600	16,800	1,450	2,430	1,370,000	
1992	963,755	16,838	980,593	805,000	232,000	55,900	19,200	92,700	16,800	788	2,150	1,220,000	
1993	814,415	6,891	821,305	730,000	139,000	46,900	18,800	59,900	6,890	824	6,530	1,010,000	
1994	679,129	4,711	683,840	651,000	72,200	37,900	18,400	45,200	4,710	854	672	831,000	
1995	595,890	1,444	597,334	587,000	43,300	28,900	18,100	42,700	1,440	312	202	722,000	
1996	627,124	1,934	629,057	617,000	49,100	28,300	17,700	35,800	1,930	318	1,290	752,000	
1997	679,329	453	679,782	664,000	59,600	27,800	17,300	35,400	453	480	3,810	809,000	
1998	736,459	0	736,459	716,000	70,400	27,200	17,000	29,800	0	467	0	861,000	
1999	762,622	0	762,622	744,000	75,500	26,600	16,600	32,200	0	544	0	895,000	
2000	813,768	0	813,768	792,000	74,200	26,100	16,300	38,400	0	684	0	948,000	
2001	818,962	444	819,406	795,000	74,500	23,600	15,900	44,600	444	650	515	955,000	
2002	829,090	870	829,960	812,000	64,100	21,100	15,500	41,200	870	537	347	956,000	
2003	852,885	2	852,887	840,000	57,700	18,700	15,200	41,300	2	547	119	973,000	
2004	876,045	0	876,045	865,000	55,900	16,200	14,800	38,600	0	292	0	991,000	
2005	825,046	0	825,046	810,000	59,200	13,700	14,400	32,900	0	236	0	930,000	
2006	832,025	14	832,039	829,000	48,200	18,400	14,100	33,400	14	230	455	944,000	
2007	817,474	9	817,483	815,000	46,700	23,000	13,700	35,400	9	208	0	934,000	
2008	763,935	0	763,936	756,000	48,000	23,100	13,400	35,700	0	231	12	876,000	
2009	758,672	444	759,116	753,000	44,700	23,200	13,000	38,200	444	236	62	873,000	
2010	749,458	2,745	752,204	747,000	39,000	23,300	12,700	32,700	2,750	289	62	858,000	

Appendix IV. Total reconstructed catch of the domestic and foreign fisheries in Eastern Canada's EEZ from 1950 - 2010, delineated by species.

Year	Atlantic cod	Redfish	Hake	Atlantic herring	American plaice	Skates and rays	Shrimp	Crab	Scallop	Lobster	Other species
1950	660,000	470,000	429,000	144,000	183,000	177,000	0	23	400	29,300	462,000
1951	588,000	448,000	401,000	135,000	178,000	163,000	0	94	300	29,400	416,000
1952	662,000	554,000	511,000	147,000	227,000	210,000	0	285	500	28,200	530,000
1953	634,000	568,000	515,000	113,000	232,000	214,000	0	296	700	27,300	526,000
1954	820,000	693,000	628,000	110,000	273,000	264,000	0	586	700	27,600	673,000
1955	751,000	732,000	665,000	101,000	291,000	278,000	0	808	800	28,500	757,000
1956	807,000	765,000	686,000	99,000	303,000	287,000	0	1,150	1,200	30,300	764,000
1957	821,000	859,000	744,000	110,000	340,000	312,000	0	1,190	1,500	26,400	756,000
1958	732,000	997,000	775,000	117,000	354,000	326,000	0	1,070	23,400	25,500	710,000
1959	831,000	1,158,000	882,000	120,000	401,000	373,000	0	1,150	22,400	27,000	780,000
1960	980,000	1,242,000	1,020,000	122,000	458,000	435,000	0	1,400	25,000	29,400	925,000
1961	1,046,000	1,198,000	1,050,000	97,500	464,000	446,000	0	1,670	40,700	28,100	959,000
1962	986,000	917,000	848,000	133,000	400,000	384,000	0	1,740	50,500	27,500	827,000
1963	1,063,000	1,031,000	1,010,000	130,000	514,000	456,000	0	2,240	60,800	26,200	929,000
1964	1,189,000	1,013,000	955,000	158,000	545,000	486,000	0	2,360	62,800	24,900	1,010,000
1965	1,245,000	993,000	915,000	208,000	594,000	509,000	0	2,790	46,800	24,200	1,040,000
1966	1,284,000	908,000	798,000	286,000	600,000	498,000	0	3,360	45,600	22,500	1,020,000
1967	1,477,000	940,000	787,000	381,000	677,000	554,000	1,200	3,600	50,000	21,200	1,070,000
1968	1,741,000	915,000	761,000	589,000	756,000	613,000	1,000	8,930	14,100	22,500	1,170,000
1969	1,535,000	790,000	656,000	643,000	687,000	544,000	1,100	12,700	16,200	23,900	1,090,000
1970	1,307,000	699,000	637,000	578,000	643,000	491,000	2,000	10,500	14,900	23,200	1,020,000
1971	1,176,000	638,000	570,000	473,000	598,000	465,000	1,800	10,800	9,270	22,600	1,040,000
1972	1,110,000	526,000	458,000	338,000	515,000	394,000	1,390	10,600	10,500	19,800	924,000
1973	953,000	542,000	571,000	261,000	510,000	392,000	2,200	14,600	6,910	21,000	1,150,000
1974	904,000	358,000	308,000	266,000	398,000	297,000	3,610	13,800	3,160	18,800	1,050,000
1975	712,000	300,000	268,000	288,000	321,000	245,000	4,700	10,200	4,560	22,600	1,030,000
1976	568,000	214,000	186,000	252,000	254,000	161,000	5,930	12,900	13,400	20,900	877,000
1977	314,000	90,600	26,900	252,000	127,000	50,000	7,220	17,200	8,360	22,900	310,000
1978	363,000	87,000	18,500	272,000	107,000	35,200	8,560	24,300	7,620	24,400	343,000
1979	442,000	98,100	21,200	208,000	112,000	39,600	11,600	34,100	13,100	27,300	432,000
1980	484,000	59,600	23,300	196,000	101,000	29,400	11,600	32,400	27,100	25,500	371,000
1981	494,000	81,200	22,200	179,000	84,400	13,000	17,600	41,600	23,400	27,400	333,000
1982	562,000	73,900	19,700	163,000	80,100	15,100	13,000	52,000	29,400	28,600	310,000
1983	635,000	66,300	15,400	158,000	55,500	4,630	16,600	44,700	28,500	34,300	267,000
1984	609,000	74,300	15,000	147,000	59,500	4,200	12,000	46,300	20,300	35,500	274,000
1985	618,000	79,400	17,100	214,000	62,400	6,660	15,400	47,300	15,600	39,900	305,000
1986	629,000	89,700	18,600	207,000	58,200	6,850	16,800	46,900	56,900	46,300	375,000
1987	585,000	89,100	21,700	275,000	58,300	5,330	25,200	33,300	73,800	47,800	336,000
1988	601,000	90,500	14,200	308,000	49,200	7,760	41,800	36,700	77,500	48,900	381,000
1989	551,000	88,500	15,500	254,000	51,700	7,670	47,600	29,800	92,200	52,800	389,000
1990	506,000	94,000	16,800	288,000	39,700	5,040	38,100	32,700	83,300	57,100	438,000
1991	397,000	106,000	14,800	240,000	37,000	5,500	43,500	42,500	79,500	57,700	343,000
1992	263,000	118,000	18,000	239,000	25,400	9,860	40,600	44,400	92,100	49,800	326,000
1993	115,000	98,400	12,600	218,000	14,000	5,440	39,800	55,000	91,000	48,600	310,000
1994	47,400	58,900	8,260	228,000	4,320	8,480	47,300	67,200	91,600	49,100	220,000
1995	25,800	21,500	10,400	214,000	5,820	10,200	53,600	74,200	68,700	47,800	190,000
1996	31,500	25,100	10,100	208,000	4,740	7,180	55,300	72,700	60,000	46,300	231,000
1997	53,800	21,900	10,300	206,000	5,780	7,680	76,100	80,900	66,000	46,900	234,000
1998	65,300	28,900	14,100	211,000	4,180	4,160	107,000	85,000	63,000	47,800	230,000
1999	92,900	22,600	13,500	223,000	5,640	4,980	115,000	104,000	57,900	50,400	205,000
2000	81,100	22,600	16,600	224,000	4,930	3,670	135,000	105,000	86,600	52,300	215,000
2001	71,800	22,900	22,700	220,000	6,300	5,320	125,000	109,000	90,500	59,000	223,000
2002	62,100	19,300	18,800	211,000	4,950	4,690	135,000	120,000	95,000	51,700	233,000
2003	42,200	17,600	15,500	221,000	4,650	4,220	143,000	109,000	93,400	55,600	268,000
2004	43,200	15,300	17,600	203,000	3,920	3,410	176,000	115,000	82,200	53,900	278,000
2005	43,400	18,600	16,400	180,000	4,210	3,380	167,000	107,000	57,000	49,700	283,000
2006	50,300	16,600	16,700	177,000	2,530	2,480	178,000	102,000	63,400	61,900	273,000
2007	54,800	11,300	15,600	185,000	3,050	3,160	188,000	103,000	65,300	54,900	250,000
2008	55,500	9,500	15,900	155,000	2,880	2,440	167,000	104,000	67,600	65,800	231,000
2009	46,900	14,500	13,300	171,000	3,720	3,570	138,000	106,000	62,900	64,900	248,000
2010	42,800	15,400	10,900	165,000	2,780	1,430	167,000	93,000	60,200	70,000	229,000