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Review of the NAFO 3Pn4RS Atlantic cod assessment framework: commercial and recreational fisheries catch and tagging program data

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

The foundations for a new reliable stock assessment model ideally consist of high-quality data on the quantity and demographic composition of fishery removals as well as any other information to estimate total mortality, including that caused by commercial and recreational fishing activities. In the part 1 of the review of the northern Gulf of St. Lawrence (nGSL, NAFO Subdivision 3Pn and Divisions 4RS) Atlantic cod (*Gadus morhua*) assessment framework, held on April 21–22 and May 12, 2021, a detailed review of commercial landings data was undertaken to obtain an accurate picture of all landings recorded to date. An estimate of discards of Atlantic cod in commercial fisheries was also based on data from at-sea observers. In addition, although the recreational cod fishery in the nGSL has existed for many years without any structured catch monitoring, harvest estimates by this activity were derived using different approaches and information sources. Among other things, these estimates indicate a significant annual cod harvest since the mid-2000s. A review of historical tagging data was also carried out. These data are expected to feed into the new assessment model for the nGSL Atlantic cod stock, although work is required to address issues such as non-homogeneous population tagging and interannual variability in tag return rates.

1. GENERAL INTRODUCTION

For more than 30 years, the assessment of the stock of Atlantic cod (*Gadus morhua*) in the northern Gulf of St. Lawrence (nGSL, NAFO[1] Subdivision 3Pn and Divisions 4R and 4S, hereinafter referred to as stock the *3Pn4RS stock*) has included a virtual population analysis (VPA). Since 2015, the VPA has been conducted using a framework available in the *National Oceanic and Atmospheric Administration's Virtual Population Analysis* (VPA/ADAPT) toolbox (NOAA 2014). This program is a model for estimating the age structure of a population, developed from the model of Gavaris (1988), to which characteristics from other versions of ADAPT have been incorporated. The pattern of residual values obtained from the model for this stock suggest substantial model mispecification (Brassard et al. 2020). A new, more flexible and better adapted model is therefore needed and careful consideration of the data available for this stock is the first step required to achieve this objective.

The reliable assessment of the status of a stock is based on an accurate count of the quantity and demographic composition of removals by fisheries. Lower quality advice for sustainable fisheries management can occur when the magnitude of unaccounted catch varies over time, as this can result in a loss of precision and accuracy of important parameters in the assessment models (Rudd and Branch 2017). Among other things, it can become difficult to assess the relative roles of observed changes in natural and fishing mortality. These elements are critical to understanding the causes of stock collapse and a lack of stock recovery despite apparent declines in fishing mortality for many stocks in Atlantic Canadian waters (for example, Swain et al. 2011, 2019; Neuenhoff et al. 2019).

On the other hand, landings are partly incomplete because some catches are not reported. This can occur in several contexts, including under-reporting of landings, whether in a commercial or recreational fishery context, as well as unreported discards. For example, unreported catches of cod (NAFO Subdivisions 4Tv and 4Tn stock) and redfish (*Sebastes spp.*) from commercial fisheries in the Gulf of St. Lawrence during the 1980s and early 1990s are considered to be an important component of the catches from these populations, particularly with respect to redfish. (Bousquet et al. 2010; Duplisea 2018; Neuenhoff et al. 2019). Similar information was not previously available for the nGSL cod stock. It is reasonable to believe that in the context of the nGSL commercial fishery, the frequency and magnitude of unreported and unaccounted catches has been significantly reduced since the early 1990s. This would be explained by significant improvements in fisheries monitoring since 1990, including the implementation of dockside monitoring and the mandatory presence of at-sea observers for a certain percentage of groundfish and shrimp fishing trips in the Gulf (Benoît and Allard 2009). In addition, the adoption of the Nordmore grate in the shrimp fishery in the early 1990s, which minimizes the catch of groundfish larger than shrimp, is expected to have led to a significant reduction in incidental cod catch per unit of fishing effort (Richards and Hendrickson 2006).

In addition, nGSL cod is harvested in a recreational fishery for which there has been no systematic or structured catch monitoring. Recreational cod catches of the 2J3KL stock in Newfoundland and Labrador (NL, Figure 1) are estimated to have accounted for a high proportion (> 25%) of total removals for at least a few years (DFO 2011, 2013). It is therefore reasonable to assume that this may also have been the case for nGSL cod. Following a post-season survey to assess catch and effort in the recreational cod fishery, an estimated 73,425 people participated in recreational fishing in 2007 in the province of NL (BriLev Consulting Inc. 2008). The inclusion of recreational catches in an assessment model can be relevant even

[1] Northwest Atlantic Fisheries Organization.

when these catches represent a small percentage (e.g. 10%) of commercial landings (Griffiths and Fay 2015). Data on recreational catches are usually poorly documented and are extrapolated using different methods: extrapolation from management measures, telephone or field survey, tagging, etc. A survey based on interviews conducted in 2021 with experienced commercial nGSL fishers using a structured questionnaire was used to qualify plausible bounds for unaccounted catches, including the recreational cod fishery (Benoît et al. 2021).

Within this vision of using as much information as possible in a new integrated model, the incorporation of tagging data would provide information on fishing mortality rates (F) and natural mortality (M). This type of data could also be used to estimate selectivity through fishing (Cadigan 2016) and to assess migration between subpopulations.

This document presents a review pf commercial landing data, an estimate of discards from data from the At-Sea Observer Program, an estimate of the harvest by the recreational fishery using different methods, and a review of currently available tagging data. This research document covers part of the results presented in the part 1 of the review of the nGSL Atlantic cod stock assessment framework that took place on April 21–22 and May 12, 2021. This first meeting reviewed the data available for the establishment of a new model being developed in 2022.

2. LANDINGS

2.1. HISTORY OF DATA USED

The 3Pn4RS cod stock has been exploited since at least the 16th century (Chouinard and Fréchet 1994; Mimeault 1997; Lear 1998). However, it was not until the early 1950s that reliable fishing statistics were published by fishing sector and not by landing sector (Chouinard and Fréchet 1994). This period also corresponds to the introduction of trawlers and an ensuing significant increase in landings (Wiles and May 1968; Lear 1998).

Starting in 1951, fishing statistics were published in the statistical bulletins of the International Commission for the Northwest Atlantic Fisheries (ICNAF 1952–1961). However, these statistics are often broken down to a level that is too imprecise to allow the sorting of landings associated with the 3Pn4RS stock (Table 1). Indeed, from 1951 to 1952, the data are only summarized by Subarea (SA[2]). It is thus impossible, for example, to distinguish landings attributable to 3Pn from those of other Divisions or Subdivisions of the same SA (e.g.: Division 3K or Subdivision 3Ps). From 1953, fewer and fewer landings were reported at the SA level, but the level of precision (for example the 3P Division) still did not allow a distinction between 3Pn and 3Ps since it was not until 1959 that these two Subdivisions appeared in the statistical bulletins. This separation between 3Pn and 3Ps is important because a separate cod stock resides and is caught in 3Ps (Figure 1). ICNAF data were not broken down by month.

NAFO succeeded ICNAF in 1960. Their landing data are available in two formats:

- NAFO 21A: This database is updated more regularly, but only provides annual landings by species, country and NAFO Division.
- NAFO 21B: This database provides a more detailed breakdown of landings, including year, month, country and gear. As of April 2021, these data were only available until 2016.

From 1985, an additional source of landing data, ZIFF data (Zonal Interchange File Format, STACAC 1984), was introduced. These files are the result of a standardization of fisheries data

[2] For example, the NAFO unit area 4Ra is in Division 4R, which is in Subarea 4.

for the different regions of the Department of Fisheries and Oceans Canada (DFO) in the Atlantic, thus facilitating the exchange of statistics between regions (STACAC 1984). These data also have the advantage of being reported per fishing trip. Traditionally, landings in the two most recent years are considered preliminary. For this report, data for 2019 and 2020 were therefore considered preliminary.

Several countries fished cod from the 3Pn4RS stock before the Canadian fishing zone was extended to 200 nautical miles from the coast in 1977 (Sanguin 1980, Table 2). After 1977, only France (the Metropolitan France and/or the overseas community of Saint-Pierre-et-Miquelon) continued to fish for 3Pn4RS cod until 1992. As the ZIFF data provide only Canadian landings, NAFO reported landings are consistently higher than those reported by ZIFF data over the period 1985–1992 (Figure 2).

Beginning in 1999, the management year for this stock was changed. It no longer corresponds to the calendar year, but begins on May 15th and ends on May 14th of the following year. For the 1999/2000 management year, this change meant that the management year was from January 1st, 1999 to May 14th, 2000. Since NAFO 21B data provide only the years and months of landings, it is therefore impossible to use this data source after 1998 to break down landings by management year and month, for example. However, for stock assessment purposes, landings associated with the calendar year are required and thus the NAFO 21B data are appropriate.

Historically, although the 3Pn4RS stock data were available from 1959 (Table 1, Figure 2), they are generally presented only from 1964 in the tables of research documents published by DFO. Table 3 is a good example of what is normally published. The omission of the pre-1964 data was justified by the lack of information on the month of landing and/or that landings were reported as coming from Division 3P, which does not allow to isolate data from 3Pn (Gascon 1983).

Since NAFO data are not updated as frequently as ZIFF data, the dataset used to produce Table 3 consisted of the following:

- 1964–1984: NAFO 21B data,
- 1985–…:
  - Canadian landings: ZIFF data,
  - Landings of foreign fleets: NAFO 21B data.

2.2. SEARCH FOR ADDITIONAL LANDINGS

Research was conducted to obtain landings specific to the 3Pn4RS stock prior to 1959, the 1st year in which Subdivision 3Pn is used in the ICNAF data breakdown (Table 1). Wiles and May (1968) mention that the first trawlers exploiting the 3Pn4RS stock would have started in 1954. It is therefore legitimate to assume that commercial fishing was mainly coastal beforehand, and therefore very localized (e.g.: a vessel whose home port is in unit area 4Ra would be deemed to land catches from 4Ra at the same port). Chouinard and Fréchet (1994) detail how they were able to create a time series of landings beginning in 1920 for the cod stock in the southern Gulf of St. Lawrence, well before the arrival of the first ICNAF landing statistics. However, following an investigation with the same bibliographic sources, namely the Fisheries Statistics of Canada documents (1917–1921, 1922–1955), it was impossible to similarly extract landings for 3Pn4RS because:

- NL did not become a Canadian province until 1949. As a result, fishing data for a large proportion of fishermen were absent.

- The counties or districts used to report landings in the province of Quebec are not located in areas where it could be assumed that the landings originate from 3Pn4RS.

In addition to attempting to retrieve older data, we also evaluated potential additional additions related to landings recorded in a way that did not allow them to be linked to the 3Pn4RS cod stock (e.g., landings recorded as coming from somewhere in SA 3 or 4 without specifying where, from Division 3P or from a completely unknown origin). NAFO 21B data were used for the period 1960–1992 (1992 being the last year in which landings by foreign fleets are known, see Table 2) and ZIFF data for the period 1993–2020. It can be seen that until 1983, landing values (W) provided by NAFO are still reported to spatial levels too imprecise to be excluded beyond any doubt as not coming from 3Pn4RS (Tables 4 and 5). For example, 14,160 and 2,770 t of Atlantic cod were landed in 1960 from NAFO SA and Division 3 and 3P respectively (Table 4). Using simple rules of three, an estimate of potential additional landings could be made. Continuing with the same example, the potential additional landings for 3Pn attributable to SA 3 in 1960 were calculated as follows:

$$\text{Addition to 3Pn from SA 3} = W_3 \cdot \frac{W_{3Pn}}{W_{SA\,3}} = 14{,}160 \cdot \frac{11{,}281}{1{,}137{,}041} = 140.5\text{ t} \tag{1}$$

For landings recorded as originating from Division 3P, the potential additional landings in 1960 were calculated as follows:

$$\text{Addition to 3Pn from Division 3P} = W_{3P} \cdot \frac{W_{3Pn}}{W_{3Pn} + W_{3Ps}} = 2{,}770 \cdot \frac{11{,}281}{11{,}281 + 72{,}636} = 372.4\text{ t} \tag{2}$$

According to our calculations, the potential additional landings for 3Pn never exceeded 1,000 tonnes per year (< 5% of the annual landings already reported for 3Pn, Table 4). For SA 4, problematic landings were present until 1973 (Table 5). Except for 1970 (668.4 t) and 1971 (218.8 t), the potential additional landings that could be attributable to 4RS Divisions were always low (< 50 t), and represented < 1% of the annual landings already reported for these Divisions.

With regards to landings for which the NAFO Division was not provided in the ZIFF files during the 1993–2020 period (Table 6), potential annual additional landings were always < 25 t (less than 1% of landings already reported as belonging to 3Pn4RS).

2.3. CONCLUSION

This investigation of the different data sources leads us to conclude that the landing dataset used should be composed of two sources, ZIFF and NAFO 21B, and in this way:

- 1964–1984: NAFO 21B data,
- 1985–…:
  - Canadian landings: ZIFF data,
  - Landings of foreign fleets: NAFO 21B data.

The potential additional landings shown in the previous section for the 3Pn4RS stock would not change the annual pattern of landings since 1964 (Figure 3). We believe that including these additional landings would be unnecessary given their low importance and that these estimates were made without taking into account other variables (e.g.: months, gear, countries), which could perhaps have helped to better distinguish these ambiguous landings. For example, perhaps all landings recorded as coming from SA 3 in 1972 came from a single country that extensive research would reveal as having fished historically only in Division 3K.

3. DISCARDS

3.1. CONTEXT

This section presents estimates of discards of Atlantic cod from the 3Pn4RS stock in targeted or bycatch fisheries based on data from at-sea observers. The only other structured source for this information is a compilation of responses to a recent questionnaire to fishermen (Benoît et al. 2021).

Discards are not presently included in the assessment of the stock. There are, however, several approaches to incorporating them into assessments to account for the fishing mortality they represent, including 1) adding them to landings, thereby assuming that discards and landings have the same age composition, 2) adding them as age-specific removals, modelling selectivity functions such that they can account for size-selective discarding and 3) using them to motivate the selection of catch bounds in censored catch assessment models (Hammond and Trenkel 2005; Punt et al. 2006; Aarts and Poos 2009; Fernández et al. 2010; Cook 2019).

At-sea observers are generally the only constant source of data on discarding in groundfish fisheries in Atlantic Canada. At-sea discarding of cod in GSL fisheries directed at cod or groundfish have not been permitted since 1993. Catch must be landed, and is therefore accounted for in landing statistics. Under the discard ban, observations of discarding in these fisheries should largely reflect spoiled catch resulting from depredation or degradation in fixed fishing gear caused by scavengers or microbes. It is known for GSL fisheries (Benoît and Allard 2009) and other fisheries worldwide (for example, Faunce and Barbeaux 2011) that fishermen can alter their fishing patterns when an observer is on board. To the extent that these changes in behaviour are intended to avoid catches that would otherwise result in discards when there is no at-sea observer, then discard estimates produced using observer data could be biased (e.g., Allard and Chouinard 1997). It is generally not possible to know the extent to which this is the case. Biases in the estimates made from groundfish fisheries after the imposition of the discard ban can therefore not be ruled out. In this section, we also present estimates of Atlantic cod discards from groundfish fisheries in the years that preceded the ban. For this period when discarding was permitted, we expect fewer biases caused by a change in behaviour when observers were present. We also estimate discards in the northern shrimp (*Pandalus borealis*) fishery, in which a Nordmore grate was introduced beginning in 1993. This device limits the capture and eventual discarding of cod and other groundfish to smaller-sized individuals (Savard et al. 2013).

3.2. METHODOLOGY

The data used for the estimates are 1) at-sea observer records from all observer companies operating in the GSL, summarized as catches by species and fishing trip, and 2) landings information from the ZIFF and NAFO databases. The data used in this study were limited to those from fisheries targeting the following species: Atlantic cod, redfish, Atlantic halibut (*Hippoglossus hippoglossus*), Greenland halibut (*Reinhardtius hippoglossoides*), witch flounder (*Glyptocephalus cynoglossus*) and northern shrimp. These are by far the nGSL fisheries that capture cod most frequently and in the largest quantities. From the landing data, we retained only the landings for each species in its targeted fishery. The landing data were then summed by the following factors: target species, gear class, NAFO unit area, year and month. The following gear classes were included, depending on the target species :

- Atlantic cod: gillnets, handlines, longlines, bottom trawls, Danish seines;
- Redfish: bottom trawl, pelagic trawl;

- Atlantic halibut: longlines;
- Greenland halibut: gillnets;
- Witch flounder: Danish seines, bottom trawls;
- Northern shrimp: shrimp trawls.

The at-sea observer data were also initially grouped by the same factors as for the landings: target species, gear class, NAFO unit area, year and month. This grouping represented the target level of aggregation (Level 1). There were cases in which there were landings for a group but no observer records. In these instances we applied hierarchy of increasingly coarse groupings until all landing groups were matched by at least two observer records (individual observed fishing trips). The hierarchy was as follows:

- Level 2: target species, gear class, NAFO unit area, year and quarter,
- Level 3: target species, gear class, NAFO unit area, year,
- Level 4: target species, gear class, year,
- Level 5: target species, gear class, period.

For level 5, periods were defined as 1990–1993 (pre-moratorium), 1994–2003 and 2004–2016 for all species except northern shrimp where the first period was 1990–1992 (prior to the mandatory use of the Nordmore grate).

For each landings grouping *g*, the discards of cod D_g were estimated using the discard ratio as:

$$D_g = L_g \frac{\sum_i d_{gi}}{\sum_i k_{gi}} \tag{3}$$

where:

- L_g are the total directed-species landings for the grouping *g,*
- d_{gi} is the discards (kg) of cod in fishing trip *i* of grouping *g,*
- k_{gi} is the kept catch of the target species (kg) in fishing trip *i* of grouping *g*.

Values of D_g were then summed over NAFO unit areas, gear classes and months to produce annual values by target species, and further summed over target species to provide total annual values. The time series for the total annual directed landings of each target species are presented in Figure 4.

Estimating discards from at-sea observer data is usually most reliably accomplished using estimators based on the sampling design of at-sea observer fishing trips (Rochet and Trenkel 2005). However, the actual or realized sampling design used in the GSL observer program is neither clear nor simple (Benoît and Allard 2009), which has prevented the use of this approach. The reliability of a ratio based estimator depends on there being a relationship between the variable in the numerator and denominator of the ratio, in this case, cod discards (numerator) and retained target species catch (denominator). We evaluate this relationship qualitatively. For the pre-moratorium period (1990–1993), there was a positive correlation between Atlantic cod at-sea discards and target catch for fisheries targeting cod, redfish and witch flounder in at-sea observer records (Figure 5). There were few records in general, and many fewer that reported cod discards for Atlantic and Greenland halibut targeted fisheries, although this period corresponded to one in which landings were low for both these species (Figure 4). For northern shrimp, we considered the period preceding the imposition of the Nordmore grate, thus 1990–

1992, and also found a positive correlation between cod discards and shrimp catch (Figure 5). For the following period, the correlations were generally somewhat less apparent and a majority of observer records indicated no cod discards, consistent with the discard ban introduced at this time for the groundfish fisheries (Figure 6).

Confidence intervals were estimated for the total discards using a Monte Carlo simulation. In each of the 1,000 iterations (determined a priori to be sufficient), observer records were resampled within each grouping and total discards were estimated. The 2.5^{th} and 97.5^{th} percentiles of the resulting set of annual estimates were taken respectively as the lower and upper confidence intervals.

The ratio estimator and the approach to estimate confidence intervals have previously been validated to some extent in a study of bycatch estimates of skates (family Rajidae) in the GSL. Benoît (2013) used observer records of retained catches of skates and the methods described above to estimate the annual landings for skates and associated confidence intervals. These estimates were found to be correspond reasonably well to observed landings, indicating that the method should also be valid for estimating discards. Unfortunately, it was not possible to apply that approach here given that landings are dominated by cod retained in the targeted fishery.

Cod length measurements made by at-sea observers were summarized to provide information on the size composition of discarded cod. In many cases, it was not possible to determine whether the length measurements were made on cod kept by fishermen, on discarded cod, or on a mixture of both. Length frequency data from sets in which the entire cod catch was reported as discarded were assumed to represent discarded catches, while length frequencies from sets with both retained and discarded fractions could represent a mixture. The two were considered separately. Annual length frequencies were generated as a simple tally of the available data for several reasons. First, the sampling scheme used to decide when length frequencies were taken by observers was not known to us and it was thus not clear how to combine length frequencies otherwise (e.g. by weighting more length frequencies recorded following large catches). Second, the number of fish in a sample did not differ significantly among samples, thereby lessening the risk of having certain samples dominate the results. Third, for some target species and years, the number of samples was quite small and there appeared to be little benefit to attributing unequal weights. Finally, the length frequencies were summarized to provide a general portrait of size composition and not as specific estimates that might be carried into a quantitative assessment, for instance.

3.3. RESULTS

The level of hierarchy used to aggregate the at-sea observer data is summarized based on annual landings in Figure 7 and annual number of records in Figure 8. Using annual landings is likely a better indicator of the impact of aggregation on the accuracy of discard estimates since landings are used to scale the discard ratios. For the pre-moratorium period, the majority (by landings) of annual groupings were associated with observer records at the first level of the hierarchy for cod, redfish and particularly shrimp directed fisheries (Figure 7). A much coarser level was required for Atlantic and Greenland halibut, but again this was a period of lower landings and fishing activity for these species (Figure 4). Subsequently, coarser groupings were required during the moratorium years for cod and many years during the index fishery for redfish. For Atlantic and Greenland halibut, a majority of groupings were supported by observer data at the first level of hierarchy and all by data within the first three levels. For witch flounder, coarser groupings were often required, while for northern shrimp, groupings outside the first level were rarely required and those of levels 3–5 were never required.

Estimated discards of cod increased from around 2,250 tonnes in 1990 to over 3,500 tonnes in 1991, before declining to a low of around 25 tonnes when the moratorium was imposed in 1994 (Figure 9). Discards increased progressively after 1998, peaking at 192 tonnes in 2000, dropping to 22 tonnes during the 2003 moratorium and fluctuating around 50 tonnes annually since then.

Discards in cod, redfish and northern shrimp fisheries constituted the majority of total discards before the first moratorium, while discards in cod fisheries constituted the majority of at-sea cod discards from the late 1990s to the early 2000s and again in the late 2000s (Figure 10). In the most recent years considered, most discards were from the Atlantic halibut and northern shrimp fisheries and to a lesser extent the Greenland halibut and cod fisheries.

In the shrimp and redfish fisheries of the early 1990s, the summarized annual cod length frequencies for all fishing sets with at least some discards were essentially the same as those for sets where no cod was retained (Figure 11). In contrast, in the 1991 and 1992 cod-directed fisheries, cod from the latter group were larger, although this result is based on a single sample and may not be representative. For the data involving all fishing sets with at least some discards, the length frequencies of captured cod caught were remarkably similar across all fisheries targeting different groundfish species, including cod, within a single year. The modal length of cod measured by observers in these fisheries was around 50 cm in 1990, shifting to just above 40 cm in 1992. While the shrimp fisheries also caught cod of these sizes, the modal size tended to be smaller, in the range of 30–40 cm.

There were very few measurements of cod after 1992 from groundfish fishing sets in which cod was discarded (Figure 12). These measures are therefore not shown.

After 1994, when the Nordmore grate was fully adopted in the shrimp fishery, the length distribution of discarded cod was shifted considerably to smaller sizes. In most years, the length frequency is characterized by a mode under 20 cm, likely comprising age 1 fish, and a second mode just above 20 cm, likely comprising age 2 fish. Relatively few cod in the range of 30–40 cm are caught, and only in some years.

3.4. CONCLUSION

There remains some doubt as to the precision and accuracy of annual discard estimates given the nature of at-sea observer data, although the estimate of discards of other species (e.g. skates) has previously been validated. Nevertheless, unless there is a large negative bias in the estimate, the amount of cod discarded annually since 1990 has been small compared to landings, accounting for a maximum of 5% of commercial catches, except in 1991 (about 10%). In addition, on average, nearly a quarter of these catches were made in the shrimp fishery and therefore represent the vast majority of cod under 3 years of age since the introduction of the Nordmore grate.

4. RECREATIONAL FISHING

4.1. CONTEXT

The 3Pn4RS cod stock assessment includes limited data on recreational fishing. This issue has been raised many times in recent years. The estimated natural mortality of this stock includes mortality from recreational fishing as well as predation (Brassard et al. 2020). A new population dynamics model could separately integrate harvesting through recreational fishing, thus distinguishing it from estimating natural mortality. Harvest estimates in the form of a minimum value and a maximum potential value for different periods would thus be relevant.

This part of the research document presents the methodology used to arrive at estimates of potential cod harvests from recreational fisheries.

4.2. REGULATION

It is difficult to accurately establish the beginning of a regulated recreational (sport or food) fishery during the long history of the Atlantic cod fishery. Although a recreational fishery survey reported the capture of more than 3 million cod by recreational NL fishers in 1974 (Cox 1977), from a legislative point of view, it was not until 1994 that the Atlantic Fishery Regulations, 1985, allowed recreational fishing to be controlled by ruling on a daily quota and closure periods (SOR[3]/94-60, Canada 1994). In fact, prior to the moratorium of the early 1990s, "the population of Newfoundland and the Lower North Shore of Quebec had unrestricted access to groundfish for food or leisure purposes" (Canada 2001). However, we had access to only a few regulatory documents governing recreational fishing during the period 1994–2000 (Figure 13).

No type of fishing licence is required to engage in recreational fishing for Atlantic cod, except for the years 2001 and 2002 when fishing licences were then required[4]. In 2001, each licence authorized the capture of 30 cod for the season (Fréchet et al. 2002), while the total allowed was 15 in 2002 (D. Parsons, DFO, pers. comm. 2021). Tags that the fishers were required to attach to each captured fish were provided with each licence. Due to the 2003 moratorium, no recreational cod fisheries were allowed from 2003 to 2005. As of 2006, the use of fishing licences (and associated tags) was abolished. A summary of the regulations is provided in Table 7.

4.3. ESTIMATION METHODS

4.3.1. Canadian surveys

Several surveys of all Canadian provinces on the recreational fishing of several fish species including cod have been carried out, including in 1974 (Cox 1977), 1985 (DFO 1988), 1990 (DFO 1994), 1995 (DFO 1997), 2000 (DFO 2003), 2005 (DFO 2007), 2007 (BriLev Consulting Inc. 2008), 2010 (DFO 2012a) and 2015 (DFO 2019). Specifically for some provinces, including NL, surveys include a draw among families (people living at the same address) regardless of whether or not they have obtained a recreational fishing licence. The estimates for the province of Quebec were not used because the population of the North Shore is too small compared to the population of the province; the province-wide were therefore considered unrepresentative. A distinction for saltwater fishing is usually part of these surveys. These surveys estimate a total number of cod caught for the province of NL (in full) with the exception of 2015 when only a number of days of saltwater fishing was estimated. However, the cod catch was estimated at 2,582,389 cod in 2015 (J. Hosein, DFO, pers. comm., 2021). The latter value was estimated using the same calculation method used in DFO (2012a). The 1974 and 2007 surveys focused only on the recreational cod fishery for the province of NL as a whole, while the 2007 survey presents biomass cod harvest estimates specifically for the west coast (3Pn4R).

With the exception of the 2007 survey, the estimated cod harvest in NL represents province-wide annual cod harvest by recreational fishers. To estimate the harvest for the 3Pn4RS (H_i) stock, we used the ratio between the harvest estimates for the entire NL human population (517,126 inhabitants, corresponding to the average of the populations estimated by the 2011

[3] Statutory orders and regulations.
[4] The unit price was $10. 14,568 fishing licences were sold in 2001 (Fréchet et al. 2002).

and 2016 censuses) and that of the inhabitants living along the NL coast (3Pn4R, 78,000 inhabitants) and the North Shore (4S).

To estimate the demography of the northern part of NAFO Division 4S, located in Quebec (QC), we considered the demographic data of Quebec in 2020 for these three regional county municipalities (RCM): Sept-Rivières (34,910 inhabitants), Minganie (6,437 inhabitants) and Golfe-du-Saint-Laurent (4,620 inhabitants). However, the majority of recreational fishermen are concentrated in the Golfe-du-Saint-Laurent RCM (P. Nadeau, APBCN[5], pers. comm. 2020). We therefore considered the populations of Golfe-du-Saint-Laurent and also that of Minganie leaving aside the RCM Sept-Rivières although recreational fishing activities have been reported to us in this RCM, in Sept-Îles more precisely (H.F. Ellefsen, DFO, pers. comm. 2019). A total of 11,057 therefore represents the potential of the population that would be most likely to be interested in the recreational cod fishery along the north shore of NAFO Division 4S. The total population selected for 3Pn4RS is therefore 89,057 inhabitants.

Annual harvest estimates for the stock of 3Pn4RS (H_i, in tonnes) for the years *i* 1974, 1985, 1990, 1995, 2000, 2005, and 2010 were obtained from this calculation:

$$H_i = Nb_i \cdot \frac{2.02}{1000} \cdot 0.172 \quad (4)$$

where:

- Nb_i = number of cod caught at NL in year *i*, estimated from the various DFO surveys,
- 2.02 = average weight (kg) of cod caught in 2007 as reported in BriLev Consulting Inc. (2008)
- 0.172 = demographic ratio between the 3Pn4RS and NL populations.

For 2007, the estimate was calculated as follows:

$$H_{2007} = 161.4 \cdot 1.14 \quad (5)$$

where:

- 161.4 = harvest estimate (t) for 3Pn4R according to the 2007 survey (BriLev Consulting Inc. 2008),
- 1.14 = demographic ratio between the populations of 3Pn4RS (89,057 inhabitants) and 3Pn4R (78,000 inhabitants).

Since the number of cod is not estimated in the 2015 survey (DFO 2019), the 2015 harvest estimate was calculated based on the 2010 harvest:

$$H_{2015} = 756{,}978 \cdot \frac{H_{2010}}{418{,}900} \quad (6)$$

where:

- 756,978 = number of saltwater fishing days conducted at NL in 2015 (DFO 2019)

[5] *Association des pêcheurs de la Basse-Côte-Nord*, or in English the Lower North Shore Fishermen's Association.

- 418,900 = number of saltwater fishing days conducted at NL in 2010 (DFO 2012a),
- H_{2010} = cod harvest in the year 2010 calculated using equation 4.

4.3.2. Science surveys

A survey based on interviews with experienced commercial fishermen in nGSL using a structured questionnaire was used to qualify and sometimes quantify plausible limits of unaccounted catches (including a specific section on recreational fishing) of 3Pn4RS cod from the beginning of industrial fishing in the early 1960s to the present day (Benoît et al. 2021). Specifically, the questionnaire defined the following time periods:

- Period 1: before the 200-mile limit and the imposition of a quota (< 1977),
- Period 2: until the first moratorium (1977–1994),
- Period 3: inter-moratorium period (1996–2002),
- Period 4: post-moratorium period (2004–2008),
- Period 5: Low quota period (2009–2020).

One question specifically related to recreational fishing. Respondents were asked to quantify the harvest from recreational fishing in their home community by period. For each of the periods, the responses should therefore normally reflect average annual values over the entire period. Although respondents had the choice of responding with an estimated number of annual recreational fishing trips or an estimate of the harvest (kg) of cod caught by members of their community, all respondents responded for both types of measures. Based on the question on the average harvest values obtained per community, and an approximation for the number of communities per province (QC = 4S, NL = 3Pn4R), Benoît et al. (2021) were then able to calculate a total annual harvest for 3Pn4RS (ESC-H). Responses based on the number of annual fishing trips were based on five ordinal categories: no fishing trip (0), 1 to 50, 50 to 150, 150 to 200 and > 200 fishing trips. The harvest was estimated for three fishing scenarios by considering daily catches of 3 cod (ESC-Trip-low), 9 cod (ESC-Trip-mid) and 15 cod (ESC-Trip-upper) caught per fishing trip. Additional details in Benoît et al. (2021).

4.3.3. 3Pn4RS stock assessment

Previous stock assessment for 3Pn4RS cod includes estimates of recreational catches for the 2001, 2002, 2006 and 2008 fishing seasons (Brassard et al. 2020). The estimation method for 2001 and 2002 is based on the sale of licences and a survey (Fréchet et al. 2003) while it is not documented for 2006 and 2008 (DFO 2008; Fréchet et al. 2009).

4.3.4. 2J3KL stock assessment

The 2J3KL cod stock assessment includes an annual estimate of recreational fishing from 1997 to 2019 for this stock based on the tags returns (capture-mark-recapture) by recreational fishers. The ratio between the number of tags returned to the commercial fishery and the commercial landings is used to estimate the harvest by the recreational fishery from the tag returns in that fishery (DFO 2021).

We postulated that the characteristics (type of fishers, interest, catch rate, etc.) of the recreational fishery were relatively similar between the coastal populations of NAFO Divisions 2J3KL and 3Pn4RS. In order to estimate the harvest potential by recreational fishing of the 3Pn4RS stock, we therefore used the ratio between the number of inhabitants of the coasts of 3Pn4RS (89,057 inhabitants) and of the coasts of 2J3KL (393,708 inhabitants), established using the demographic information of the federal electoral districts presented in Table 8. The demography of the coasts of 3Pn4RS (89,057 inhabitants) was used to estimate harvest potential through recreational fishing.

Harvest estimates (H_i, in t) for the years *i* 1997 to 2019 were obtained from the 2J3KL assessment using this calculation:

$$H_i = H_{2J3KL,i} \cdot 0.226 \tag{7}$$

where:

- $H_{2J3KL,i}$ = estimated recreational fishing catches for 2J3KL in year *i* (DFO 2021),
- 0.226 = demographic ratio between the populations of 3Pn4RS (89,057 inhabitants) and 2J3KL (393,708 inhabitants).

4.3.5. Calculation of harvest potential

Another approach was developed, based on intuitive assumptions following discussions with colleagues and people in the community. The goal was to obtain an estimate of the cod harvest potential of coastal communities for the period 2001 to 2020 through recreational fishing. We assumed:

- 75 and 20 communities for the west coast of NL (3Pn4R) and the North Shore (4S),
- 8 to 15 fishermen per community with a boat for 3Pn4R and 5 to 9 for 4S,
- an average of 2.3 fishermen per boat[6],
- 40% of the number of days in the fishing season with favourable weather conditions, and
- a daily harvest of 5 cod per fisherman with an average weight per fish of 2.02 kg (BriLev Consulting Inc. 2008).

From 2001 to 2020, minimum ($H_{min,i}$) and maximum ($H_{max,i}$) annual harvest estimates were obtained from:

$$H_{min,i} = \left(\left(NC_{TNL} \cdot NPC_{min,NL} \right) + \left(NC_{QC} \cdot NPC_{min,QC} \right) \right) \cdot 2.3 \cdot 5 \cdot \frac{2.02}{1000} \cdot NDPF_i \tag{8}$$

$$H_{max,i} = \left(\left(NC_{TNL} \cdot NPC_{max,NL} \right) + \left(NC_{QC} \cdot NPC_{max,QC} \right) \right) \cdot 2.3 \cdot 5 \cdot \frac{2.02}{1000} \cdot NDPF_i \tag{9}$$

where:

- *i* = year,
- NC_{NL} = number of NL communities (3Pn4R),
- $NPC_{min,NL}$ = minimum number of active boats per NL community,
- $NPC_{max,NL}$ = maximum number of active boats per NL community,
- NC_{QC} = number of Quebec communities (4S),

[6] Observations made by DFO Fishery Officers in NL in 2020, S. Dwyer pers. comm.

- $NPC_{min,QC}$ = minimum number of active boats per Quebec community (4S),
- $NPC_{max,QC}$ = maximum number of active boats per Quebec community (4S),
- 2.3 = average number of fishermen on board each vessel,
- 5 = number of cod caught per fisherman per fishing trip,
- 2.02 = average weight of a cod caught (kg),
- $NDPF_i$ = number of days of potential fishing in year *i*.

4.4. RESULTS

4.4.1. Canadian surveys

Estimates range from 40 t (2005) to 1,222 t (1974, Figure 14). The values for 1974 (1,222 t), 1985 (709 t) and 1990 (1,150 t) correspond to the period of high intensity of commercial fishing. The low value in 1995 (95 t) follows the introduction of a moratorium on commercial fishing the previous year and the introduction of new regulations (period and daily limit) in 1995.

In 2005, recreational fishing was prohibited and the estimate is 40 t. The estimated harvests of 2007 (218 t), 2010 (503 t) and 2015 (908 t) suggest a clear increase in the harvest from 2005 onwards. However, during the period covered (1985 to 2015) Canadian recreational fisheries surveys underwent changes to the questions posed and strategies for data validation and weighting (DFO 2019). The interpretation on interannual variations is therefore complex. The 1974 and 2007 values are values specific to the recreational cod fishery and only in the province of NL.

4.4.2. Science surveys

Estimates for both types of response are low (0 to 50 t) before 1996. After 1996, estimates based on the number of fishing trips (ESC-Trip-low, ESC-Trip-mid, ESC-Trip-upper) range from 100 to 280 t while they vary from 360 to 480 t according to estimates of the response of fishermen to the annual harvest of caught cod (ESC-H, Figure 14).

This survey was carried out in 2021, the memories of this fishery before 2006 (regulations similar to those of recent years) and particularly before the first moratorium, are perhaps vague especially since commercial fishing was generally important and that the regulations on recreational fishing were possibly non-existent especially between 1975 and 1990. It is highly likely that the survey respondents, who were all commercial fishers and therefore very active and busy before the first moratorium, would not have been concerned about recreational fishing at that time.

4.4.3. 3Pn4RS stock assessment

Estimated values are 253 t in 2001; 34 t in 2002; 75.3 t in 2006 and 67 t in 2008 (Figure 14). The estimate for 2001 is of the same order of magnitude as that of the estimates using both types of surveys. Since the methods used in 2006 and 2008 are not published, it is not possible to discern the elements that may explain the low values compared to those of the other methods.

4.4.4. 2J3KL stock assessment

Estimates range from 112 t to 395 t between 1999 and 2002. The low values in 2003, 2004 and 2006 correspond to a very low return of tags from recreational fishing in 2J3KL (only 4 tags, K.

Dwyer, DFO, pers. comm.); recreational fishing was also prohibited during these three years. Estimates increased from 2006 (180 t) to 2008 (587 t) and then fluctuated between 180 and 903 t (Figure 14). The 2019 estimate may increase as 2019 tag catches continue to be reported (DFO 2021). Since the ratio of landings in the commercial fishery to the return of tags in this fishery is necessary to estimate the harvest by recreational fishing in the estimate for the stock of 2J3KL, annual changes in landings influence the estimates. For example, there were essentially the same number of tag returns in the recreational fishery in 2015 and 2016 (K. Dywer, Pers. Comm.) while estimates fluctuated with commercial landings which increased by 120% between 2015 and 2016.

4.4.5. Calculation of harvest potential

These estimates inevitably follow the pattern of variation in the number of fishing days allowed annually. Indeed, it is the only variable that can generate variations over time. In 2001 and 2002, the number of days was 60 and 52 respectively and the estimates with the minimum number of fishermen per community are 293 and 390 t respectively and from 546 to 728 t with the maximum number of fishermen per community. In 2003, 2004 and 2005, the values are zero since this fishing was prohibited. Subsequently, the number of days of fishing allowed ranged from 32 to 46 days and estimates with the minimum number of fishers per community ranged from 180 t to 299 t and from 340 to 558 t with the maximum number of fishers per community (Figure 14). These estimates are of the same magnitude as those of the other methods, especially from 2003 onwards.

4.5. DISCUSSION

Since there is no accurate database of cod harvesting in the northern gulf through recreational fishing, we had to use indirect estimation methods for the period following the first moratorium. Figure 14 shows some consistency between the different harvest estimation methods, although each method has its own advantages and disadvantages.

Recreational fisheries surveys are undertaken in many countries to estimate catch and effort, but these surveys are often logistically difficult and costly due to the diffuse spatial and temporal distribution of fishing effort and rarely include fishermen (Griffiths and Fay 2015). The 2007 Canadian survey presented cod biomass harvest estimates specifically for the west coast (3Pn4R) and the values obtained are similar to the ones obtained for the minimum estimated using harvest potential, which involves a specialized fisherman concept.

The 2021 science survey involved participants in commercial fishing, who are able to provide unique knowledge (economic, social) that is an important part of the "best available information" for fisheries science and management (Hind 2014; Stephenson et al. 2016). The maximum values obtained from total cod harvest estimates in their community are among the highest, but similar to values expressed using other methods.

Recreational harvest estimates for the northern cod stock (2J3KL) are also relevant to the extent that the characteristics (behaviour, success, etc.) of recreational fisheries on both "sides" of the island of Newfoundland are comparable in this regard.

According to our perception, Canadian survey harvest estimates are the most relevant prior to 1998 and the concordance of estimates using different methods thereafter allows us to propose upper and lower limits of potential recreational cod catches. The different estimation methods lead to these suggestions for minimum and maximum values for the following periods:

- 1975-1993 : min. 700 t, max. 1,200 t,
- 1994-1998 : min. 0 t, max. 20 t,

- 1999–2002 : min. 200 t, max. 400 t,
- 2003–2005 : min. 0 t, max. 40 t,
- 2006–2013 : min. 300 t, max. 500 t,
- 2014-2020 : min. 300 t, max. 600 t.

During the April and May 2021 peer review meeting, some participants in this workshop tried to evaluate the harvest for recent years intuitively and these values were close to the proposed minimum values. Finally, these estimates do not include, in particular, recreational fishing activities carried out illegally (e.g.: exceeding daily quotas, activity outside the allocated periods) and mortality caused by improper release or injuries following capture. Thus, true removals could exceed the proposed upper bound values.

4.6. CONCLUSION

It is appropriate to include estimates of potential harvest from recreational fisheries as part of the application of the new assessment model for the 3Pn4RS cod stock. However, it is still relevant to develop an accurate method for measuring harvest through recreational fishing (actual harvest, fish size). The results of the next model should allow us to assess the relevance of developing a method for structured catch monitoring.

5. TAGGING

Numerous tagging studies spread over a hundred years have been carried out on cod (Robichaud and Rose 2004) and a synthesis is presented for the 3Pn4RS stock in Table 9. In addition to aiming to better understand the biology of this stock, these various works also aimed to determine the intensity of interactions with other nearby stocks (Figure 1). For example, the work carried out jointly between DFO and the MAPAQ[7] during the period 1983–1986 was intended to assess the extent to which the 3Pn4RS and 2J3KL stocks overlapped during the year (Gascon et al. 1990, Figure 1). Their work had revealed that the majority of cod tagged in 3Pn4RS were recaptured in that same area, with the exception of those tagged at the northeastern tip of the Strait of Belle Isle, most of which were found further east on the 2J3KL stock territory (Gascon et al. 1990). Tagging work carried out in 2J3KL corroborates these results by showing recaptures in the nGSL, especially in the Strait of Belle Isle (Lear 1982, 1984).

However, it was mainly the winter mix between the 3Pn4RS and 3Ps stocks (Figure 1) that generated many research projects in the mid-1990s (Campana et al. 1998, 1999; Bérubé and Fréchet 2001) to try to address concerns about the impacts related to the assessment and management of these two stocks (Chouinard 2001). A major tagging program carried out jointly by DFO and FFAW[8] was initiated in the fall of 1995 (Table 9). This ongoing program, hereinafter referred to as the nGSL sentinel fisheries tagging program, uses fishers participating in the sentinel fisheries program to tag cod. A description of the method is provided in Bérubé and Fréchet (2001). In addition to better understanding the migration of the species in NAFO 3Pn4RS zones (Figure 15), this program has made it possible to:

[7] *Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec.*

[8] Fish Food & Allied Workers Union.

- obtain estimates of exploitation rates independent of commercial catches (Brattey and Healey 2004; Le Bris et al. 2009; DFO 2012b; Brassard et al. 2016, 2018, 2020),
- assess the effects of abiotic and biotic factors on cod distribution (Tamdrari et al. 2012),
- estimate tag loss and reporting rates (Le Bris et al. 2009),
- to evaluate the fidelity phenomenon (*homing*, Yvelin et al. 2005),
- to assess the evolution of migration corridors over the years (Yvelin et al. 2005).

Another tagging program conducted jointly between DFO and FFAW between 2007 and 2012 this time involved data-storage tags (temperature and pressure) implanted in the abdominal cavity of cod (Le Bris et al. 2013a, 2013b).

In parallel with the nGSL sentinel fisheries tagging program, a cod tagging project in Division 4S[9] was completed from 2017 to 2020 (phase 1). As part of the Fisheries Science Collaborative Program (FSCP), a tagging pilot project was conducted from 2017[10] to 2019 in the western sector of 4S in collaboration with the ACPG[11] and in 2020 in the eastern sector of 4S in collaboration with the APBCN (Table 9). More than 1,500 cod have been tagged in three years with external *spaghetti* tags. In addition to helping to develop regional tagging expertise, this project tested an *in situ* method to estimate the survival rate of tagged cod. This first phase will have made it possible to decide:

1. that it is essential to recommend the period when cod is abundant in 4S, i.e. summer,
2. that the longline seemed more effective than the baited trap at catching fish in 4S, and
3. that it was necessary to help a non-negligible proportion of cod to sink (swim bladder problem) since the sites allowing better cod catches were located at depths of about 110 m (60 fathoms).

A second phase of the project in NAFO Division 4S (2020–2022) will explore the possibility of catching cod at shallower depths (35–65 m, 20–35 fathoms) using hand lines (similar to that of the west coast of the island of Newfoundland) or longline, in order to improve the survival rate of tagged fish. In addition, the tagging zone will be extended to the entire coastal zone of 4S between Sept-Îles and Blanc-Sablon. Residents of the North Shore will be trained to continue the development of local partners trained for tagging.

Finally, a third phase (2021–2023), in collaboration with the ACPG, will aim at continuing the work started in phase 1. The search for shallow depth tagging sites using longline in the Anticosti Island area will be initiated, as will the continuation of tagging training for ACPG members.

For the purposes of this research document, 2018–2020 tagging data from the FSCP Program have been combined with those from the nGSL sentinel fisheries tagging program. An update of the data available from this program is presented to validate whether these data are acceptable for use as inputs in the next assessment model.

[9] 290 cod were also tagged in 4R in 2020.
[10] No tagged cod.
[11] *Association des capitaines propriétaires de la Gaspésie*.

5.1. METHODOLOGY

Capture-mark-recapture data is entered into a *Microsoft Access* format (.mdb) database[12] maintained by FFAW. It is composed of two datasets, the tagging dataset and the recapture dataset.

An initial validation of these two datasets was performed. To achieve this, the data were imported into *R* (R Core Team 2020). All variables were validated and corrections made as needed. The main corrections made were:

- Fix impossible values. For example, a cod with a registered length of 0 cm was corrected by the value *NA* (meaning in *R* that the value was not available).
- Standardization of date formats.
- Standardization of latitude/longitude formats.
- For cod with valid spatial coordinates, it was verified that the coordinates do not fall on land or at impossible positions (e.g.: in the middle of the Atlantic Ocean).
- For valid spatial coordinates, a validation of the NAFO Division and unit area was performed. For a considerable number of cod, unit areas were not provided and the suffix *u* (for *undetermined*) was used. For example, 4Su meant that the marked cod had been tagged somewhere in Division 4S. With the spatial coordinate, it was possible to describe this place more precisely.
- Presence of duplicates. Each row in the tagging dataset corresponded to a tagged cod. If more than one line corresponded to the same unique tag number, then there was a problem, and all those lines were eliminated. For the recapture dataset, more than one line could correspond to the same cod (only a few cases) in the perspective where it was recaptured more than once (with release).

Once the tagging dataset was validated, it was found that 183 cod had been tagged outside Divisions 3Pn4RS based on spatial positions, in Divisions 3Ka (123), 3Psa (41) and 4Vn (19). These cod were excluded from the final tagging set.

5.2. RESULTS AND DISCUSSION

5.2.1. Tagging

100,987 cod have been tagged since the nGSL sentinel fisheries tagging program began in 1995. Excluding 1996, when a major tagging effort was made (13,704 cod), approximately 3,500 cod were tagged per year (Table 10). According to the different NAFO Divisions, 40,079 (39.7%) cod were tagged in 3Pn, 47,200 (46.7%) in 4R and 13,708 (13.6%) in 4S. NAFO unit areas 4Ra and 4Sw, those furthest north for the 3Pn4RS stock (Figure 1), contributed 35% of the total tagging effort and each represented in their respective NAFO Division the most used unit area in terms of tagging effort. Without DFO's increased effort in recent years to conduct tagging activities in NAFO 4S, there would have been no tagging in this Division since 2011. Figures 16 and 17 show the different tagging sites used throughout the years of the program.

Six gear types have been used since 1995 (Table 11). Longlines and handlines are mainly used. Tagging activities mainly took place from May to October (Table 12). Tagging operations in months other than July to October have mainly occured in 3Pn (Table 13). The absence of

[12] Extraction as of January 18, 2021.

cod and/or ice cover may have limited tagging in the other unit areas for these months. The vast majority of cod were tagged with a single tag (Table 14). The tagging of cod with high reward tags ($100) did not begin until 2000.

The annual length frequency curves are similar, except for the first year of the program (1995) which shows a very low mode compared to the rest of the series (< 25 vs ~ 50 cm, Figure 18).

A comparison of the importance of the NAFO unit areas (Figure 19) and the months (Figure 20) in which landings of 3Pn4RS cod stock were recorded in relation to the tagging program was carried out. It appears that the majority of annual tagging takes place in NAFO Subdivision 3Pn, while the latter only provides about 15% of the annual landings of the 3Pn4RS cod stock (Figure 19). However, this Subdivision constitutes an area of annual spring and fall migration. The importance of the summer months (June to August) in cod tagging (41.8% of total annual tagging) was less than the landings reported there (65.7% of total annual landings) during the period 2014–2018 (Figure 20).

5.2.2. Recaptures

Since the start of the tagging program, 8,226 tagged cod have been recaptured (Table 15). About 8% of the tagged cod each year are eventually recaptured. Some cod have been recaptured more than 15 years after being tagged. These considerably late recaptures would be unlikely due to the mortality rate of this stock. For example, the 35 cod tagged in 1996 and reported in 2007 are most likely errors. These observations could be explained by the return of tags in batches that may come from several years of captures. Fishermen would thus have waited to accumulate several tags before handling them over to DFO.

Keeping only cod recaptured for one to four years (at ± 15 days) from the tagging date, 75% of cod are recaptured within a very small radius of the tagging site (< 100 km, Figure 21). These results are similar to those of Yvelin et al. (2005). Monthly recaptures in 3Pn4RS (Figures 22-23) show a monthly distribution that follows well the migratory movements known for this stock (Figure 15).

5.3. CONCLUSION

The tagging database includes relevant information. However, some adjustments would be necessary to refine this program. For example, it would be appropriate to improve the spatial distribution of tagging sites by taking into account the different types of migratory behaviours of nGSL cod (Robichaud and Rose 2004; Le Bris et al. 2013a). On the other hand, the numerous catches of cod after several years reported sporadically do not seem to reflect reality. Also, the value of high reward tags has not changed since their arrival in 2000 ($100) and the assumption that 100% of them have been returned could be wrong given the general increase in the cost of living over the years[13]. For these reasons, the tagging data will require additional validation analyses to be included in the new model. It would also be beneficial to initiate a rigorous reflection on this program to improve the tagging program and the return of tags.

6. GENERAL DISCUSSION

This research document provides a summary of data that can be used as inputs in the application of a new assessment model for the nGSL Atlantic cod stock. A detailed investigation of commercial landing data provided a portrait of all landings recorded to date. Although the

[13] For example, according to the Bank of CanadaThe same « basket » of goods and services costing $100 in 2000 would cost nearly $150 in 2021.

values obtained are not very different from those used to date in the assessment of this stock, the analysis has made it possible to better highlight the limitations of each of the data sources (ZIFF, NAFO 21A, NAFO 21B) and their optimal use for further analysis. This stage of data analysis is rarely detailed in the research documents associated with stock assessments and so this review of the framework was the ideal context for doing so.

Aiming to improve the estimation of all the mortality caused by commercial fishing, the estimation of at-sea discards based on observer data made it possible to quantify these cod discards. However, it was not possible to estimate the accuracy of these estimates, which in particular may be affected by the various factors affecting the coverage achieved (fisheries management protocol, remote region, variability in the intensity of the types of directed fishing) and the behaviour of fishermen while they are monitored at sea (Benoît and Allard 2009). The estimates obtained are comparable to those estimated by the 2020 survey (Benoît et al. 2021) and will help improve the accuracy of the estimate of mortality by commercial fishing.

Estimates of cod harvesting by recreational fishing from several sources of information have determined that this practice is important in the nGSL. However, the extent to which some cod are captured and released is not known. However, mortality associated with it is likely low since according to Capizzano et al. (2016) and Weltersbach and Strehlow (2013), the survival of a cod caught by line in recreational fisheries and then released generally varies between 80 and 90%. It is important to note that for the period since 2008, the majority of recreational catch estimates ranged from 200 to 500 tonnes per year, which could represent 3 to 10% of annual catches in early 2010 and possibly more than 40% in recent years. Recreational fishing therefore has the potential to represent an important component of unaccounted fishing mortality. However, our harvest estimates from recreational fishing do not include catches resulting from quota overruns or fishing outside the permitted period.

Finally, the tagging data raise certain questions, in particular the geographical distribution of tagging sites that varies over time and the presence of certain tags that are reported late. These data will need to undergo additional validation analyses before being included in the new assessment model for this stock.

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9. TABLES

Table 1. ICNAF reported cod langings (t) for different Subareas associated to the 3Pn4RS stock for the 1951–1959 period. The column "3" represents the landings reported in Subarea 3 for which the Division or Subdivision is unknown. The "Total" column for Subarea 3 represents the sum of all landings reported for that Subarea and not just the sum of the landings reported here. This explanation also applies to Subarea 4 for the "4*" and "Total" columns.*

	Subarea 3					Subarea 4				
Year	3*	3P	3Pn	3Ps	Total	4*	4R	4S	Total	Unknown
1951	-	-	-	-	281,277.0	-	-	-	115,932.0	213,906.0
1952	-	-	-	-	307,628.2	-	-	-	131,432.6	157,962.3
1953	192,119.5	3,424.8	-	-	323,746.6	55,870.4	17,373.8	7,171.3	148,398.1	-
1954	5,670.0	48,295.0	-	-	471,632.0	-	32,226.0	2,928.0	148,777.0	-
1955	5,062.0	71,337.0	-	-	429,040.0	-	46,234.0	5,235.0	159,499.0	-
1956		49,304.0	-	-	381,705.0	-	39,062.0	2,648.0	198,076.0	-
1957	22,970.0	77,921.0	-	-	448,815.0	-	47,872.0	5,813.0	187,777.0	-
1958	12,657.0	50,138.0	-	-	292,796.0	-	71,656.0	7,812.0	213,330.0	-
1959	12,585.0	3,745.0	6,773	60,170	425,261.0	-	40,930.0	10,357.0	213,468.0	-

Table 2. Annual 3Pn4RS cod landings reported by country/entity other than Canada since 1960. Source: NAFO 21B data.

Year	Landing (t)	Country/entity*
1960	49,871	1, 2, 3, 4, 5, 6
1961	61,784	1, 3, 5
1962	39,259	1, 3, 5
1963	25,006	1, 3, 5, 7
1964	42,251	1, 3, 4, 5, 6, 7, 8, 9
1965	31,481	1, 3, 4, 5, 6
1966	28,327	1, 3, 4, 5, 6, 8, 10
1967	41,948	1, 3, 4, 5, 6, 7
1968	39,102	1, 3, 4, 5, 6
1969	20,703	1, 3, 4, 5
1970	57,243	1, 3, 4, 5, 9
1971	48,474	1, 3, 4, 5, 9
1972	27,385	1, 3, 4, 5, 6, 11
1973	37,236	1, 3, 4, 5, 11
1974	32,265	1, 3, 4, 5, 6, 11, 12
1975	31,644	1, 3, 4, 11
1976	34,275	1, 3, 4, 11
1977	18,138	1, 4
1978	15,771	1, 4
1979	13,769	1, 4
1980	9,396	1, 4
1981	12,508	1, 4
1982	12,013	1, 4
1983	10,684	1, 4
1984	11,623	1, 4
1985	9,185	1, 4
1986	13,122	1, 4
1987	1,535	4
1989	2,587	4
1990	2,485	4
1991	2,447	4
1992	2,333	4

* 1 = France Mainland, 2 = Italy, 3 = Portugal, 4 = Saint Pierre and Miquelon, 5 = Spain, 6 = United Kingdom, 7 = Soviet Union, 8 = Iceland, 9 = United States of America, 10 = Poland, 11 = Faroe Islands, 12 = Norway.

Table 3. Historical monthly landings statistics (t) of the 3Pn4RS cod stock for the period 1964–2020. Until 1998, the management year corresponded to the calendar year. For 1999, landings included those from January 1, 1999 to May 14, 2000. Since then, the management year corresponds to the period going from May 15 to May 14 of the following year. Unk. = unknown. '0' values indicate landings ≤ 0.5 t.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Unk.	Total
1964	1,104	24,423	15,760	6,059	3,106	10,349	12,526	5,853	2,154	1,385	864	651	-	84,234
1965	791	12,577	21,171	3,698	2,146	5,267	10,421	5,945	3,636	1,359	927	990	-	68,928
1966	1,965	22,817	8,929	2,516	1,638	8,371	7,483	4,740	2,493	1,146	1,779	1,208	-	65,085
1967	7,873	7,028	14,792	8,448	2,017	7,524	12,665	5,232	7,154	3,314	1,352	1,912	1	79,312
1968	725	7,980	22,799	9,060	3,087	10,719	17,214	9,400	4,913	1,784	1,171	819	-	89,671
1969	875	4,654	9,675	4,220	5,192	10,958	12,103	8,639	7,866	3,557	2,035	1,366	-	71,140
1970	1,635	25,494	18,223	27,886	4,816	6,017	8,963	3,896	2,184	3,114	1,937	1,300	-	105,465
1971	845	44,587	7,580	5,265	2,346	5,857	8,427	3,042	2,343	1,600	1,003	915	-	83,810
1972	1,494	14,961	5,337	7,400	7,334	4,594	6,818	3,296	2,365	1,406	994	212	2,026	58,237
1973	16,472	10,556	7,586	4,826	3,235	5,860	5,125	4,145	2,365	1,459	1,016	567	2,593	65,805
1974	12,995	10,753	5,959	5,665	6,231	5,021	6,235	5,396	2,214	1,331	1,009	479	3,148	66,436
1975	8,232	19,486	2,702	2,616	5,316	5,122	5,042	4,488	2,767	1,267	819	704	1,672	60,233
1976	15,637	15,204	3,610	3,437	7,071	6,930	6,978	4,310	3,348	2,286	1,537	578	6,055	76,981
1977	11,143	8,603	3,790	11,312	10,057	7,368	8,133	5,780	3,361	1,751	1,814	454	-	73,566
1978	20,754	6,307	5,161	3,156	6,717	9,796	13,255	7,000	2,836	1,979	1,309	236	-	78,506
1979	15,543	4,273	6,475	6,647	8,517	12,890	12,085	8,660	2,971	2,449	1,816	451	-	82,777
1980	5,280	8,965	9,925	8,087	7,147	14,096	23,158	10,719	5,687	2,773	1,311	431	-	97,579
1981	9,156	15,368	3,170	3,763	12,835	17,257	16,344	10,343	5,676	2,550	1,172	277	-	97,911
1982	2,289	11,671	10,122	5,544	12,723	16,826	22,492	9,136	8,412	4,465	1,227	32	-	104,939
1983	4,152	10,213	11,335	6,251	21,049	18,341	16,228	8,173	5,698	3,956	530	154	-	106,080
1984	5,002	11,079	9,494	4,260	15,205	13,349	22,300	10,962	5,238	4,644	1,113	997	-	103,643
1985	2,416	16,369	7,661	3,407	6,904	12,612	13,874	11,414	7,730	3,130	1,005	1,959	-	88,481
1986	2,468	18,021	10,611	4,847	12,057	7,613	12,739	5,960	4,348	2,956	834	944	-	83,399
1987	8,264	7,382	5,072	3,945	6,411	8,222	9,060	7,492	5,745	2,842	1,022	1,089	-	66,545
1988	1,505	2,710	4,270	2,697	9,897	4,971	7,679	6,282	3,264	1,747	1,143	1,536	-	47,702
1989	6,198	7,511	1,982	2,048	6,520	6,229	6,306	4,797	2,080	2,189	721	181	-	46,762
1990	5,646	2,537	1,102	394	7,953	7,741	4,664	3,122	1,968	1,554	1,856	464	-	39,000
1991	1,532	2,001	3,113	3,736	4,229	4,477	5,314	2,891	3,242	2,016	1,810	121	-	34,481
1992	4,453	2,551	226	1,825	4,696	1,729	3,211	3,538	2,316	1,869	1,868	1,261	-	29,546
1993	9	51	1,255	1,244	1,489	4,350	3,811	2,234	1,119	1,088	1,173	629	-	18,452
1994	14	48	41	7	26	12	14	100	206	28	24	18	-	537
1995	-	-	-	0	12	5	26	95	25	21	-	-	-	185

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Unk.	Total
1996	0	0	0	0	5	10	150	56	38	33	23	2	-	317
1997	0	1	-	2	357	255	1,189	962	815	1,038	145	27	-	4,792
1998	3	0	0	2	27	246	908	1,051	418	552	22	-	-	3,229
1999/2000	1	51	132	107	106	870	1,985	1,458	1,031	1,014	395	39	-	7,191
2000/2001	86	72	49	33	561	907	1,251	1,533	1,087	775	398	82	-	6,833
2001/2002[1]	110	58	6	10	447	518	1,847	1,269	1,339	865	293	125	-	6,886
2002/2003[2]	0	-	0	0	146	58	2,519	1,484	843	869	393	7	-	6,320
2003/2004	0	-	0	13	8	13	118	131	48	31	39	5	-	405
2004/2005	0	-	0	14	30	25	1,887	205	537	356	207	13	-	3,274
2005/2006	-	-	0	24	44	69	2,434	628	774	473	22	3	-	4,471
2006/2007[3]	1	0	0	15	19	101	3,285	591	645	298	669	17	-	5,640
2007/2008	-	-	1	7	22	132	3,711	447	1,126	578	447	5	-	6,474
2008/2009[4]	-	-	1	3	45	117	2,973	924	1,240	551	301	2	-	6,157
2009/2010	1	0	2	2	7	176	1,691	693	690	696	687	51	-	4,696
2010/2011	0	0	0	15	10	54	1,362	882	556	499	185	1	-	3,566
2011/2012	0	0	0	12	15	50	1,006	163	315	11	193	9	-	1,773
2012/2013	0	0	0	22	16	40	671	110	296	20	131	3	-	1,310
2013/2014	-	-	-	7	11	34	699	77	220	10	147	3	-	1,208
2014/2015	-	-	-	4	18	16	644	92	344	26	100	23	-	1,266
2015/2016	-	-	-	10	12	19	731	138	187	18	137	13	-	1,264
2016/2017	-	0	0	23	9	27	840	140	156	30	154	7	-	1,387
2017/2018	-	1	7	12	16	30	903	706	637	24	206	129	-	2,672
2018/2019	-	0	0	10	18	19	861	774	323	221	268	74	-	2,570
2019/2020[5]	1	0	-	1	15	23	304	97	168	27	87	38	-	761
2020/2021[5]	-	-	-	-	5	17	382	57	63	123	8	2	-	657

[1] Excluded 253 t. from recreational fishing. See Fréchet et al. (2003).
[2] Excluded 34 t. from recreational fishing. See Fréchet et al. (2003).
[3] Excluded 75.3 t. from recreational fishing. See DFO (2008).
[4] Excluded 67 t. from recreational fishing. See Fréchet et al. (2009).
[5] Preliminary data.

Table 4. Reported langings (t) at different geographic scales of NAFO Subarea 3, and imputation of potential additional landings for Subdivision 3Pn. The "3*" column represents the landings reported in Subarea 3 for which the Division or Subdivision is unknown. The "Total" column for Subarea 3 represents the sum of all landings reported for this Subarea and not just the sum of the landings presented here.

	Subarea 3					3Pn added landings (t) from			
Year	3*	3P	3Pn	3Ps	Total	3*	3P	Total	% added
1960	14,160	2,770	11,281	72,636	1,137,041	140.5	372.4	512.9	4.5
1961	11,458	1,581	38,218	83,620	1,304,441	335.7	495.9	831.6	2.2
1962	6,430	2,515	24,648	52,639	1,340,299	118.2	802.1	920.3	3.7
1963	29,554	-	20,204	48,569	1,372,519	435.0	-	435.0	2.2
1964	46,832	-	15,132	51,884	1,402,026	505.5	-	505.5	3.3
1965	20,570	42	16,734	49,560	1,463,216	235.2	10.6	245.8	1.5
1966	16,934	-	13,624	64,006	1,478,120	156.1	-	156.1	1.1
1967	19,498	-	20,428	61,019	1,684,412	236.5	-	236.5	1.2
1968	30,983	2	11,909	74,456	1,877,160	196.6	0.3	196.9	1.7
1969	44,910	-	4,917	58,859	1,493,918	147.8	-	147.8	3.0
1970	43,145	-	5,205	70,818	1,163,104	193.1	-	193.1	3.7
1971	32,693	-	7,844	59,942	1,055,914	242.9	-	242.9	3.1
1972	6,280	-	10,357	43,709	1,039,008	62.6	-	62.6	0.6
1979	8	-	10,916	33,006	571,918	0.2	-	0.2	0.0
1980	20	-	8,799	37,568	597,904	0.3	-	0.3	0.0
1983	17	-	16,107	38,451	691,296	0.4	-	0.4	0.0

Table 5. Reported landings (t) at different geographic scales of NAFO Subarea 4, and imputation of potential additional landings for Divisions 4RS. The "4*" column represents the landings reported in Subarea 4 for which the Division or Subdivision is unknown. The "Total" column for Subarea 4 represents the sum of all landings reported for this Subarea and not just the sum of the landings presented here.

	Subarea 4				4* landings (t) added to			
Year	4*	4R	4S	Total	4R	4S	Total	% added
1962	666	48,102	13,171	1,340,299	23.9	6.5	30.4	0.0
1963	206	42,366	12,176	1,372,519	6.4	1.8	8.2	0.0
1964	51	58,960	10,142	1,402,026	2.1	0.4	2.5	0.0
1970	7,754	91,146	9,114	1,163,104	607.6	60.8	668.4	0.7
1971	3,040	66,362	9,604	1,055,914	191.1	27.7	218.8	0.3
1973	684	43,094	11,411	807,976	36.5	9.7	46.2	0.1

Table 6. Reported landings (t) from unknown origin and imputation of potential additional landings for 3Pn4RS. The "Total" column of reported landings represents the sum of all annual landings of Atlantic cod available in the ZIFF data.

	Reported landings (t)					Unk. origin landings (t) added to				
Year	Unknown	3Pn	4R	4S	Total	3Pn	4R	4S	Total	% added
1999	6.2	1,164.6	4,881.6	844.2	55,077.4	0.1	0.6	0.1	0.8	0.0
2000	47.5	1,478.5	4,321.5	1,056.6	45,867.4	1.5	4.5	1.1	7.1	0.1
2001	88.7	1,739.5	4,308.4	902.6	40,497.8	3.8	9.4	2.0	15.2	0.2
2002	44.8	1,712.8	3,937.5	878.6	35,530.3	2.2	5.0	1.1	8.3	0.1
2003	29.4	86.3	210.5	92.6	20,514.3	0.1	0.3	0.1	0.5	0.1
2004	53.9	782.7	1,884.0	606.8	24,860.4	1.7	4.1	1.3	7.1	0.2
2005	43.3	855.8	2,951.4	653.5	26,178.5	1.4	4.9	1.1	7.4	0.2
2007	58.6	1,080.8	4,544.0	858.1	26,734.2	2.4	10.0	1.9	14.3	0.2
2008	41.6	1,130.8	4,173.1	853.7	26,829.5	1.8	6.5	1.3	9.6	0.2
2009	27.8	1,357.4	2,737.8	605.1	20,044.3	1.9	3.8	0.8	6.5	0.1
2010	31.2	705.4	2,175.6	670.6	17,155.7	1.3	4.0	1.2	6.5	0.2
2011	22.6	315.9	922.9	536.6	13,029.9	0.5	1.6	0.9	3.0	0.2
2012	41.9	187.1	731.8	384.2	10,968.9	0.7	2.8	1.5	5.0	0.4
2013	39.8	185.3	761.2	275.4	10,579.6	0.7	2.9	1.0	4.6	0.4
2014	51.7	153.0	783.2	325.4	13,322.8	0.6	3.0	1.3	4.9	0.4
2015	76.7	155.0	706.0	405.7	12,024.6	1.0	4.5	2.6	8.1	0.6
2016	82.1	174.0	799.0	399.5	18,367.8	0.8	3.6	1.8	6.2	0.5
2017	93.4	345.1	1,865.6	460.3	22,932.2	1.4	7.6	1.9	10.9	0.4
2018	144.6	438.5	1,643.9	496.0	18,048.7	3.5	13.2	4.0	20.7	0.8
2019	0.1	154.3	378.5	242.2	15,811.3	0.0	0.0	0.0	0.0	0.0
2020	0.0	118.7	376.6	166.9	13,827.6	0.0	0.0	0.0	0.0	0.0

Table 7. 3Pn4RS cod stock recreational fishing regulations in effect for different periods.

Period	Regulation
< 1994	No documented regulations.
1994–2000	Unknown fishing season with daily catch limit of 5 cod.
2001	Sale of fishing licences with 30 tags each. 30 cod could be harvested annually.
2002	Sale of fishing licences with 15 white tags and 15 black tags. Only white tags could be used in 3Pn4RS. 15 cod could therefore be harvested annually. The daily catch limit was 10 cod (provided harvesters had the required number of unused tags).
2003-2005	No recreational fishing permitted.
2006–2020	The use of the permit (and associated tags) is abolished. The fishing season varies from year to year (32 to 46 days). The daily catch limit is 5 cod.

Table 8. Federal Electoral Districts (FEDs) used to estimate coastal demographics of 2J3KL. Data are from the 2016 census. Note: percentages are assumptions to represent the proportion of the population living near the coast.

FED	Population	Note
Avalon	86,494	-
Bonavista–Burin–Trinity	74,116	-
St. John’s-East	85,697	-
St. John’s-South–Mount Pearl	81,979	-
Labrador	13,599	50% of 27 197
Coast of Bays–Central–Notre Dame	38,840	50% of 77 680
Long Range Mountains	12,983	15% of 86 553
Total	**393,708**	

Table 9. History of the various Atlantic cod tagging activities carried out for the 3Pn4RS stock.

Year(s)	Month	Site	NAFO	Nb. tagged	Organization[1]	Reference(s)
1934-35	July, Sept.	Port au Port	4R	Unknown	DFO	Templeman (1962)
1948	Oct.	Bay of Islands	4R	Unknown	DFO	Templeman and Fleming (1962)
1954	July	Red Bay	4R	363	MICQ	Lussiaà-Berdou (1979)
	July	Greeny Island	4S	233		
	July	Île de la Grande Passe	4S	298		
	June, July	Mecatina	4S	527		
	June	Natasquan	4S	275		
	July	Baie aux Saumons	4S	300		
1955	July	Forteau Bay	4S	1,124	DFO	Templeman (1963), Templeman (1974)
	Sept.	Port au Choix	4R	1,095		
	Sept., Oct.	Flowers Cove	4R	1,105		
1961	Oct.	Sept-Îles	4S	~ 1,500	Unknown	Jean (1963)
1962	Jan.	Eastern GSL	4R	1,600	DFO	Templeman (1979)
	Sept., Oct.	Centre Bank	4R	768		
	Oct.	Cape Whittle Bank	4S	768		
1963	March	Port aux Basques	3Pn	1,536		
	March	Rose Blanche	3Pn	768		
	Sept., Oct.	Bonne-Espérance	4S	1,152		
	Sept.	La Tabatière	4S	1,152		
	Sept.	Baie Johan Beetz	4S	384		
1964	Aug., Sept.	Port au Choix	4R	768		
	Sept., Oct.	Havre-Saint-Pierre	4S	384		
	Oct.	Sept-Îles	4S	1,152		
	Nov.	Hark Harbour	4R	768		
1975	Jan., Feb.	Eastern GSL	4R	465	IFREMER	Minet (1975), Minet (1977), Moguedet (1994)
	Feb.		3Pn	206		
1976	Jan.	North-eastern GSL	4R	1,496	IFREMER	Minet (1976), Minet (1977), Moguedet (1994)
	March	Banc Rose-Blanche	3Pn	1,462		
1983-86	Summer	Various	4RS	> 45,000	DFO -MAPAQ	Gagnon (1996), Gascon et al. (1990), Yvelin et al. (2005)
1995-…[2]	Various	Various	3Pn4RS	> 100,000	DFO -FFAW	Bérubé and Fréchet (2001), Brattey and Healey (2004), Yvelin et al. (2005), Le Bris et al. (2009)
2007-12	Unknown	Various	3Pn4RS	353	DFO -FFAW	Le Bris et al. (2013a), Le Bris et al. (2013b)
2018	July	Various	4S	690	DFO -ACPG	C. Brassard, MPO, pers. comm.
2019	July	Various	4S	378		
2020	Sept., Oct.	Various	4R	290	DFO -APBCN	
2020	Sept., Oct.	Various	4S	433		

[1] Acronyms not described in the document: MICQ = Ministère de l'Industrie et du Commerce du Québec, IFREMER = Institut Français de Recherche pour l'Exploitation de la Mer.

[2] nGSL sentinel fishery tagging program, still ongoing.

Table 10. Number of cod tagged and released by NAFO unit area during the period 1995–2020 in 3Pn4RS

Year	3Pn	4Ra	4Rb	4Rc	4Rd	4Ss	4Sv	4Sw	4Sx	4Sy	4Si	Total
1995	511	1,157	171	571	-	-	-	-	-	-	-	2,410
1996	4,350	3,917	1,926	1,151	713	14	138	1,493	2	-	-	13,704
1997	1,260	1,676	1,104	1,405	294	33	92	986	18	1	-	6,869
1998	406	1,790	570	547	185	160	157	2,506	318	177	8	6,824
1999	2,067	1,343	891	857	192	95	376	1,279	15	90	66	7,271
2000	2,926	1,716	707	649	628	-	382	1,234	33	11	-	8,286
2001	3,073	2,562	502	356	489	-	-	261	-	-	-	7,243
2002	3,435	668	183	450	173	-	-	656	-	-	-	5,565
2003	2,090	-	-	-	190	-	-	172	-	-	-	2,452
2004	1,547	-	-	-	143	-	-	-	-	-	-	1,690
2005	1,509	720	1,631	-	131	-	-	-	-	-	-	3,991
2006	1,354	-	1,324	1	250	-	-	308	-	-	-	3,237
2007	625	2,173	965	282	233	-	-	312	-	-	-	4,590
2008	1,296	178	335	-	-	-	-	295	-	-	-	2,104
2009	587	371	262	-	18	-	-	349	-	-	-	1,587
2010	701	596	141	-	-	-	-	116	-	-	-	1,554
2011	1,311	600	210	-	-	-	-	54	-	-	-	2,175
2012	1,359	685	431	-	-	-	-	-	-	-	-	2,475
2013	786	493	40	-	-	-	-	-	-	-	-	1,319
2014	1,511	615	-	-	-	-	-	-	-	-	-	2,126
2015	981	900	150	-	-	-	-	-	-	-	-	2,031
2016	1,363	695	115	-	-	-	-	-	-	-	-	2,173
2017	1,476	536	4	83	435	-	-	-	-	-	-	2,534
2018	1,219	90	-	-	-	-	-	-	-	690	-	1,999
2019	1,831	926	-	-	-	-	-	-	-	336	42	3,135
2020	505	705	-	-	-	-	-	433	-	-	-	1,643
Total	40,079	25,112	11,662	6,352	4,074	302	1,145	10,454	386	1,305	116	100,987

Table 11. Number of cod tagged and released during the period 1995–2020 in 3Pn4RS, by gear type used to catch cod..

Year	Gear type[1] FG	FPN	GNS	LHP	LLS	OTB	Total
1995	-	846	-	-	1,564	-	2,410
1996	-	281	433	2,102	10,193	695	13,704
1997	-	-	-	1,076	3,838	1,955	6,869
1998	-	351	-	4,448	480	1,545	6,824
1999	-	24	63	3,418	2,880	886	7,271
2000	-	20	19	4,265	3,573	409	8,286
2001	-	327	-	3,071	3,648	197	7,243
2002	-	-	-	1,694	3,871	-	5,565
2003	-	-	-	170	2,282	-	2,452
2004	-	-	-	-	1,690	-	1,690
2005	251	-	-	720	3,020	-	3,991
2006	-	-	-	1,325	1,912	-	3,237
2007	-	911	-	366	3,313	-	4,590
2008	-	-	-	261	1,843	-	2,104
2009	-	-	-	-	1,587	-	1,587
2010	-	-	-	536	1,018	-	1,554
2011	-	-	-	600	1,575	-	2,175
2012	-	-	-	741	1,734	-	2,475
2013	-	-	-	493	826	-	1,319
2014	-	-	-	615	1,511	-	2,126
2015	-	-	-	1,050	981	-	2,031
2016	-	-	236	339	1,598	-	2,173
2017	-	-	-	336	2,198	-	2,534
2018	-	-	-	-	1,999	-	1,999
2019	-	-	-	-	3,135	-	3,135
2020	-	-	-	723	920	-	1,643
Total	251	2,760	751	28,349	63,189	5,687	100,987

[1] FG = Fixed gear, FPN = Traps, GNS = Gillnets, LHP = Handlines, LLS = Longlines, OTB = Bottom trawls.

Table 12. Number of cod tagged and released per month during the period 1995–2020 in 3Pn4RS.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1995	29	-	-	-	-	-	192	969	286	452	362	120	2,410
1996	-	-	-	-	-	-	30	3,558	4,804	3,048	1,803	461	13,704
1997	6	11	-	-	1	401	1,605	1,548	1,165	1,647	429	56	6,869
1998	-	-	39	-	-	308	2,416	2,393	869	625	123	51	6,824
1999	-	10	-	-	315	1,576	1,465	1,010	990	1,075	796	34	7,271
2000	-	-	-	1,037	1,182	272	2,331	1,576	467	430	462	529	8,286
2001	-	-	-	-	743	8	1,285	988	664	1,631	1,299	625	7,243
2002	-	-	-	374	1,674	490	259	878	336	1,376	103	75	5,565
2003	-	-	-	-	207	24	-	72	100	813	1,236	-	2,452
2004	-	-	-	-	1,015	481	45	-	149	-	-	-	1,690
2005	-	-	-	-	315	1,194	1,070	1,412	-	-	-	-	3,991
2006	-	-	-	-	1,502	1,427	-	308	-	-	-	-	3,237
2007	-	-	-	-	625	2,747	-	846	242	130	-	-	4,590
2008	-	-	-	-	507	-	149	381	278	789	-	-	2,104
2009	-	-	-	-	515	279	49	334	393	17	-	-	1,587
2010	25	-	-	-	251		39	768	46	375	50	-	1,554
2011	-	-	-	-	436	163	160	753	648	15	-	-	2,175
2012	-	-	-	-	-		1,102	232	375	600	166	-	2,475
2013	-	-	-	-	-	117	-	1,202	-	-	-	-	1,319
2014	-	-	-	-	-	103	628	122	195	1,078	-	-	2,126
2015	-	-	-	-	-		293	-	795	287	656	-	2,031
2016	-	-	-	-	-	124	838	-	564		305	342	2,173
2017	-	-	-	-	762	373	-	370	166	863	-	-	2,534
2018	-	-	-	-	-	416	690	513	304	76	-	-	1,999
2019	-	-	-	-	-	153	966	1,380	229	44	363	-	3,135
2020	-	-	-	-	-	-	-	-	733	910	-	-	1,643
Total	60	21	39	1,411	10,050	10,656	15,612	21,613	14,798	16,281	8,153	2,293	100,987

Table 13. Number of cod tagged and released per month and NAFO unit area during the period 1995–2020 in 3Pn4RS.

Month	3Pn	4Ra	4Rb	4Rc	4Rd	4Si	4Ss	4Sv	4Sw	4Sx	4Sy	Total
Janv.	60	-	-	-	-	-	-	-	-	-	-	60
Févr.	21	-	-	-	-	-	-	-	-	-	-	21
Mars	39	-	-	-	-	-	-	-	-	-	-	39
Avr.	1,411	-	-	-	-	-	-	-	-	-	-	1,411
Mai	9,832	-	-	-	217	-	-	-	-	1	-	10,050
Juin	3,438	2,455	2,840	1,505	343	-	-	-	75	-	-	10,656
Juill.	2,222	5,686	2,671	1,300	813	116	288	259	704	368	1,185	15,612
Août	2,430	9,302	1,935	1,305	155	-	-	580	5,841	-	65	21,613
Sept.	2,731	5,211	2,162	723	267	-	-	270	3,418	15	1	14,798
Oct.	8,332	2,458	2,032	1,482	1,455	-	14	36	416	2	54	16,281
Nov.	7,286	-	-22	37	808	-	-	-	-	-	-	8,153
Déc.	2,277	-	-	-	16	-	-	-	-	-	-	2,293
Total	40,079	25,112	11,662	6,352	4,074	116	302	1,145	10,454	386	1,305	100,987

Table 14. Number of cod tagged and released by tag type over the period 1995–2020 in 3Pn4RS.

Year	Simple	Double	High reward	Total
1995	2,407	3	-	2,410
1996	13,547	157	-	13,704
1997	6,829	40	-	6,869
1998	6,672	152	-	6,824
1999	6,712	559	-	7,271
2000	7,385	689	212	8,286
2001	6,374	598	271	7,243
2002	5,126	439	-	5,565
2003	2,352	100	-	2,452
2004	1,074	526	90	1,690
2005	3,316	540	135	3,991
2006	1,936	476	825	3,237
2007	3,541	451	598	4,590
2008	1,687	189	228	2,104
2009	1,211	201	175	1,587
2010	1,404	36	114	1,554
2011	1,880	28	267	2,175
2012	2,127	48	300	2,475
2013	1,177	-	142	1,319
2014	1,791	95	240	2,126
2015	1,768	39	224	2,031
2016	1,854	-	319	2,173
2017	2,236	-	298	2,534
2018	1,435	235	329	1,999
2019	2,610	129	396	3,135
2020	1,192	206	245	1,643
Total	89,643	5,936	5,408	100,987

Table 15. Summary of recaptures of Atlantic cod tagged since 1995 in 3Pn4RS. The first column represents the years when cod were tagged and their number (n). The other columns provide the number of cod from a given tagging year that were recaptured in a particular year (last two digits).

Year (n)	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	Total (% recaptured)
1995 (2,410)	19	23	11	14	5	1	-	1	1	-	2	1	-	-	-	-	-	-	1	-	-	-	-	-	-	79 (3.3)
1996 (13,704)	34	185	156	143	58	39	44	12	9	2	1	35	2	10	-	-	2	1	1	1	-	-	-	-	-	735 (5.4)
1997 (6,869)	-	55	76	70	37	27	22	6	8	6	1	9	1	2	-	-	-	-	-	2	-	-	-	-	-	322 (4.7)
1998 (6,824)	-	-	40	82	58	54	30	1	7	1	1	3	1	-	1	2	-	-	1	1	-	-	1	-	-	284 (4.2)
1999 (7,271)	-	-	-	140	147	105	53	4	13	11	2	11	4	1	-	2	-	-	-	1	-	-	-	-	-	494 (6.8)
2000 (8,286)	-	-	-	-	139	199	127	11	26	16	12	15	3	2	-	3	1	1	-	-	-	-	-	-	-	555 (6.7)
2001 (7,243)	-	-	-	-	-	156	225	24	35	35	20	15	9	1	-	1	-	-	-	1	-	-	1	-	-	523 (7.2)
2002 (5,565)	-	-	-	-	-	-	232	44	86	38	35	19	9	2	-	1	-	-	-	1	-	-	1	-	-	468 (8.4)
2003 (2,452)	-	-	-	-	-	-	-	10	108	82	43	21	-	1	3	-	-	1	1	-	-	1	-	-	-	271 (11.1)
2004 (1,690)	-	-	-	-	-	-	-	-	147	105	69	26	9	6	1	1	-	-	-	2	-	-	1	-	-	367 (21.7)
2005 (3,991)	-	-	-	-	-	-	-	-	-	410	249	95	36	10	2	3	-	-	1	3	-	1	-	-	-	810 (20.3)
2006 (3,237)	-	-	-	-	-	-	-	-	-	-	358	175	49	14	5	2	-	-	-	3	2	-	-	-	-	608 (18.8)
2007 (4,590)	-	-	-	-	-	-	-	-	-	-	-	460	158	53	10	7	-	-	-	3	1	-	-	-	-	692 (15.1)
2008 (2,104)	-	-	-	-	-	-	-	-	-	-	-	-	120	98	30	14	2	6	-	3	-	1	1	1	-	276 (13.1)
2009 (1,587)	-	-	-	-	-	-	-	-	-	-	-	-	-	124	21	10	5	2	2	1	-	3	3	-	-	171 (10.8)
2010 (1,554)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	41	24	7	3	-	1	-	-	1	-	-	77 (5.0)
2011 (2,175)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	94	56	18	2	2	-	-	3	-	-	175 (8.0)
2012 (2,475)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	83	44	20	6	2	-	2	-	-	157 (6.3)
2013 (1,319)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	38	52	19	7	3	2	2	-	123 (9.3)
2014 (2,126)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	49	59	37	14	7	-	1	168 (7.9)
2015 (2,031)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	19	33	17	6	1	-	76 (3.7)
2016 (2,173)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	71	46	7	3	1	128 (5.9)
2017 (2,534)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	108	110	16	1	235 (9.3)
2018 (1,999)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	147	33	16	198 (9.9)
2019 (3,135)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	139	51	190 (6.1)
2020 (1,643)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	44	44 (2.7)
Total (100,987)	53	263	283	449	444	581	733	113	440	706	793	885	401	324	114	164	156	115	130	128	153	194	293	195	114	8,226 (8.1)

10. FIGURES

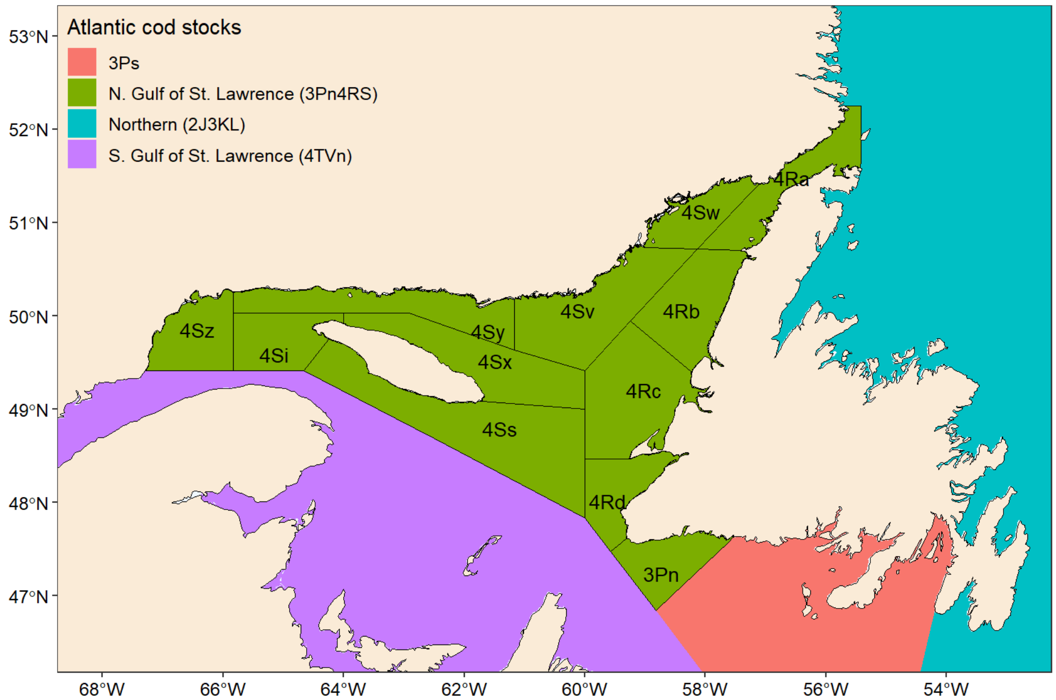

Figure 1. Different stocks of Atlantic cod from the northwest Atlantic surrounding the nGSL stock. NAFO unit areas for the nGSL stock are provided.

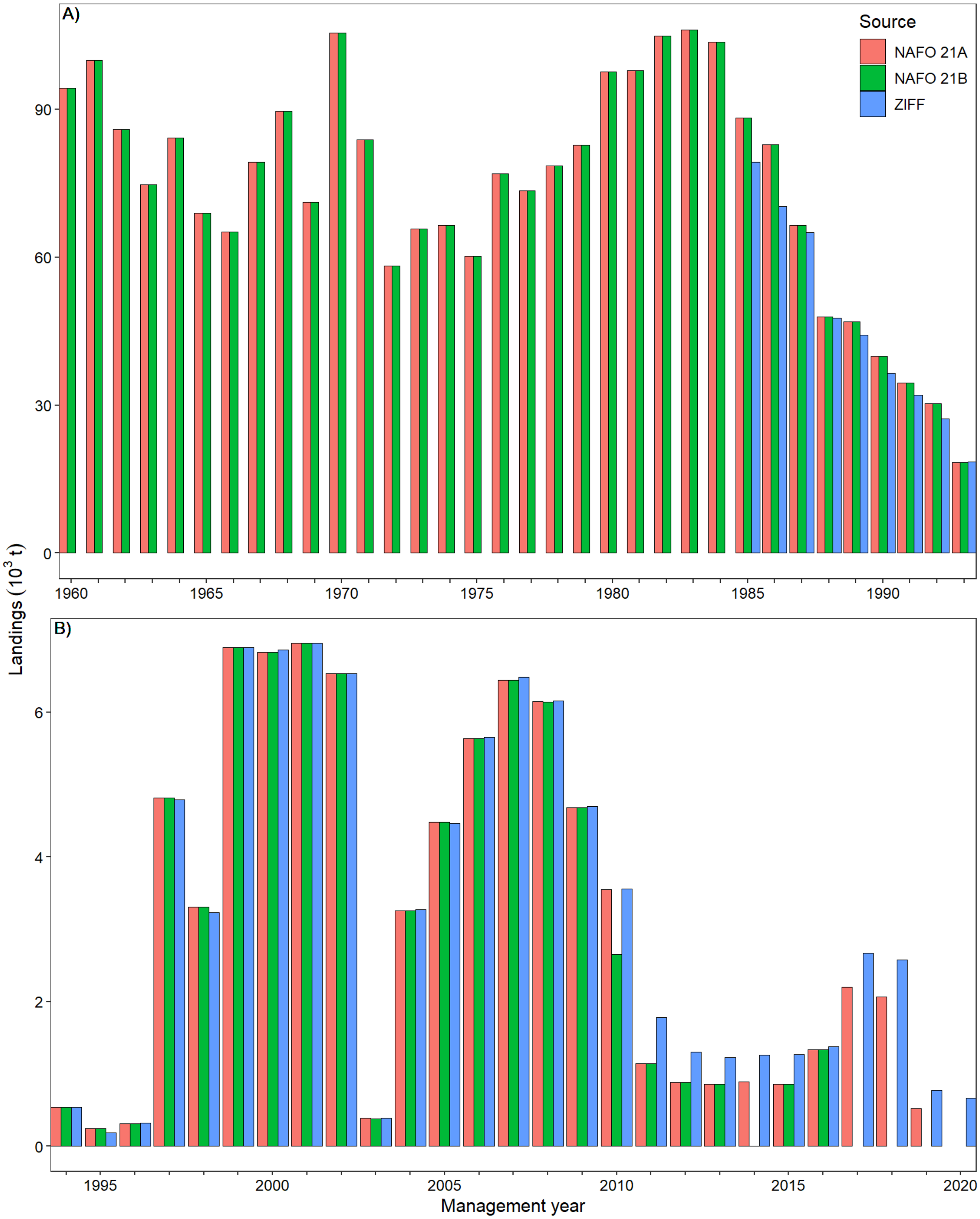

Figure 2. Comparison of annual landings of the 3Pn4RS Atlantic cod stock according to 3 data sources for the periods a) 1960–1993 and b) 1994–2020.

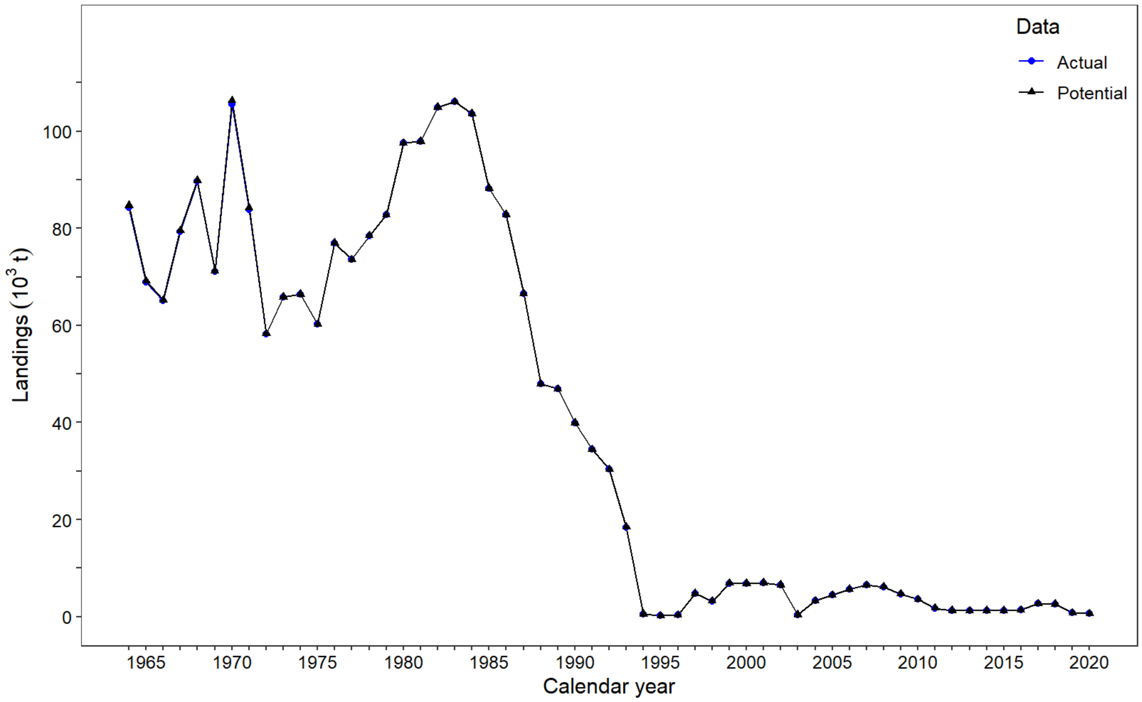

Figure 3. Comparison of the annual landings currently used for the 3Pn4RS Atlantic cod stock assessment and what could potentially be used based on landings from which their geographical origin is inaccurate or missing.

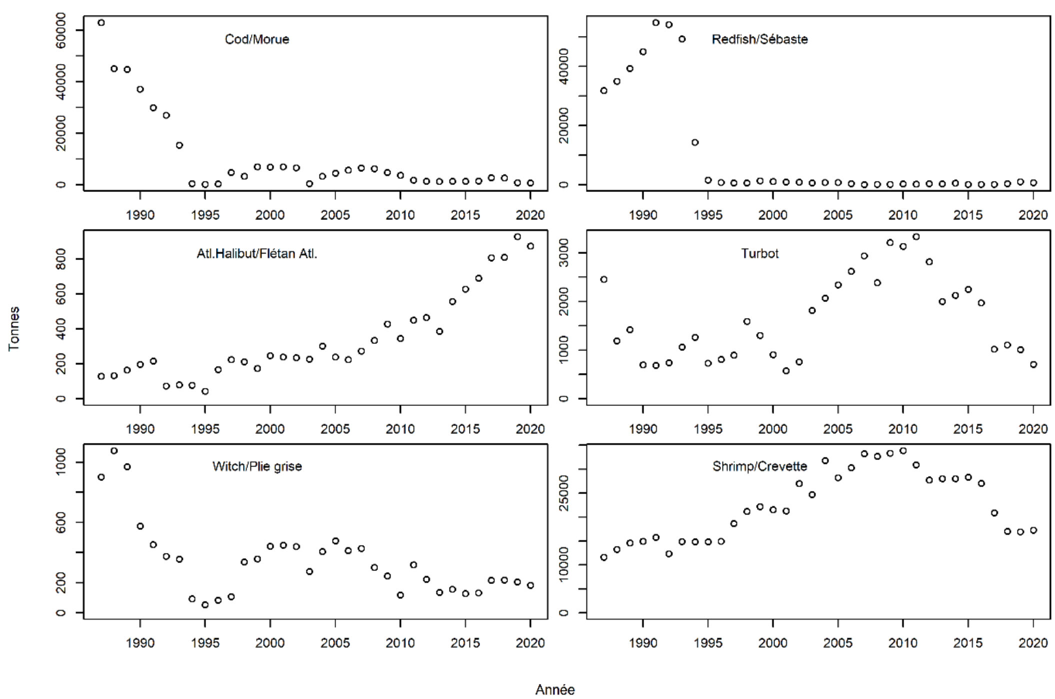

Figure 4. Total annual directed-fishery landings (tonnes) for each target species used in the cod discard estimation.

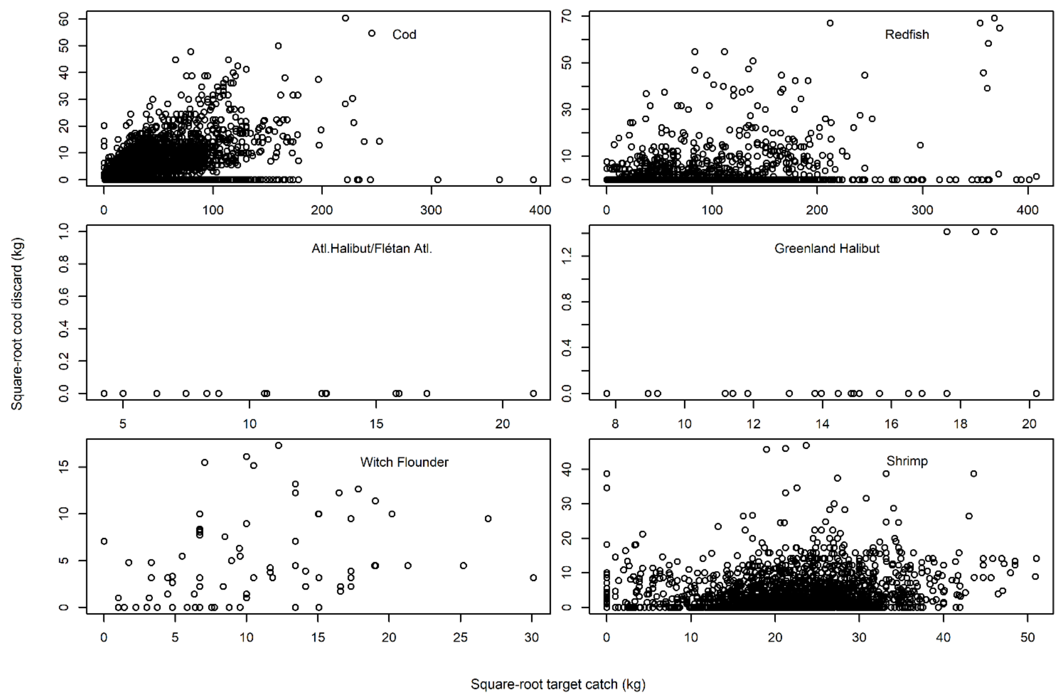

Figure 5. Relationship between target species catch and cod discards in at-sea observer data for each target species in the pre-moratorium period (1990–1993; groundfish target species) or pre-Nordmore period (1990–1992; shrimp). Note that for both target species and cod, it is the square-root of catch that is plotted. Notez que pour les espèces visées et la morue, c'est la racine carrée de la capture qui est montrée in order to reduce the deviation of the data in the graph.

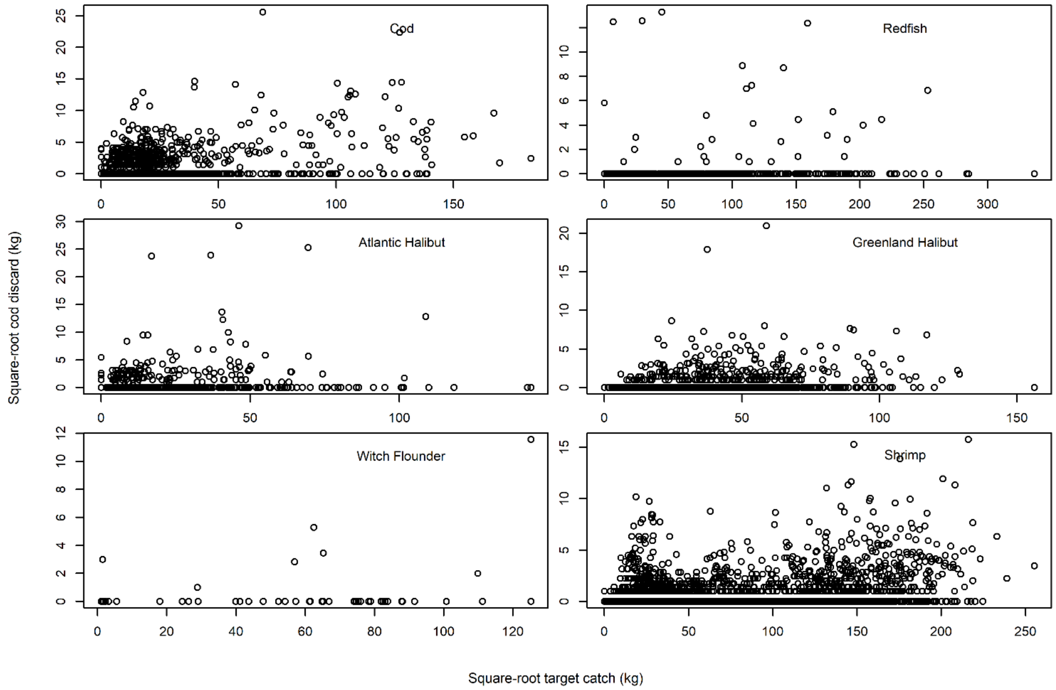

Figure 6. Relationship between target species catch and cod discards in at-sea observer data for each target species in the moratorium and post-moratorium period (1994–2019; groundfish target species) or Nordmore grate period (1993–2019; shrimp). Note that for both target species and cod, it is the square-root of catch that is plotted in order to reduce the deviation of the data in the graph.

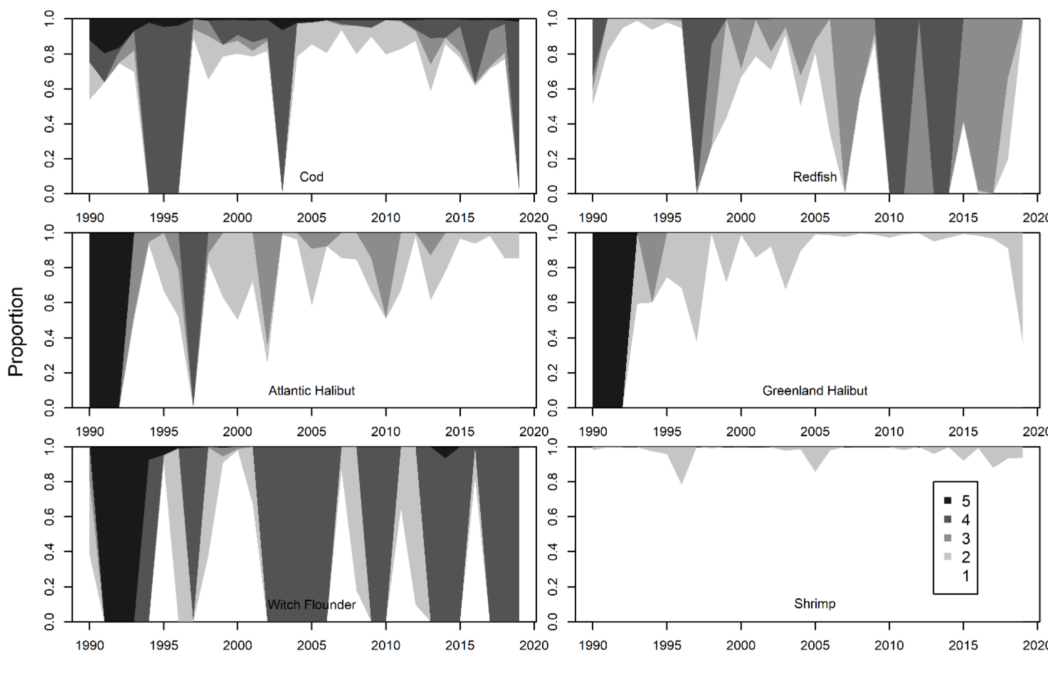

Figure 7. Relative proportion, by annual landings, of aggregation hierarchy levels used to attribute at-sea observer records to landings groups by year and target species.

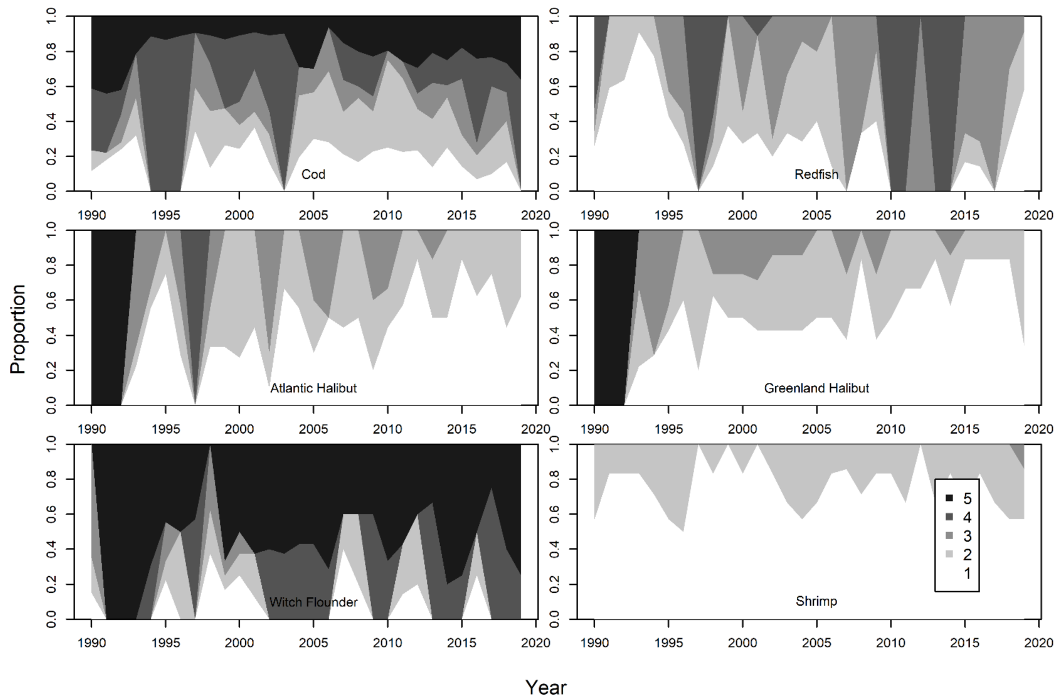

Figure 8. Relative proportion, by annual number of records, of aggregation hierarchy levels used to attribute at-sea observer records to landings groups by year and target species.

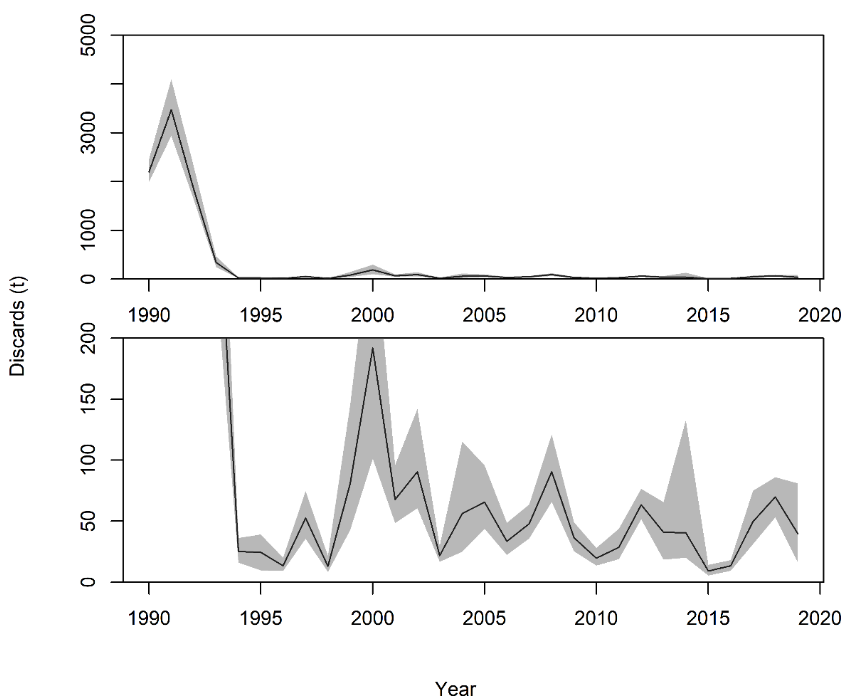

Figure 9. Total estimated annual discards of cod across all target fisheries in NAFO Subdivision 3Pn and Divisions 4RS for 1990–2019. The lower panel shows a finer resolution of values. The grey ribbon represents confidence intervals.

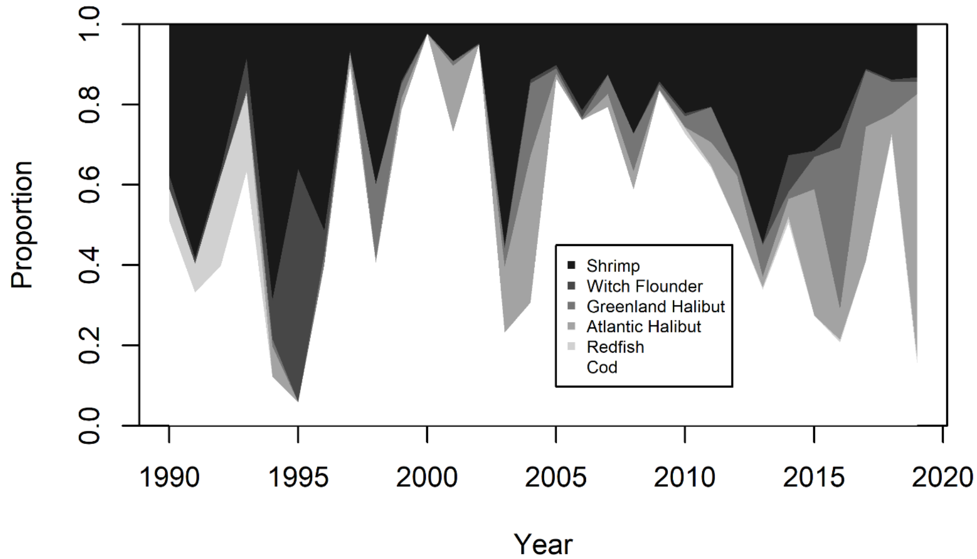

Figure 10. Relative annual contribution of the different target species fisheries to the total discards of cod in NAFO Subdivision 3Pn and Divisions 4RS for 1990–2019.

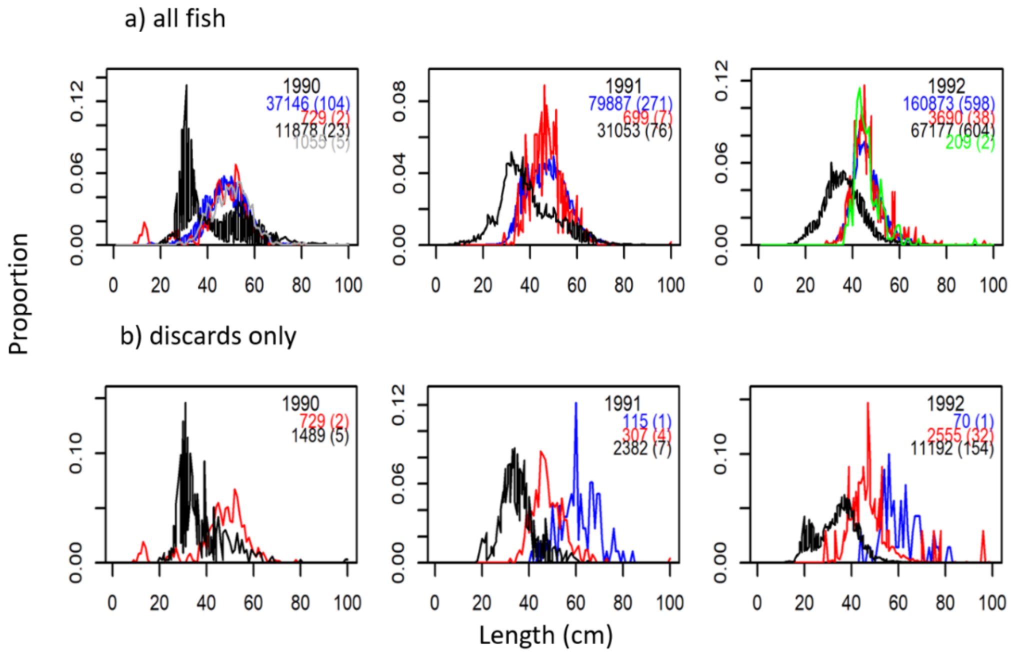

Figure 11. Length frequencies of cod captured in fisheries targeting cod (blue), shrimp (black), redfish (red), witch flounder (grey) and Greenland halibut (green), based on available data for 1990–1992. Top row panels show cod length measurements from all available hauls, while bottom row panels show cod measurements from only hauls in which all cod were discarded. In each panel, the year is indicated followed by the number of cod measured, and, in parentheses, the number of fishing tows with measurements, for each target species (colour).

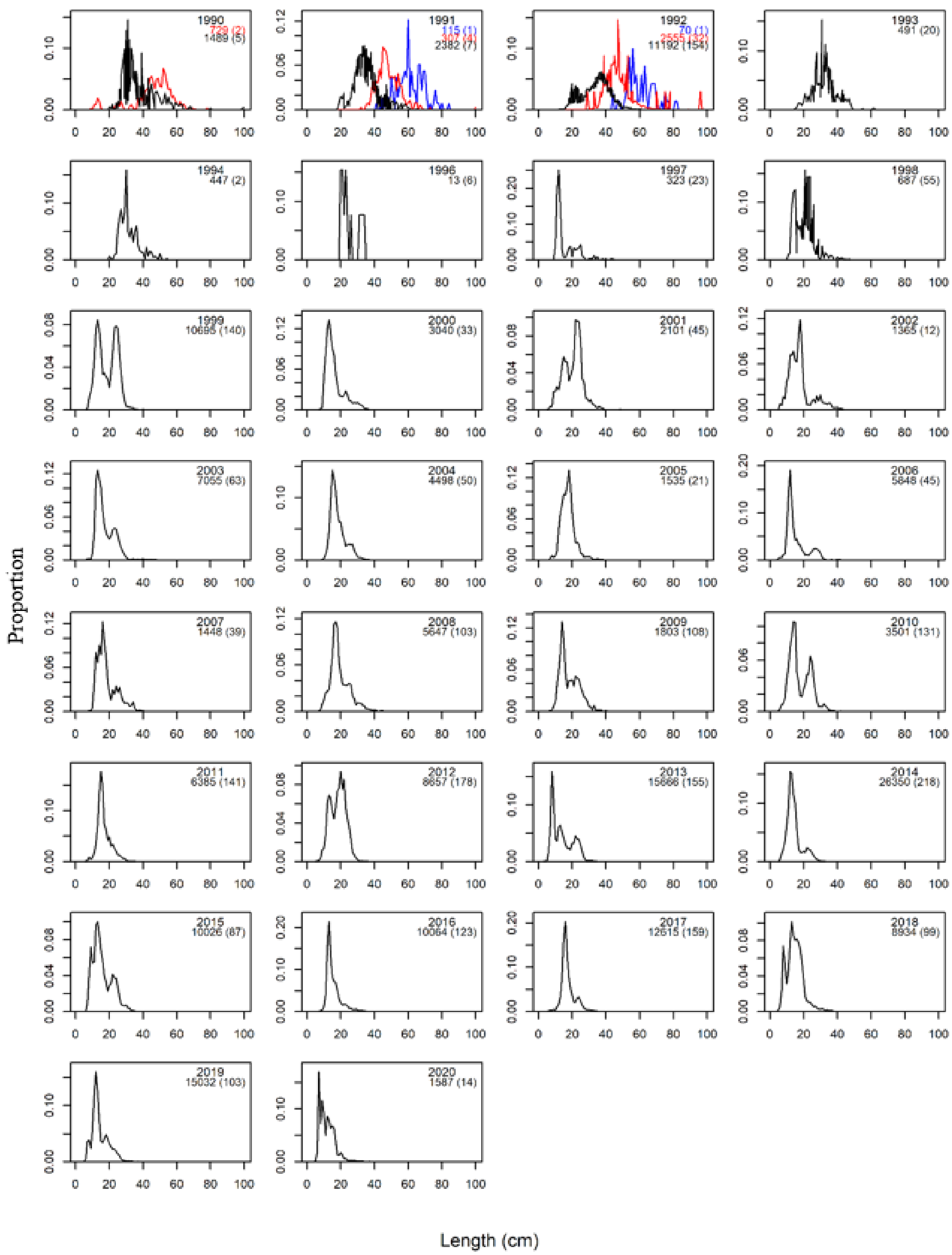

Figure 12. Annual length frequencies, 1990–2020, of cod measured and discarded in fisheries targeting cod (blue), shrimp (black) or redfish (red). In each panel, the year is indicated followed by the number of cod measured, and, in brackets, the number of fishing sets with measurements for each target species (colour). There were no data available for 1995.

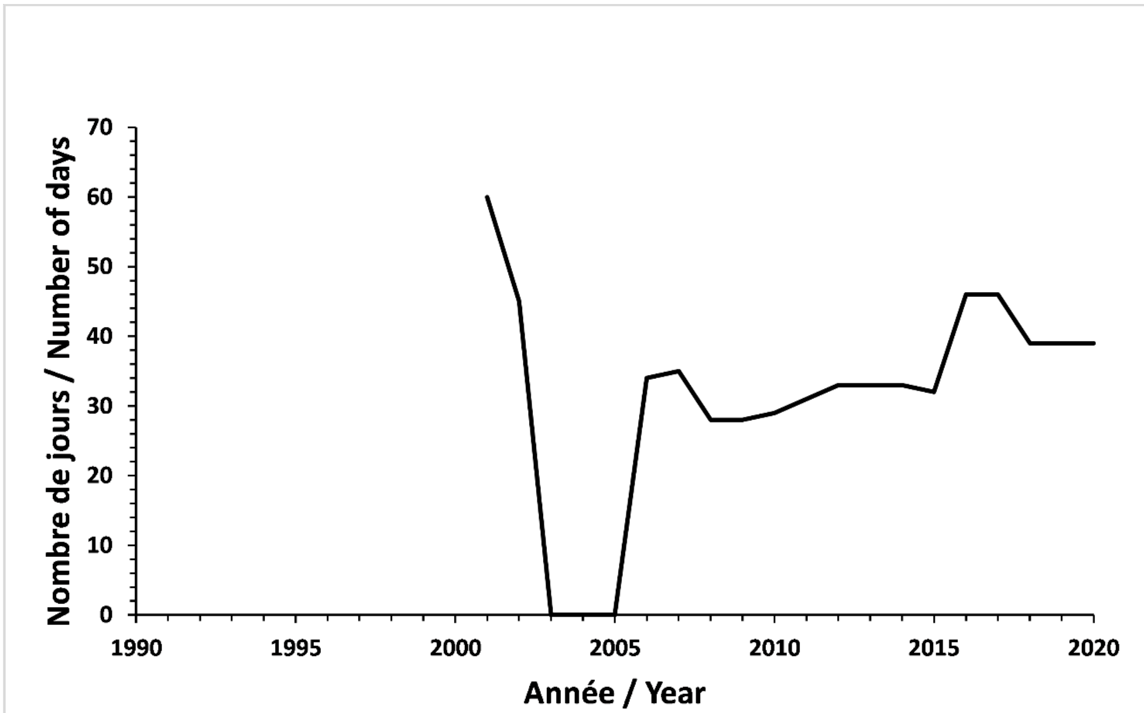

Figure 13. Regulations regarding the number of fishing days authorized for the population of Newfoundland and the Lower North Shore between 2001 and 2020 for the recreational Atlantic cod fishery.

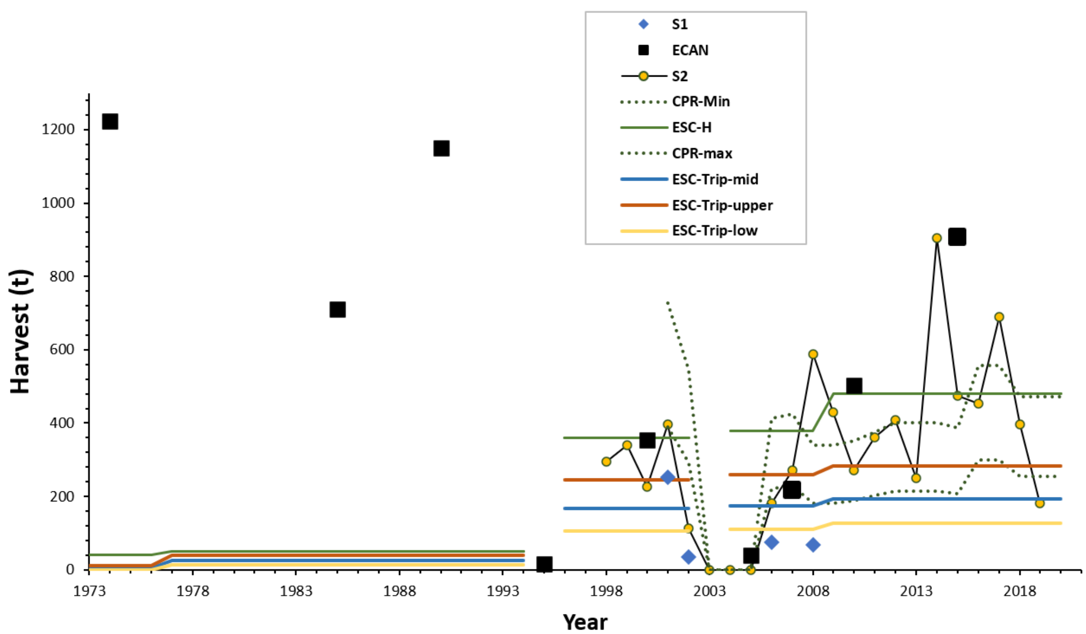

Figure 14. Estimates of the harvest (t) by the 3Pn4RS cod stock recreational fishery using different methods. S1 = assessment of the 3Pn4RS stock, ECAN = Canadian surveys, S2 = assessment based on the 2J3KL stock, CPR = calculation of the minimum (min) and maximum (max) potential harvest, ESC = science survey from an overall estimate of the harvest (ESC-H) and from the number of fishing trips with catch of 3 (ESC-Trip-low), 9 (ESC-Trip-mid) and 15 (ESC-Trip-upper) cod caught per fishing trip.

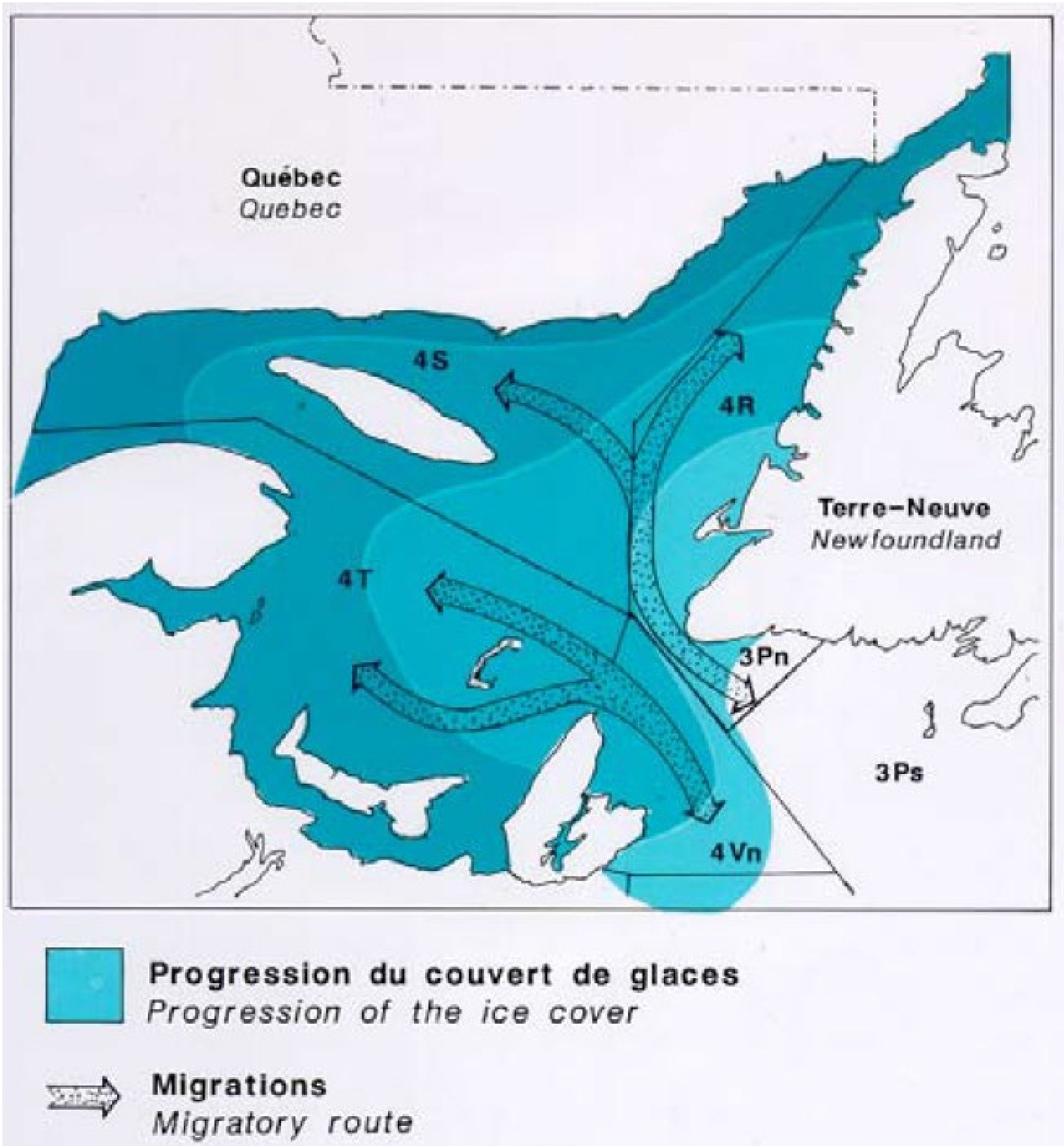

Figure 15. General migration routes of cod stocks in the Gulf of St. Lawrence. Figure taken from Yvelin et al. (2005) and from the work of Fréchet (1990).

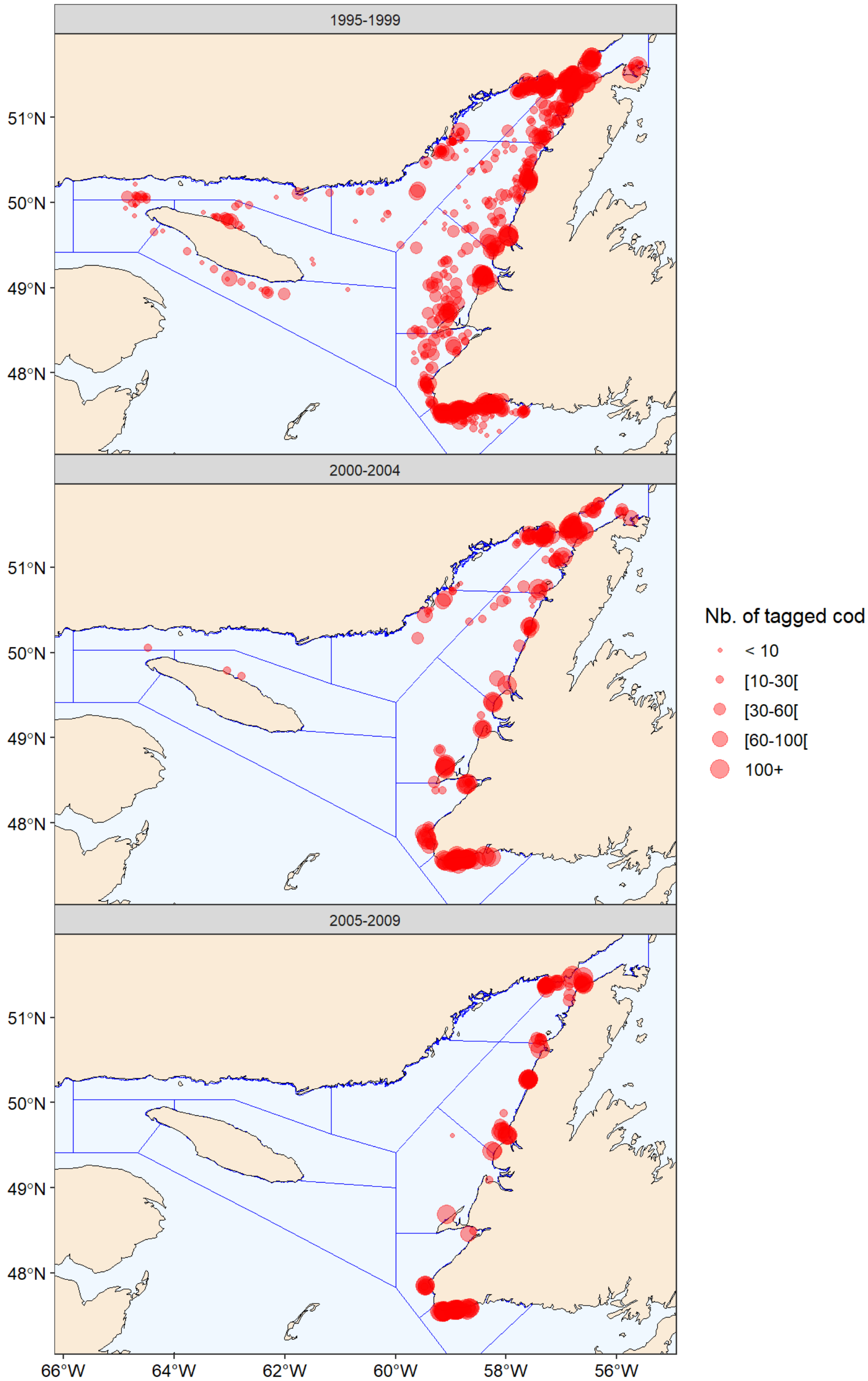

Figure 16. Distribution of tagging sites for the period 1995–2009, broken down into 5-year blocks.

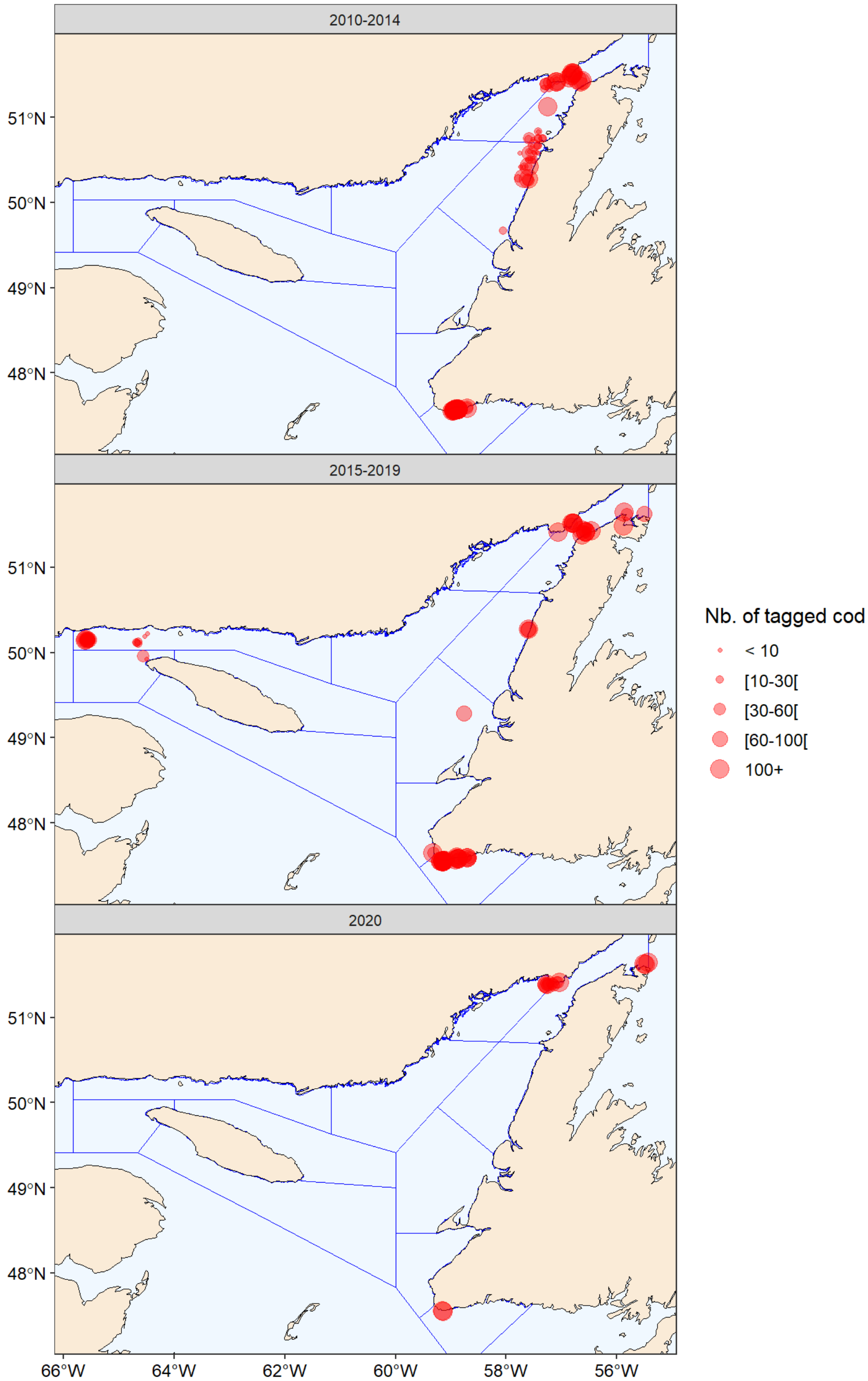

Figure 17. Distribution of tagging sites for the period 2010–2020, broken down into blocks of 5, 5 and 1 year(s).

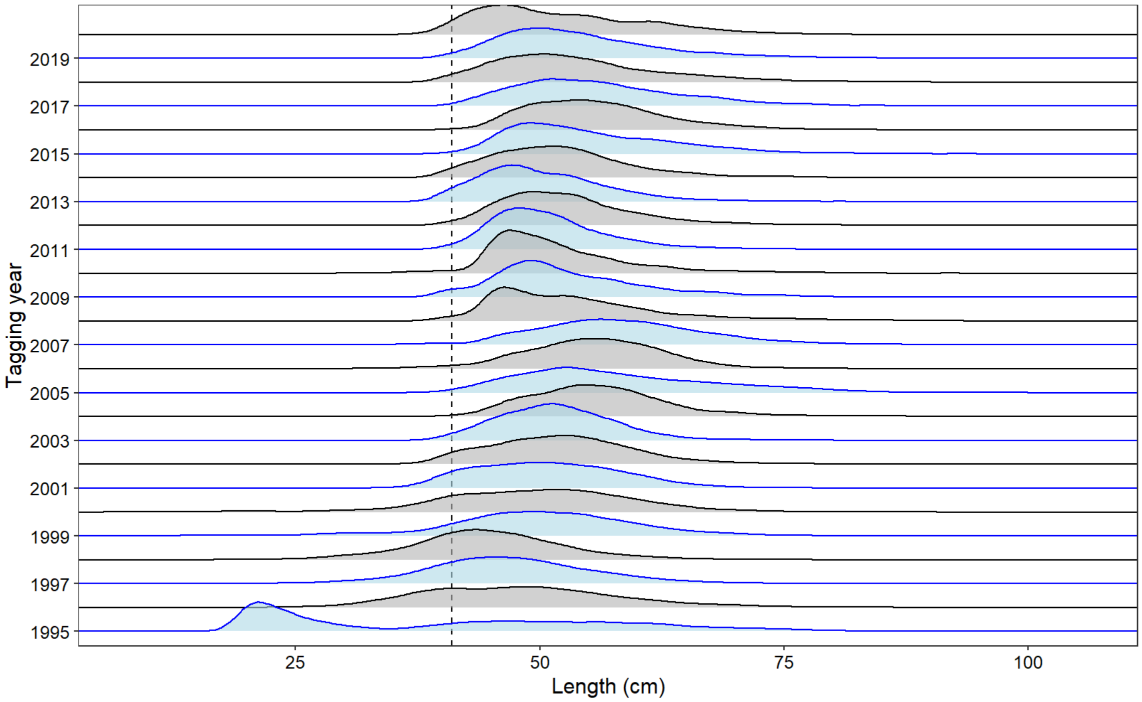

Figure 18. Length frequency of tagged cod by year of tagging. The vertical line represents the minimum legal length, i.e. 41 cm.

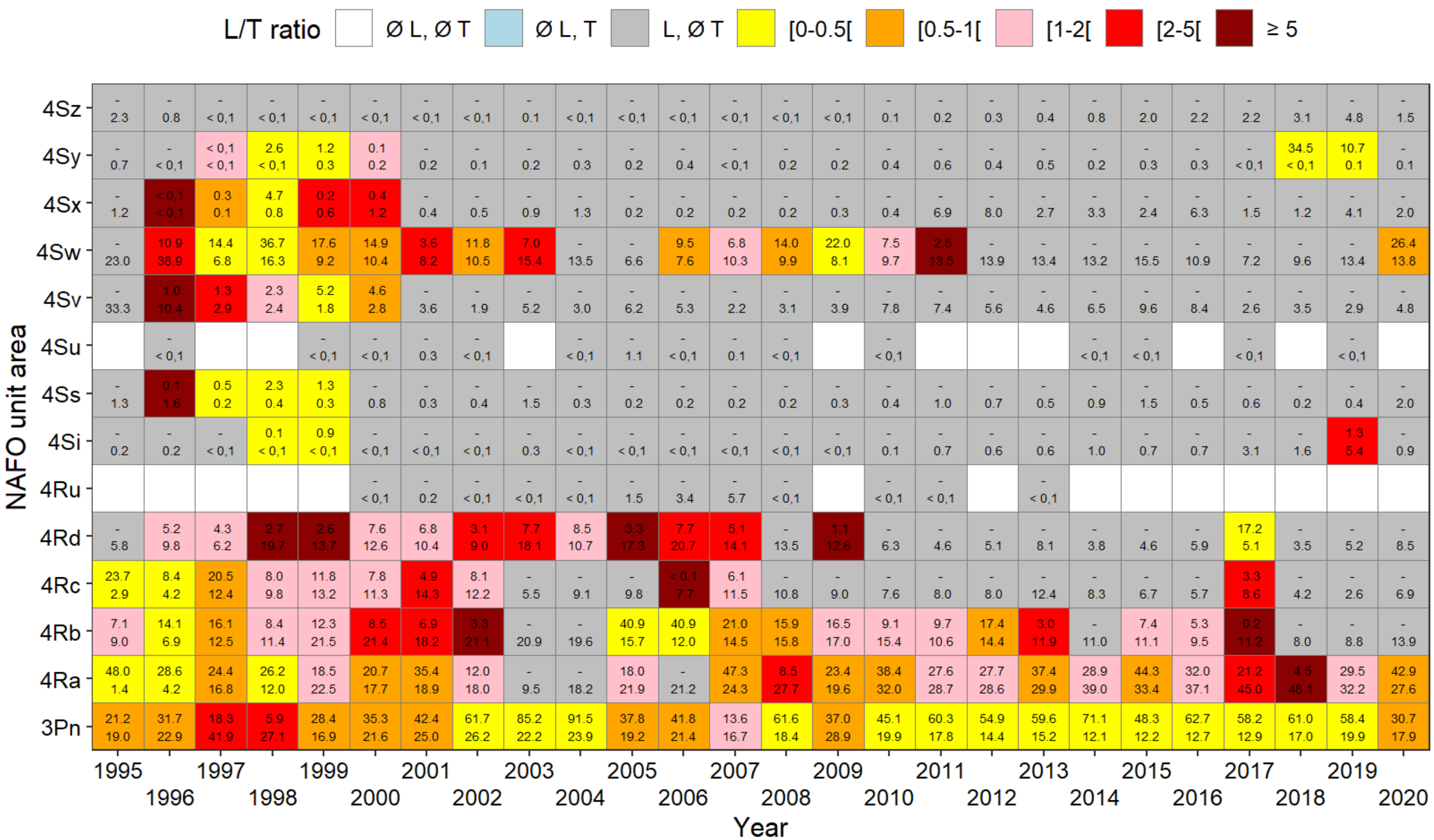

Figure 19. Comparison of the importance of NAFO unit areas in landings (L) of Atlantic cod from the 3Pn4RS stock compared to the tagging program (T), by year. The values provided in each cell are the annual percentages of landings (bottom) and tagging (top) of the total reported. '-' means that no landing or tagging (as applicable) is reported. A white cell means that no landing or tagging has taken place. A blue cell means tagging has taken place, but no landings are reported. A gray cell means that landings are reported, but no tagging. The other fill colors reflect the importance of the L/T ratio within a cell.

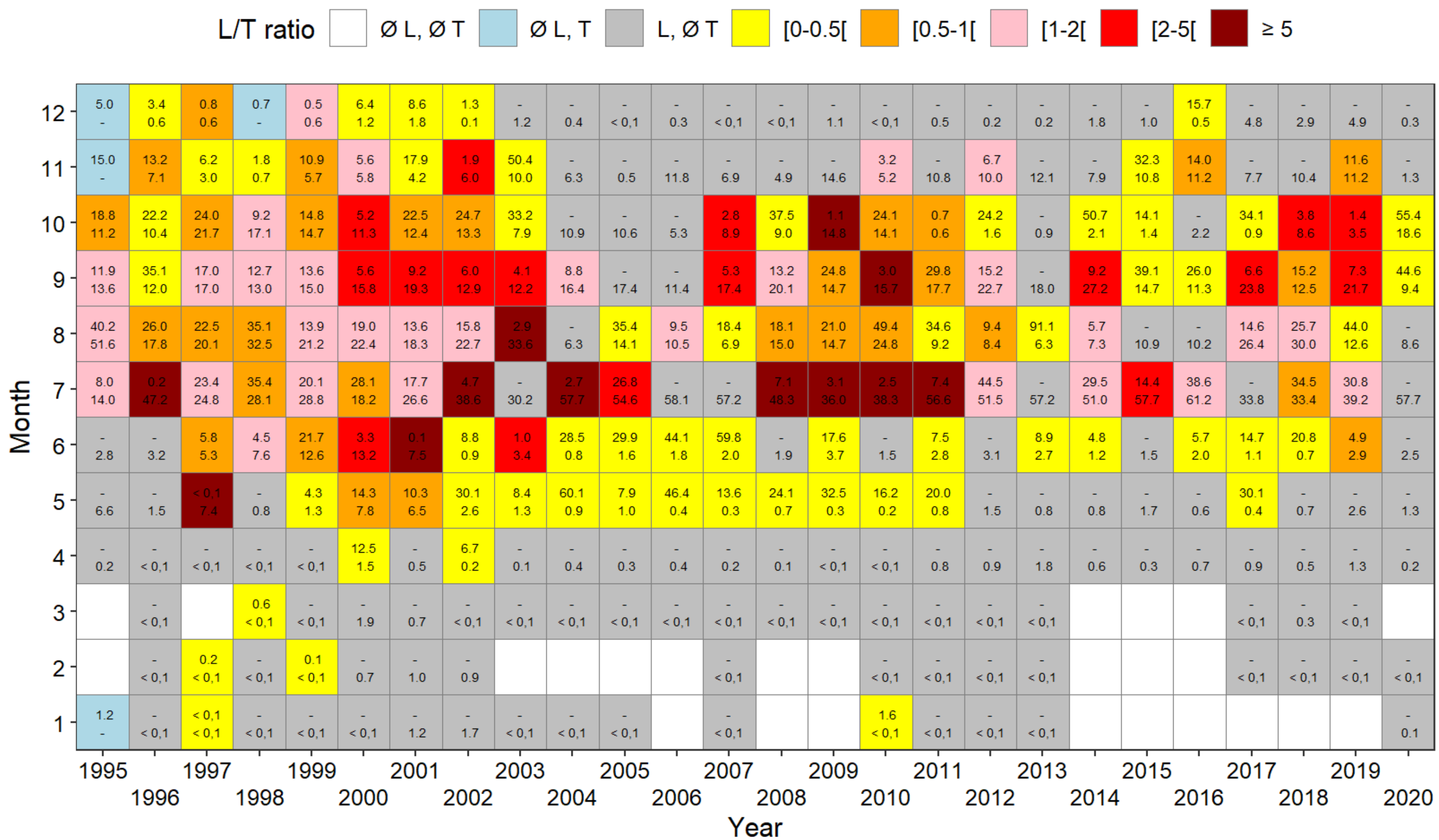

Figure 20. Comparison of the importance of months in the landings (L) of Atlantic cod from the 3Pn4RS stock compared to the tagging program (T), by year. The values provided in each cell are the annual percentages that the landings represent (bottom) and tagging (top) over the reported total. '-' means no landing or tagging (as applicable) is reported. A white cell means no landing or tagging has taken place. A blue cell means tagging has taken place, but no landings are reported. A gray cell means landings are reported, but no tagging. The other fill colors show the importance of the L/T ratio within a cell.

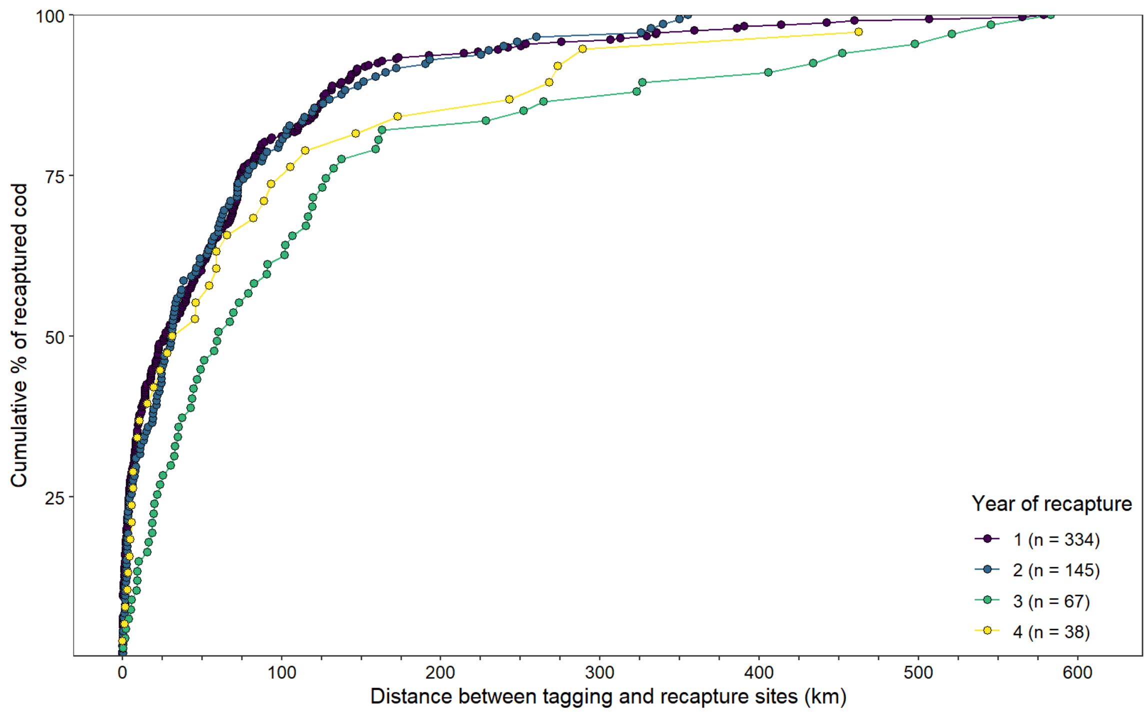

Figure 21. Cumulative percentage of cod recaptured 1 to 4 years after tagging (± 15 days) as a function of the distance from the tagging site. Numbers according to time spent at sea are provided in the legend.

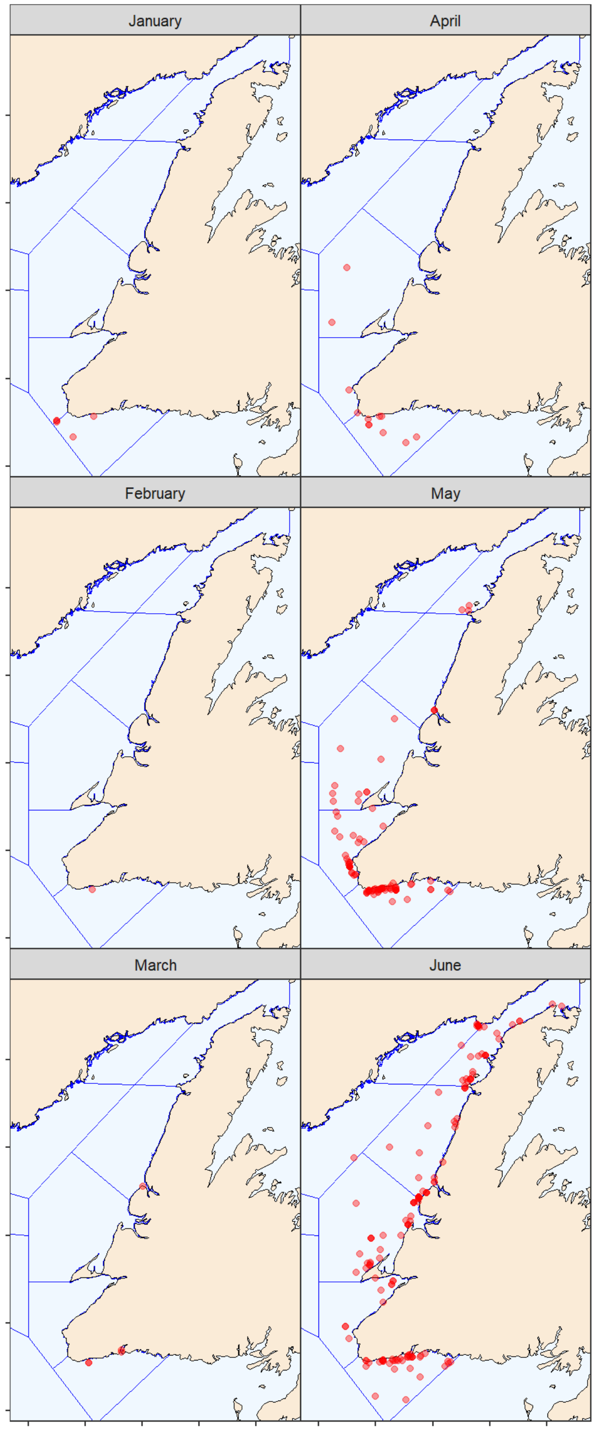

Figure 22. Cod recaptures recorded from January to June, all years combined, since the start of the tagging program in 1995. Only cod both tagged and recaptured in 3Pn4RS, and whose release time is at least 1 year, are shown.

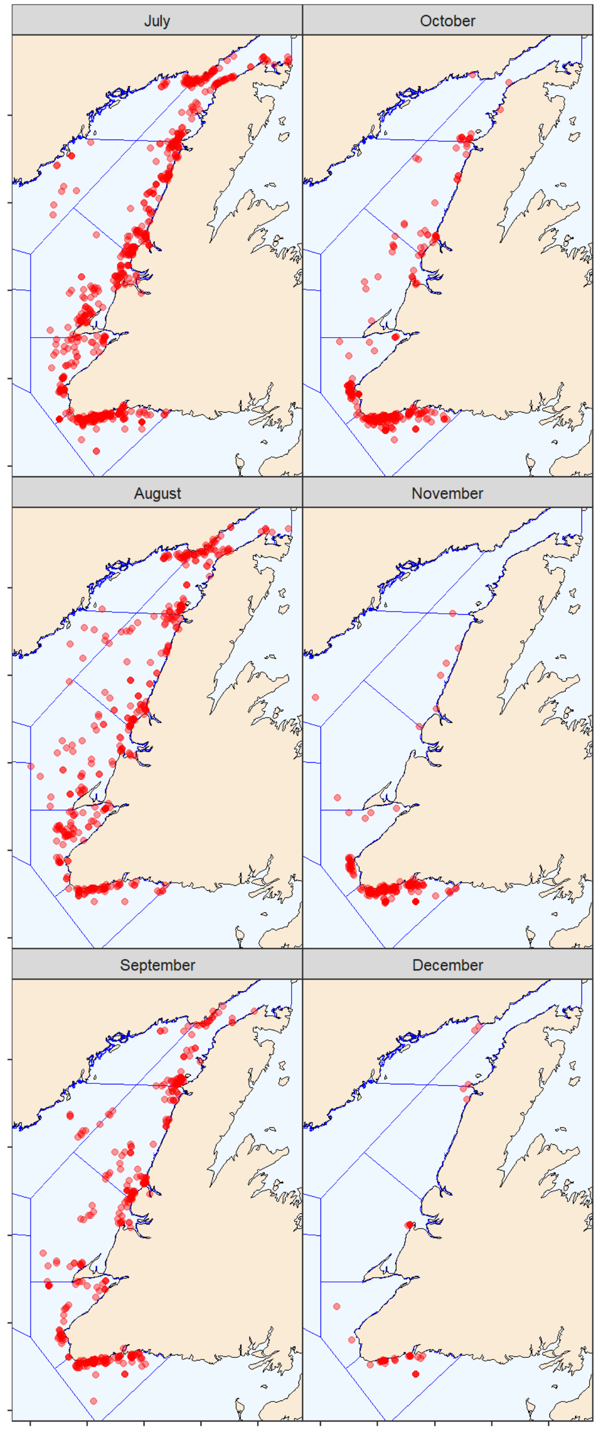

Figure 23. Cod recaptures recorded from July to December, all years combined, since the start of the tagging program in 1995. Only cod both tagged and recaptured in 3Pn4RS, and whose release time is at least 1 year, are shown.