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ARTICLE

Fishermen's Historical Knowledge Leads to a Re-Evaluation of Redfish Catch

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Abstract

A series of interviews with Canadian redfish *Sebastes* spp. fishing industry participants active in the 1980s and 1990s was conducted to determine how fish were caught, how much was caught (reported landings, unreported landings, and discards), and the sizes of fish caught during that time. Indicators of total fish catch derived from these interviews showed that reported catch may have underestimated catch by a factor of 2 or more. The proportion of small fish landed may also have been underestimated by a factor of 150–200. The re-examination of catches from interviews with fishermen can provide a useful context for interpreting population model abundance estimates for this stock. This interpretation can have implications for present-day stock assessment and fishery advice.

During the period 1984–1994, Canadian east coast groundfish fisheries and fishing communities were undergoing a large transition (Hutchings et al. 1997; Dolan et al. 2005). The rapid decline in abundance of Atlantic Cod *Gadus morhua* stocks caused a redistribution of fishing capacity to invertebrates, such as snow crab *Chionoecetes opilio*, American lobster *Homarus americanus*, and northern shrimp *Pandalus borealis*, and to other fish, most notably redfish *Sebastes* spp. (Figure 1). This occurred throughout the east coast of Canada, but the redfish fisheries in the northwestern Laurentian Channel (now Unit 1; Figure 2) and the southeastern Laurentian Channel (now Unit 2) experienced large increases in fishing effort during this period (Goetting 2008). The redfish stock was abundant through the early 1990s, but in 1995, the redfish fishery was closed in most of this area after a large decline in biomass and catch (Figure 1; Duplisea et al. 2016).

During the redfish fishery expansion period (~1985–1993), redfish were not as valuable as Atlantic Cod, but profits could be made in fishing redfish because they were easier to catch than Atlantic Cod for the same effort. Redfish tend to cluster tightly together, so even low levels of fishing effort could yield large catches. This meant that redfish fishing could be profitable even with low prices compared to the much better prices for Atlantic Cod at the same time. Price also varied regionally and was highest in Nova Scotia (NS), lower in Prince Edward Island (PEI) and then Newfoundland (NL), and lowest on Les Îles-de-la-Madeleine (IdM; Quebec [QC]). Price was probably related to the difficulty of getting fish to markets (mostly northeastern USA, midwestern USA, and Florida) from these locations. The difference in price may have set up different incentives for fleets out of different ports in terms of the amount and size of fish landed or discarded.

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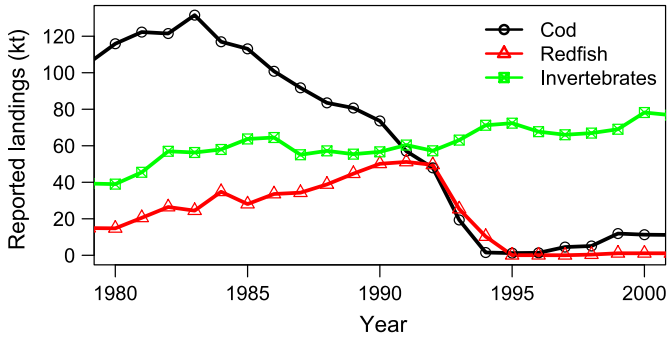

FIGURE 1. Reported Canadian fleet landings of Atlantic Cod, redfish *Sebastes* spp., and the main fished invertebrate species in Northwest Atlantic Fisheries Organization (NAFO) areas 3P4RSTV, which encompass the Unit 1+2 stock area. Landings are from the NAFO STATLANT database (www.nafo.int).

Redfish in the region at that time were relatively abundant due to large cohorts from 1972 and 1980–1981. An abundance of small fish from the large 1985 and 1988 cohorts (Valentin et al. 2015) may have suggested to fisheries managers at the time that the increased fishing mortality was not leading to recruitment overfishing. Recruitment overfishing is the phenomenon of catching so many fish that the spawner biomass is not large enough to replenish the stock (Hilborn and Walters 1992). In theory, good fisheries management is risk averse to recruitment overfishing (Myers et al. 1994). Observation of large cohorts in the 1980s led scientists and managers to believe that redfish stocks were healthy since so many juveniles were present. Therefore, total allowable catch limits set by management were not restrictive, and there were few regulations to protect small fish or mating aggregations in the fall or to protect fish that were ready to release live larvae in the spring. The lack of restrictions on the fishery meant that one company invested in three large, 41-m (134-ft) trawlers in 1989 and 1990 (East Isle Shipyard, Georgetown, PEI; Usen trawler order numbers 812096, 812157, and 813757), suggesting that the company's

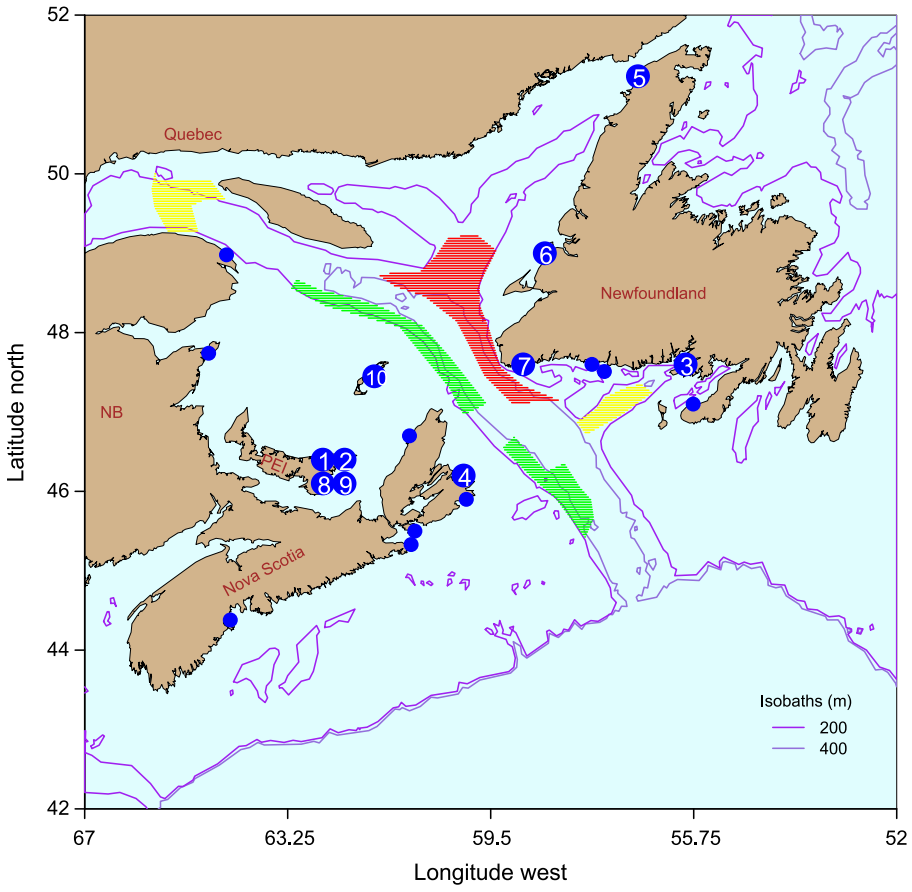

FIGURE 2. Map of Unit 1+2 redfish management areas and locations of fishermen interviewed in this study. The numbered points represent ports explicitly represented by an interview (see Table 1), but other known redfish ports (points not numbered) may also be partially represented by interviews. Most of the fishing occurred at depths between 200 and 400 m. The red-shaded area was the main fishing area in terms of effort and catch, while considerable effort was focused on the green-shaded area; the yellow-shaded areas were tertiary areas in terms of effort during the 1988–1992 period (after Power 2003).

TABLE 1. Fisherman number, location, date of interview, and fishery role of each individual surveyed in the present study (PEI = Prince Edward Island; NL = Newfoundland; NS = Nova Scotia; QC = Quebec).

Fisherman number	Fisherman's present location	Date of interview (in 2016)	Role in the redfish fishery during the 1980s and 1990s
1	Souris, PEI	Jan 15	Crew on large (24-m [80-ft]) trawler
2	Souris, PEI	Jan 18	Processing plant worker
3	Gaultois, NL	Jan 22	Refrigeration in plant and trawler crew
4	North Sydney, NS	Feb 8	Crew on large (38-m [125-ft]) trawler
5	Anchor Point, NL	Feb 9	20-m (65-ft) trawler skipper
6	Benoit's Cove, NL	Feb 9	20-m (65-ft) trawler skipper
7	Isle aux Morts, NL	Feb 12	20-m (65-ft) trawler skipper
8	Souris, PEI	Feb 12	17-m (55-ft) trawler skipper
9	Souris, PEI	Feb 12	Shore skipper
10	Îles-de-la-Madeleine, QC	Feb 15	Crew and skipper on large (38-m [125-ft]) trawler

business plan did not predict the fishery closure that would occur only a few years later.

Department of Fisheries and Oceans (DFO) catch statistics from the period 1984–1994 showed large increases in reported catch (DFO 2010) but nevertheless may have underestimated the total catch and proportion of small fish caught during that period since redfish fishing capacity was increasing quickly. In the present study, rough total catch statistics were developed from interviews with industry participants that were active during the 1980s and 1990s. I then compared the interview-based statistics to the reported catch statistics held by DFO. The minimum likely catch derived from these interviews was always larger than the reported catch and was assumed to be less than total catch (see definitions below). Although the minimum likely catch is not considered a good way of correcting reported catch statistics held by DFO, this information is valuable in aiding the interpretation of catch statistics, stock status, and assessment model output for that period. Previous analyses have shown that an understanding of redfish dynamics during the 1984–1994 period is key to estimating current redfish stock production (Duplisea et al. 2016) and can have a large influence on developing realistic projections and setting reference points for the stock going forward. In other words, there are present-day implications for considering that actual catches in the 1980s and 1990s could have differed from reported catches.

Background on Redfish Biology

Redfish *Sebastes* spp. are long-lived, slow-growing bony fishes with a wide distribution in the North Atlantic. Redfish have populations along the entire east coast of Canada well up into Arctic waters. They commonly live to 40 years old, and 70-year-old individuals can be found (Campana et al. 1990). Redfish attain average maximum sizes of only about 45 cm, and they do not reach fishable sizes (at least 22 cm; i.e., recruitment to the fishery) until about 7–10 years old. Commercial fisheries catch comprises mostly 10–14-year-old fish (Duplisea et al. 2016). Redfish have a rare reproductive strategy for a marine fish in that copulation occurs in the autumn, sperm is stored internally by the female over the winter, eggs are fertilized in the late winter, and then live larvae are released in the spring (St-Pierre and DeLafontaine 1995). Fisheries management plans often try to protect the reproductive period of fish; however, it could be argued that the redfish reproductive period lasts 6 months centered in the winter. The winter was historically an important period for the redfish fishery.

Redfish stocks in the Laurentian Channel area contain two sympatric species: the Acadian Redfish *Sebastes fasciatus* and the Deepwater Redfish *S. mentella*. These species have very similar biology aside from some difference in mean maximum size and small differences in growth rate (Cadigan and Campana 2016). The commercial fishery targets the two-species aggregate, which is reported as "redfish catch." The DFO has conducted an annual survey on portions of these stocks since 1984, and the species are distinguished in the survey through the technique of counting anal fin rays (Ni 1981) on 200 randomly selected fish from each fishing survey haul.

METHODS

Definitions.— In this paper, "minimum likely catch" is defined as the biomass of redfish killed in fishing operations, estimated by summing the recollections of catch by fishermen recorded in interviews. It represents only a portion of the Canadian fishing operations and does not

include foreign fleet catch, and care was taken not to double-count; therefore, it is considered a minimum estimate. "Reported catch" is defined as the biomass of redfish caught that was reported to governments and compiled by DFO and resides as the official catch record. Reported catch includes both Canadian and foreign catch. "Total catch" is defined as the total biomass of fish caught (and killed) in fishing operations, which includes reported catch, unreported catch, and discarded fish. Sometimes total catch is specified to be derived from interviews, while all other instances refer to this primary definition. "Unreported catch" is defined as the total catch less the reported catch. "Catch composition" is defined as the numbers of individuals in the catch that belonged to various length-classes; here, catch composition is often reported as a percentage of fish above or below a certain size threshold. Similar to the definition of catch, the catch composition can refer to reported, unreported, or total catch.

Development of the interviews.— The general term "fishermen" is used throughout this paper in reference to the fishing industry-based interviewees. Some of the interviewees were crew on boats, some were skippers, and others worked in processing plants. No women were interviewed, as none was found as a contact; therefore, a gender-neutral term is not used here.

Establishing contacts.— In September 2015, I wrote a letter to the editor of *The Navigator* magazine (an Atlantic Canadian fishing industry magazine based in St John's, NL) asking for anyone who fished redfish during the 1990s or before in Units 1 and 2 (hereafter, "Unit 1+2") to contact me and share their observations of the fishery. From this, two responses were received. The first was an inquiry into the current state of redfish, and the second was a fisherman who worked out of Souris, PEI, during the 1980s and 1990s. This interview provided a considerable amount of information and another contact. Jason Spingle of the Food, Fisheries, and Allied Workers (FFAW) was an important source for key redfish industry players on the west coast of Newfoundland. The interview representing Gaultois, NL, was set up by calling the local hotel and asking if there were individuals in the town who were associated with the redfish fishery in the 1980s. The receptionist at the hotel suggested a valuable source who worked in the Gaultois fish plant during that period. Kevin Squires of North Sydney, NS, provided a contact that became the North Sydney interviewee.

Interviews.— All interviewees were told that the purpose of this work and interview was to try to better understand the nature of the fishery and catch during the 1980s and 1990s. It was also explained that DFO assessment model fittings on these stocks could not properly explain the decline in the survey population trend with the reported catch. I kept interview notes, but there were no other records of the interviews. All interviewees were asked if it was permitted to use the information they provided, and all responded positively. I have kept the interviewees anonymous here, but they are identified by their home port and role in the fishery. No ethics consent forms were developed for this series of interviews.

Interviews were relatively free form, which allowed the interviewees to discuss their observations of the fishing, operations, catch, processing, and prices. At points during interviews, questions were asked to glean particular types of information, such as

1. How big was the vessel you fished
2. What was the hold capacity of your vessel
3. What gear type did you use
4. Was all the catch landed
5. Where did you land most of your catch
6. Did you fish all year long or for how much during a year
7. When did you fish: years, seasons, time of day
8. Where did you fish
9. What was your weekly/annual catch at different periods
10. Was the catch composition different between periods
11. How much of the catch was large fish versus small fish
12. Were there different prices for the catch based on size composition
13. Do you know what happened to the fish once they were taken in at a plant

This study is not presented as a thorough or methodologically ideal survey of fishing industry participants for that period. There were few interviewees, and many of the industry participants from the 1980s/1990s period have since died; however, the range of roles in the fishery covered by the interview group is an asset. It is believed that the main differences within the total stakeholder group is related to vessel size and possibly distance from markets, and both of these aspects were covered by the interviews. It is estimated that about 10–12 large trawlers and between 60 and 100 small trawlers operated during the most productive fishing period. Between the interviews with fishermen and the different kinds of processing plant workers, I believe that I have attained a representative overall picture of the fishery catches, which still likely underestimate the actual catches taken.

There is a trade-off between the level of formalization of interviews designed to address specific needs and still allowing room for unanticipated insights. The interviews were aimed at questions that were more factual/quantifiable (e.g., size of the boat, number of trips per week) and could be used to develop quasi-quantitative indicators of catch. During interviews, most interviewees added insights

on fishing operations that often proved useful—for example, many of the warnings from the industry on future fishing strategies to protect reproducing fish.

Analysis.— Industry participants were interviewed from the major ports surrounding the main redfish fishing areas (Figure 2). In cases where quantitative information was provided through interviews, an estimation of catch was made for comparison with DFO data. General observations of interviewees were noted where a common theme was found and where there was a contrast between interviews representing different locations.

RESULTS AND DISCUSSION

Interview Group

There were 10 responses in the present study. These interviews covered the most important fishing areas of Unit 1+2 in the 1980s and 1990s (Figure 2; Table 1). Two of the largest centers for redfish processing (Souris, PEI; and IdM, QC) were captured through interviews. Fishermen working on large boats as crew or skipper, small-boat owners, and processing plant workers were included as interviewees. The interviews may not cover all the processing ports, where other industry participant views may have been found (Figure 2; ports with small dots). However, since there was good spatial coverage of ports represented by interviews (Figure 2) and since interviews covered all the main fishing grounds, it is unlikely that increased port coverage would have significantly changed the overall results of the interviews.

Quantitative Catch Information

Total catch.— Questions related to annual catches were easily recalled by boat operators as well as shore-based processors. The unit price of redfish was easily recalled by all fishermen, as well as their "average" annual catch weight, weekly catch rates, times of year fished, and many other aspects of catch that enabled the estimation of total catch for each fisherman, port, or region. These recollections were from memory, but given the special nature of redfish fishing operations, they can be considered reliable. For example, it was rare for a boat to return to port with any remaining hold capacity; therefore, unloading at port represents a constant increment in catch. Trip length and time at port varied little for a boat, so the number of trips multiplied by boat capacity is a good indicator of total annual catch for that boat. Most fishermen knew how many boats operated out of their port and had a good idea of how many were fishing the main fishing areas. It is therefore not difficult to extrapolate interview information over the whole fishery. This situation differs from that of the Atlantic Cod fishery, as cod catches varied regionally and a wider variety of fleet sectors targeted cod, which would make it more difficult to extrapolate in this way.

The 20-m (65-ft) boat owner/operator interviews converged on about 60 boats operating in the main fishing group off Port au Basques during the late 1980s and early 1990s, then declining to six boats (Table 2). This small boat fleet was mostly based in NL, and most of these boats fished the same way. Because there were fewer large trawlers, it is more certain how many were fishing in different periods and their home ports. Processing plant workers and harbor skippers often had a good overview of total catch processed as well as size composition and what happened to the catch once graded. Processing plant workers gave a wider overview of the processed catch than boat operators since all of the landed catch was funneled through the plants. Interview 3 was particularly interesting, as that industry worker was specialized in refrigeration at the processing plant and had a very good idea of how much product entered and exited the freezing units on an average day.

Plant workers revealed the changes in size composition of landed catch over time from relatively large fish until about 1985, with progressively decreasing fish sizes thereafter. By the 1990s, more than 50% of the catch weight consisted of fish smaller than 15 cm. It is possible that for some processing plants, these small fish were treated in the same way as carcasses, and therefore the small-fish biomass may not have been reported in total catch statistics. Plant workers were aware of the processing efficiency as a point of pride. Efficiency varied between 32% and 34% of fish by weight going into filleting machines (supplemented by hand-cutting) coming out as frozen product.

On the whole, few fishermen reported small-fish discarding as a common practice, but it was more prevalent in some areas than others. Fisherman 1 reported that vessels never came home empty, and if only a small amount of fish was needed to top-up a vessel's hold, then another haul was made and the excess was dumped. The practice of "topping up" probably did not lead to a large amount of discards relative to total catch, but given the short duration of some trips (2–3 d) and year-long fishing (i.e., possibly 100 trips/year), it may not have been negligible. Fisherman 10 noted that prices for small fish were so low by the 1990s and small fish were so dominant in the catch, a discarding rate (by weight) of 50% (two hauls to get one good haul) was common.

With these observations and caveats, a total catch from each interview was calculated (Table 2). Sometimes this applied only to a single boat, other times to a port, and sometimes to a much larger part of the Unit 1+2 area. The 20-m (65-ft) vessel fleet landed just over 900 metric tons (2×10^6 lb) each per year from about the mid-1980s until 1994, while the large vessels (>38 m [>125 ft]) landed about six times as much (5,443 metric tons

TABLE 2. Summary of information from interviews with fishermen that could be used to derive quasi-quantitative information on redfish *Sebastes* spp. catch and catch composition in Unit 1+2 during the 1980–1995 fishing period. More significant digits are reported than would be expected from such an analysis, but these values reflect conversion from imperial to metric units, so the large number of significant digits is a reminder of this conversion. Northwest Atlantic Fishing Oragnization (NAFO) zones are referred to with alpha-numeric combinations (www.nafo.int).

Interview number	Base information	Pertains to	Quasi-quantitative summary	
			Total catch	Catch composition
1	68-metric ton average capacity over all vessels; 3Pn, 4Vn; 40 trips/year, 17 boats; 10% of fish biomass was less than 20 cm; no discarding	Cabot Strait area	46,240 metric tons/year, 1980–1993, especially 1986–1993	Important numbers of small fish in the catch
2	Plant processed an average of 317.5 metric tons/week; plant processed about 35% of all redfish caught in region; 20% of fish by weight less than 15 cm, no discarding	Cabot Strait area	47,097 metric tons/year, 1980–1993, especially 1986–1993	Important numbers of small fish in the catch
3	Plant processed an average of 317.5 metric tons/week; plant operated 9 months/year; by 1991 and after, 50% of biomass of fish smaller than 17.5 cm went to meal, no discarding	Cabot Strait area and SW Newfoundland	12,383 metric tons/year, 1986–1994	Important numbers of small fish in the catch
4	Average hold capacity of boats was 181.4 metric tons; half time spent fishing in 3NO and half spent in 3Pn, 4R; 10 boats, 12-d trips, 2 d in port, fished all year; no discarding	Cabot Strait area and SW Newfoundland	23,650 metric tons/year, 1986–1993	Unimportant catch of small fish
5	Boat landed 907 metric tons/year; six 20-m (65-ft) boats fishing 1992–1995	Cabot Strait area and SW Newfoundland	5,443 metric tons/year, 1992–1995	Unimportant catch of small fish
6	Boat landed 907 metric tons/year; sixty 20-m (65-ft) boats fishing 1986–1992; six 20-m boats fishing 1993–1995	Cabot Strait area and SW Newfoundland	54,420 metric tons/year, 1986–1992; 5,443 metric tons/year, 1993–1995	Unimportant catch of small fish
7	907 metric tons/year per boat; sixty 20-m (65-ft) boats fishing 1989–1993	Cabot Strait area, SW Newfoundland, and S Newfoundland	54,420 metric tons/year, 1989–1993	Unimportant catch of small fish
8	907 metric tons/year per boat; sixty 20-m (65-ft) boats fishing 1990–1995; six boats fishing after 1995	Cabot Strait area	54,420 metric tons/year, 1990–1995; 5,442 metric tons/year after 1995	Unimportant catch of small fish
9	Plant processed 16,329 metric tons/year, 1989–1993	Cabot Strait area and SW Newfoundland	16,329 metric tons/year, 1989–1993	Unimportant catch of small fish
10	Plant operated five 41-m (134-ft) vessels and one 34-m (110-ft) vessel from early 1980s to 1993; from 1981 to 1985, one 41-m vessel landed 2,721 metric tons/year and the 34-m vessel landed 2,267 metric tons/year; from 1986 to 1987, each landed twice as much as earlier period; from 1988 to 1994, 50% discarding rate by weight at sea for fish smaller than 20 cm	Gulf of St. Lawrence and Cabot Strait area	18,185 metric tons/year, 1980–1985; 36,287 metric tons/year, 1986–1987; 72,575 metric tons/year, 1988–1994	Important catches of small fish

[12×10^6 lb]) each per year (Table 2). In the earlier period from about 1980 to 1985, catches were approximately 50% of those in the latter period, but the latter period involved more discarding and meal production owing to an increased proportion of small fish in the catch.

Minimum likely catch for the Unit 1+2 area (Figure 3) was calculated as the sum of catch estimates from selected responses. The included responses were selected so that as much of the catch as possible was included but double-counting was avoided. The selected responses were from (1) Fisherman 3 (Gaultois, NL), who described the total processing plant incoming and outgoing product from refrigeration units and represented much of the easterly Unit 2 catch, including the Hermitage Channel; (2) Fisherman 4 (North Sydney, NS), who described large-boat capacity, number of boats, number of trips, and proportion of time fishing in Unit 2; (3) Fisherman 6 (Benoit's Cove, NL), who described the Newfoundland 20-m (65-ft) fleet annual landings per boat and the total number of boats fishing at that time; (4) Fisherman 9 (Souris, PEI), who described total processing plant incoming product; and (5) Fisherman 10 (IdM, QC), who knew boat capacity, number of boats, and number of trips as well as total processing plant incoming product.

This calculation suggests that the early 1980s catch was about 54,000 metric tons, peaking at about 180,000 metric tons in the first 3 years of the 1990s and then dropping quickly thereafter (Figure 3). This interview-derived catch estimate is termed the "minimum likely catch" for several reasons. First, it does not include all landings at Lunenburg and Canso, NS. Second, it does not include any landings at ports in Shippagan, New Brunswick; Riviere-au-Renard, QC; Louisbourg, NS; Petit-de-Grat, NS; or Cheticamp, NS. The Shippagan fleet in particular consisted of at least two large (38-m [125-ft]) vessels, which could have taken many fish (i.e., IdM boats of the same size took 5,443 metric tons/year each). Third, it probably captures only a portion (though an important portion) of the fish landed at the important redfish landing ports of Burgeo, Ramea, and Grand-Bank, NL. Fourth, some fleet sectors reported no catch or discarding of small fish, while other fleets fishing at the same time and sometimes in the same areas reported discard rates of up to 50%. Finally, it does not include any non-Canadian catches.

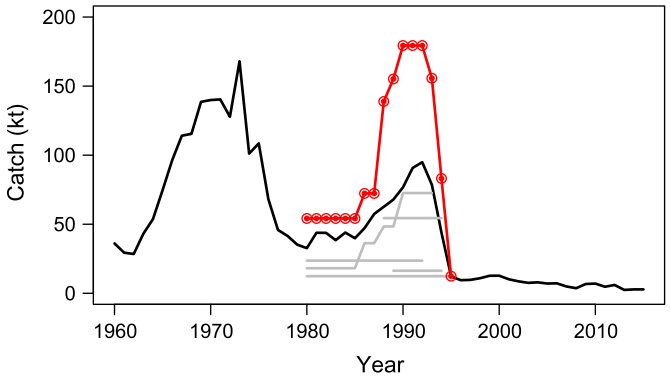

FIGURE 3. Catch (kt = thousands of metric tons) of Unit 1+2 redfish. Reported catch (Canadian + foreign) is represented by the solid dark line over the whole period. Individual fishermen's catches established from the interviews are represented by the light-gray solid lines; the line with symbols is the minimum likely catch (Canadian), estimated as the sum of catches established from the interviews of selected fishermen to avoid double-counting.

These estimated values for minimum likely catch were quite similar to reported catch in the first half of the 1980s (Figure 3), but by 1990, they were more than twice the reported catch, and if correct, they would be the highest catches since statistics began in 1960.

Catch composition.— The DFO catch statistics (reported catch) show only a very small percentage of catch consisting of fish smaller than 20 cm (Figure 4), peaking at 2.5% (by number) in 1993 and demonstrating a lesser peak at 1.4% in 1987. Fishermen 1, 2, 3, and 10 reported that from about 1986 to 1990, approximately 20% of the catch by weight was made up of fish smaller than 20 cm; after 1990, this could have been as much as 50%. I assumed that a "large" fish (>20 cm) had a mean length of 23 cm and a "small" fish (<20 cm) had a mean length of 15 cm. With this assumption, the catch abundance derived from interviews would have been about 48% small fish (<20 cm) from 1986 to 1990 and 79% small fish from 1991 to 1994 (Figure 4). Assuming different mean sizes for small (15–19-cm) and large (23–30-cm) fish changes the abundance percentage calculation by ±10%. Clearly, the redfish catch composition data held by DFO for Unit 1+2 do not properly account for the amount of small redfish that were actually killed in fishing operations during the period of interest.

Gear Selectivity and Discarding

All of the fishermen noted that there were changes in gear technology and fishing methods during the 1980s. Traditionally, the redfish fishery was conducted with a bottom trawl, and this continued up until the mid-1980s. However, from the early 1980s, the midwater "diamond" trawl became more commonly used and at least doubled the catch rates of a bottom trawl. Bottom-trawl fisheries were often inefficient at night since redfish tend to migrate up in the water column at night and were therefore less catchable by bottom trawls. Bottom trawling at night therefore can lead to more bycatch to obtain the same amount of redfish. Sometimes, fishing operations were only conducted during daylight hours to minimize bycatch, and the best bottom-trawl catches of redfish seemed to occur between 1100 and 1400 hours. In 1986, the larger trawlers began using a midwater trawl that was referred to as the "turbo trawl." This gear was reported in interview 1 as 5–10 times more efficient

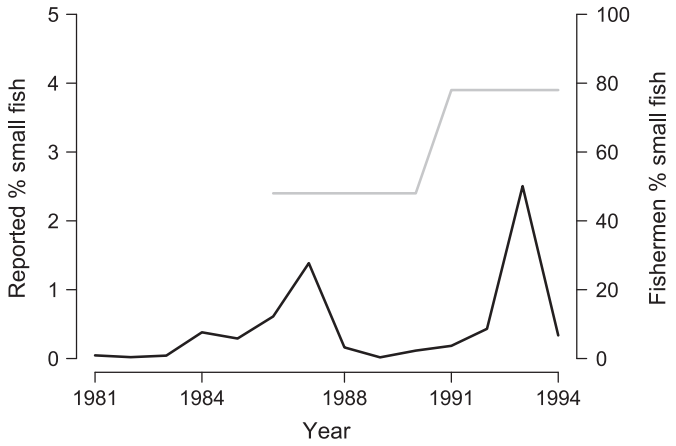

FIGURE 4. Redfish catch composition (percentage of captured redfish that were small [<20 cm]) according to the official catch statistics (left *y*-axis, black line) and as reported by fishermen in interviews (right *y*-axis, gray line).

than the bottom trawl and could be successfully fished 24 h/d by adjusting where it fished in the water column. The turbo trawl had a low bycatch of other species, but because it was a midwater trawl, it likely had a greater selectivity for smaller redfish, which tend to be concentrated higher in the water column than large redfish (Ian McQuinn, DFO, personal communication).

By 1986, the Atlantic Cod fishery in the northern Gulf of St. Lawrence was in quick decline, and Atlantic Cod fishing capacity was switching to the redfish and invertebrates. This changing effort coincided with year-round fishing for most redfish operations. When the Gulf of St. Lawrence became too icy in winter, fishing effort moved mostly to the more southern parts of the Laurentian Channel in Unit 2. For the processing plant in Souris, PEI, the harbor became too full of ice to be usable, so the Souris boats would land their catch in Mulgrave, NS, and transport it to Souris for processing (interviews 1 and 2).

It appears that a change in fishery selectivity may have occurred around 1986 for several reasons: (1) an increase in capacity of the redfish fishery by adopting part of the declining capacity of the Atlantic Cod fishery; (2) introduction of the highly efficient midwater turbo trawl gear, which allowed 24-h fishing and possibly increased catch of smaller fish that were more concentrated in midwater; and (3) a year-round fishery, with much of the effort from the Gulf of St. Lawrence moving into the southern Laurentian Channel in winter. After 1994, selectivity changed again due to the dismantling of much of the mobile groundfish fleet, especially in Unit 1 (Murray et al. 2008).

Other Observations of Fishermen

Most fishermen noted that at the time, they were uncomfortable with the amount and kind of fishing being allowed on redfish; however, because it was a competitive fishery, they felt that individual actions were futile. All noted the "devastating" effect on the redfish stocks from the introduction of the midwater trawl. Fishermen noted that in spring, the freshly caught mature fish leaked a thick layer of larvae over the boat decks. They felt that this interference with reproduction seemed detrimental to the stock. Occasionally, they were instructed to move elsewhere by DFO, but sometimes this just displaced effort to small fish in another area. Because price differentials for landed catch based on composition began to be introduced in the late 1980s by processors (as noted in several interviews), an incentive for discarding was set up. This was not because quotas were limiting but rather because it was not worthwhile bringing a low-value catch to port. This was particularly true for IdM, where prices were lower than elsewhere. Price differentials between regions and sizes of fish may have provided the incentive to discard.

Fishermen reported knowing how and where to select larger fish, although those areas did not always produce the large yields necessary to support their operations. Large catches of mixed sizes of fish were brought to port, particularly when fishing occurred on the prime winter fishing grounds close to Port au Basques, NL. The difference in prices based on fish size introduced in the late 1980s may have changed this practice, leading to greater discarding at sea.

Impact on Population Trends

This work suggests that the total catch of both redfish species was larger than the reported catch in the 1980s and 1990s, particularly between 1986 and 1994. It is known that there were strong cohorts of Deepwater Redfish from the early 1970s and early 1980s, and these supported the large-fish fisheries in the mid-1980s and early 1990s. These large fish, however, were scarce by 1994, but abundant year-classes of young Acadian Redfish from 1985 and 1988 were present. It may be that increased fishing effort beginning in 1986 removed the larger mature Deepwater Redfish from the stock area, while captures of young fish (many <20 cm) by 1990 primarily affected the Acadian Redfish.

One of the enigmas of redfish in this area is the phenomenon of "disappearing" cohorts of Acadian Redfish (Valentin et al. 2015): that is, some Acadian Redfish cohorts tend to be present in the Gulf of St. Lawrence (Unit 1) until age 3–4 and then are no longer found in the Unit 1+2 area but partially appear as larger fish in the more eastern shelf-edge waters off the Grand Banks (Gascon 2003). These cohorts also do not carry the genetic signature of Unit 1+2 Acadian Redfish (Valentin et al. 2015). The 1988 year-class of Acadian Redfish was one of these cohorts (Morin and Hurtubise 2003). By 1993, the 1988 cohort of Acadian Redfish was hardly apparent above the background numbers of 5-year-olds in the Gulf of St. Lawrence. Interestingly though, Fisherman 3, who represented a large part of the catch from Hermitage

Channel (the channel extending southwest from Gaultois, NL; Figure 2), reported much larger numbers of small redfish in the 1990s. Power (2003) cited the paucity of fishermen's logbook data for the Hermitage Channel area, which could have been used to corroborate or refute evidence of the catch of smaller redfish (perhaps the 1988 cohort). This increase in small-redfish catch in Unit 2 during the time those redfish disappeared from Unit 1—and a lack of logbook information to contradict it—could be a result of the fishery around Hermitage Channel intercepting this eastward-migrating cohort.

Conclusions

Based on the present findings, the following conclusions can be drawn. Total catch statistics for redfish in Unit 1+2 from the late 1980s and early 1990s should be interpreted cautiously and, at best, as minimum estimates of total catch. The proportion of small redfish (<22 cm) killed in fishing operations during the 1980s and 1990s was many times higher than what was reported in official landings statistics. Explaining the decline of the 1980–1981 cohort of Deepwater Redfish is the key leveraging process in assessment model fitting for this stock (Duplisea et al. 2016), whereas this is the cohort most affected by catch misreporting, as explored here. Assessment model fitting for these stocks needs to account for the potential misreporting from 1986 to 1994, if only by allowing increased uncertainty and increased catch residuals for this period. Catches should not be retrospectively corrected through the present analysis, but alternative sensitivity runs for assessment modeling should consider catch misreporting scenarios from 1986 to 1994. Effective port and sea sampling procedures to determine redfish catch and composition are required for future population modeling efforts, and this is pressing given the very large 2011–2013 redfish year-classes in the water presently.

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