Temporal changes in harvesting dynamics of Canadian inshore fisheries for northern Atlantic cod, *Gadus morhua*[1]

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Abstract: We quantified temporal changes in catch rate, fishing effort, and catch misreporting for two sectors of the fixed-gear fishery for Newfoundland's northern Atlantic cod, *Gadus morhua*, from 1980 to 1991, the year preceding the stock's commercial fishing moratorium. Over the 12-year period, fishermen reported catch rate declines of 40 and 75% in the trap and gillnet fisheries, respectively, associated with significant increases in nominal fishing effort. Additional changes to effort included smaller gillnet and trap mesh sizes, larger traps, longer soak times, and modifications to trap design to increase catch retention probabilities. Compared with the early 1980s, unreported catches among inshore fishermen may have trebled by the late 1980s and early 1990s due to longer gillnet soak times, increased gear selectivity for small fish, and declining availability of fish of marketable size. These patterns in harvesting dynamics are consistent with the hypothesis that the decline of northern cod was gradual and that increased rates of catch misreporting contributed to increases in fishing mortality. The concomitants of declining fixed-gear catch rate, increasing quantitative and qualitative fishing effort, increased selectivity for smaller fish, and increasing levels of unreported catches may represent general correlates of imminent fish stock collapses.

Résumé : Nous avons quantifié les variations temporelles du taux de capture, de l'effort de pêche et des déclarations erronées pour deux secteurs de la pêche à engin fixe de la morue franche, *Gadus morhua*, du nord de Terre-Neuve de 1980 à 1991, l'année précédent le moratoire imposé à la pêche commerciale de ce stock. Au cours de cette période de douze années, les pêcheurs ont signalé une baisse du taux de capture de, respectivement, 40 et 75%, pour la pêche à la trappe et la pêche au filet maillant cela en dépit d'accroissements appréciables de l'effort de pêche nominal. Les autres modifications apportées à l'effort comportaient l'utilisation d'un maillage plus petit pour les filets maillants et les trappes, de plus grosses trappes, des temps de séjour plus longs et la modification de la configuration des trappes afin d'en accroître la probabilité de rétention des poissons. Comparativement au début des années 1980, les captures non signalées des pêcheurs côtiers peuvent avoir triplées à la fin des années 1980 et au début des années 1990 suite à des temps de mouillage plus longs, à l'augmentation de la sélectivité des engins pour les poissons plus petits et à la moins grande présence de poissons de taille commercialisable. Ces allures de la dynamique de la récolte sont cohérentes avec l'hypothèse selon laquelle le déclin de la morue franche du Nord a été graduel et l'augmentation des déclarations erronées a donné lieu à une augmentation de la mortalité par pêche. L'existence simultanée d'un taux de capture à l'engin fixe à la baisse, d'une augmentation quantitative et qualitative de l'effort de pêche, d'une plus grande sélectivité envers les poissons de petite taille et de l'accroissement des captures non déclarées peuvent présenter une corrélation générale avec un effondrement imminent des stocks de poisson.

[Traduit par la Rédaction]

Introduction

Attribution of commercial fishery collapses to factors unrelated to fishing is premature in the absence of comprehensive data on fishing activity, sources of fishing mortality, and the influence of fishing on individual growth, behaviour, and life history. Spatial and temporal changes in catch rate, fishing effort, and unreported catches that precede stock collapses, for example, have the potential to provide information on rate of stock decline and on changes in the abundance of fish of marketable size. Although the necessity of monitoring fishing effort has long been recognized (e.g., Cunningham 1895), contemporary data on fishing activity in the Northwest Atlantic are often limited, with little or no information on quantitative or qualitative changes either to fishing gear (e.g., mesh size, trap design, hook type) or to the technological deployment of that gear. And despite the considerable uncertainties and inaccuracies that temporal trends in catch misreporting pose to the output of stock assessment models such as virtual population analysis (VPA) (Hilborn and Walters 1992; Myers et al. 1997*a*), there are comparatively few estimates of discarding for most commercial fisheries (Alverson et al. 1994; Allard and Chouinard 1997; Kulka 1997).

Our study focuses on the fishery for northern Atlantic cod,

Received February 11, 1999. Accepted August 26, 1999. J15017

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Gadus morhua, whose distribution from a management perspective, although probably not a biological one (Templeman 1966; Hutchings et al. 1993; Ruzzante et al. 1996), extends from southern Labrador (Northwest Atlantic Fishery Organization (NAFO) Division 2J) through the northeast Newfoundland Shelf (Division 3K) to the northern half of the Grand Bank off eastern Newfoundland (Division 3L). Since the early sixteenth century (Hutchings and Myers 1995), commercial fishing for northern cod has comprised an inshore and an offshore sector. Between 1977, the year in which Canada extended its fisheries jurisdiction to 200 miles, and 1991, the last complete year of the commercial fishery for this stock prior to the 1992 fishing moratorium, the inshore sector landed an average of 44% of the total reported catches annually (Lilly et al. 1998). The two primary gear types in the inshore fishery since the late 1960s (Hutchings and Myers 1995), gill nets and cod traps, accounted for an average of one third of the annual total landings of northern cod from 1977 to 1991, 16 and 17% having been landed by gill nets and traps, respectively (Lilly et al. 1998).

Our examination of the inshore fishery for northern cod encompassed three objectives: (*i*) to describe temporal changes in catch rate for the primary gear sectors of the inshore fishery, (*ii*) to document temporal changes in fishing effort (e.g., number of nets and traps, mesh size, trap design), and (*iii*) to estimate the magnitude of, and temporal changes in, unreported catches.

Methods

The absence of data on catch rates for boats less than 35 ft (1 ft = 0.3048 m) in length (data available for boats greater than 35 ft have been analysed by Hutchings and Myers (1994) and Murphy and Shelton (1997)), fixed-gear fishing effort, and unreported catches in the inshore fishery necessitated the use of interviews to obtain this information.

Between July 1995 and December 1996, 47 fishermen were interviewed about their experiences with the inshore fishery for northern cod between 1980 and 1991. The responses by 17% of fishermen were supplemented by written documentation. The geographical range of communities in which the fishermen resided was wide, ranging from Fogo, Notre Dame Bay, southeast to Cape Broyle on the southern shore south of St. John's, Nfld. Most individuals (85%) had fished in Division 3L, with the remainder having fished in Division 3K. The fishing experience of interviewees averaged 32.1 (± 2.2 SE) years, ranging from 18 to 53 years. Our sample represented approximately 1% of all 4677 fishermen (and 2% of the 1956 fishermen in Division 3L) licensed to fish northern cod in boats less than 35 ft in 1985 (the earliest year for which vessel-specific license data are available; Department of Fisheries and Oceans (DFO), Fisheries Management Branch, P.O. Box 5667, St. John's, NF A1C 5X1, Canada). By comparison, the research surveys conducted annually by DFO sampled approximately 0.005% of the area inhabited by northern cod between 1981 and 1992 (based on an average 424 annual tows; Hutchings 1996).

For each year from 1980 to 1991, for gill nets and cod traps separately, fishermen were asked to report (*i*) total catch of cod, (*ii*) number of traps/nets fished, (*iii*) gear mesh size(s), (*iv*) trap design (see below), (*v*) incidence of unreported trap catches, (*vi*) gillnet soak times, and (*vii*) minimum size of marketable cod (Appendix). Annual catch rates for each fisherman, by gear, were calculated by dividing the fisherman's reported catch by the number of nets/traps that he deployed in each year.

Random sampling of all fishermen was precluded by the lack of an accurate, up-to-date list of full-time fishermen possessing a fixed-gear groundfish license for vessels under 35 ft in length and by a high rate of nonparticipation, due to the engagement by fishermen in fishing-related activities and a reluctance to be interviewed. Although the majority of interviewees (64%) were randomly selected from a Fish, Food and Allied Workers' Union list, the remainder were selected by snowball sampling, a statistical sampling protocol widely used in social research that generates interviews through a referral process in which interviewees are asked to suggest additional names for interviewing (Biernacki and Waldorf 1981).

Snowball sampling is particularly well suited for the study of sensitive issues (Lopes et al. 1996) and can have the effect of increasing the accuracy of the data (Faugier and Sargeant 1997). Our interviews included questions, ranging from gear specifications to discarding practices, that we judged a priori to be of a potentially sensitive nature; subsequent requests for anonymity by interviewees suggest that this prejudgement was not unreasonable. In practice, when an interviewer encountered a fisherman who was particularly forthcoming in his responses to discarding, or who possessed written documentation of temporal changes in catches, or who readily provided quantitative information on fishing effort, the interviewer might ask the interviewee to identify another individual who would be similarly knowledgeable about the fishery. In the present study, no more than four individuals from the same community were interviewed as a consequence of snowball sampling.

The application of snowball sampling is not unlike that of minimizing the mean squared error in which the intention is to reduce the variance in the data at the expense of an undetermined increase in bias (Cochran 1977; Hutchings 1996). One means of assesssing the bias effected by snowball sampling in the present study is to test the null hypothesis that responses from interviewees within single groups of communities did not differ significantly from interviewee responses to the same questions among groups of communities. For the primary data reported here, i.e., temporal trends in catch rates, fishing effort, and discarding, there were no significant differences ($p > 0.05$, one-way ANOVAs) either among communities or among regional groupings of communities (e.g., Bonavista Bay, Trinity Bay, Conception Bay), suggesting that interviewees identified by snowball sampling were no more likely to provide similar responses to similar questions than individuals identified at random.

Results

Catch rate

Gillnet and trap catch rates declined through the 1980s and early 1990s, although the pattern of decline differed by gear type. Average gillnet catch rates exhibited a fairly continuous decrease from a high of 87 lb·net haul^{-1} (1 lb = 0.454 kg) in 1980 to 22 lb·net haul^{-1} in 1991, representing a 75% decline over the 12-year period (Fig. 1*a*). Average trap catch rates, also reported to be highest in 1980 (60 000 lb·trap season^{-1}), declined steadily until 1986, whereafter they remained at approximately 35 000 lb·trap season^{-1}, increasing slightly by 11% in 1989 and 1990 before declining again to the 1986–1988 level in 1991 (Fig. 1*b*). Overall, trap catch rates declined significantly by 40% between 1980 and 1991, although catch rates in the early 1990s did not differ significantly from those reported in the mid- and late 1980s.

Fig. 1. Mean (±SE) catch rates in the (*a*) gillnet and (*b*) cod trap fisheries for northern cod, as reported by gillnet (n = 25) and trap (n = 30) fishermen, between 1980 and 1991.

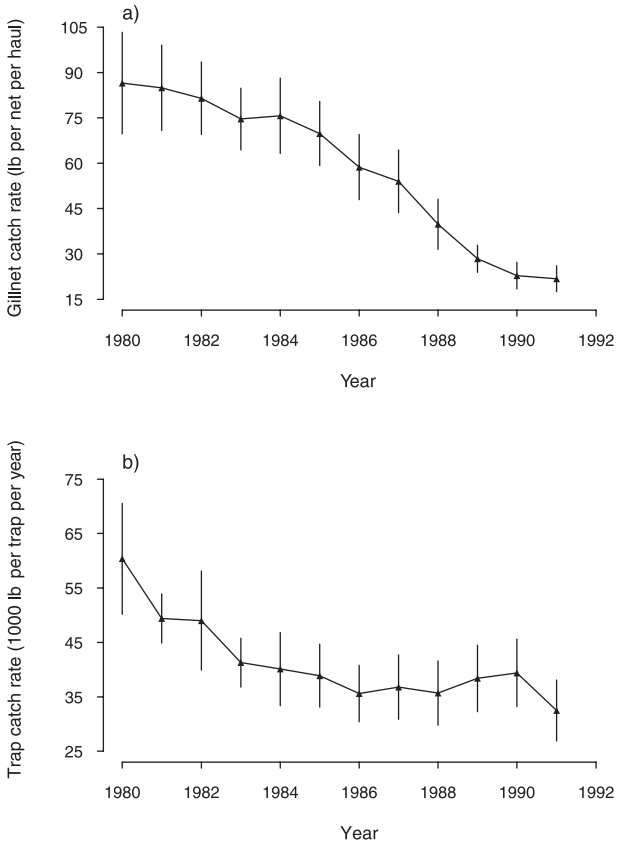
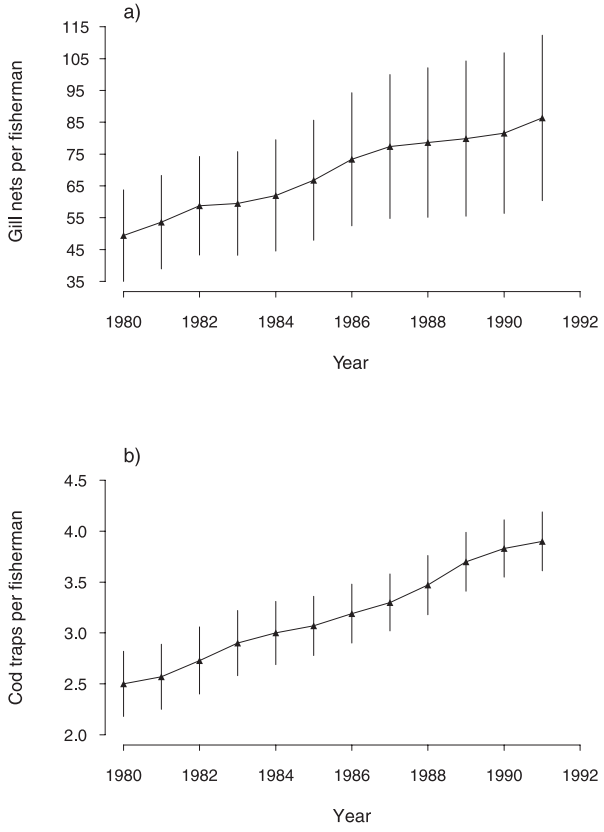


Fig. 2. Mean (±SE) nominal fishing effort in the (*a*) gillnet and (*b*) cod trap fisheries for northern cod, as reported by gillnet (n = 25) and trap (n = 30) fishermen, between 1980 and 1991.



Changes in nominal fishing effort

Nominal effort increased steadily in both the gillnet and cod trap fisheries between 1980 and 1991, although the standard errors associated with mean gillnet effort overlapped throughout the entire period. Gillnet effort increased 76% through the 1980s and early 1990s, ranging from 49 nets·fisherman^{-1} in 1980 to 86 nets·fisherman^{-1} in 1991 (Fig. 2*a*). The percentage increase over the same 12-year period in nominal trap effort (56%) was similar to that reported by gillnetters, increasing from 2.5 traps·fisherman^{-1} in 1980 to 3.9 traps·fisherman^{-1} in 1991 (Fig. 2*b*).

During the last 7 years of the fishery, the average number of gill nets and traps per fisherman among all interviewees increased 29 and 27%, respectively. However, if these data are partitioned by those who changed their nominal effort between 1985 and 1991 and those who did not, several noteworthy observations emerge. Among the 39% of gillnetters whose effort changed, number of nets per fisherman increased 44% between 1985 and 1991 (Fig. 3*a*). Those who changed their gillnetting effort were fishing twice as much gear in 1985 (103 nets·fisherman^{-1}) than those whose effort remained constant between 1985 and 1991 (52 nets·fisherman^{-1}). Among the 48% of trap fishermen whose effort changed during the same time period, the number of traps per fisherman increased 72% (Fig. 3*b*). But, unlike the gillnetters, those who changed their effort were fishing less gear in 1985 (2.57 traps·fisherman^{-1}) than those for whom effort remained constant between 1985 and 1991 (3.70 traps·fisherman^{-1}).

Qualitative and quantitative changes in fishing gear

Additional temporal trends in fishing effort were revealed by gear modifications to both gill nets and cod traps. As indicated by the increased use of mesh sizes less than 6 in. (1 in. = 25.4 mm), i.e., 5.25 and 5.50 in., average gillnet mesh size declined through the 1980s and early 1990s (Fig. 4*a*). Changes in trap construction were also evident during this time period (Fig. 4*b*). In 1980, almost 60% of the traps were of the "Newfoundland" design, for which there is no roof, or top, to the trap. The other traps in use in 1980 were of either the "modified Newfoundland" (37%) or "Japanese" design (4%). The modified Newfoundland trap is usually distinguished by the presence of inward-directed doorways to reduce the probability of fish escape. The most notable design changes in the Japanese trap are the addition of a roof and a funnel-like "porch" at the trap's entrance. These qualitative modifications to Japanese traps significantly reduce the probability of fish escape, particularly during rough weather.

Temporal modifications in trap design were distinguished by several qualitative changes. Between 1980 and 1988, the incidence of Newfoundland traps declined from 59 to 39% and remained at approximately that level until 1991. By contrast, the proportional representation of Japanese traps increased from 3% in the mid-1980s (1985) to 21% in the

Fig. 3. Mean (±SE) nominal fishing effort in the (*a*) gillnet and (*b*) cod trap fisheries for northern cod experienced by fishermen whose effort increased (solid line) or remained unchanged (dashed line) between 1985 and 1991.

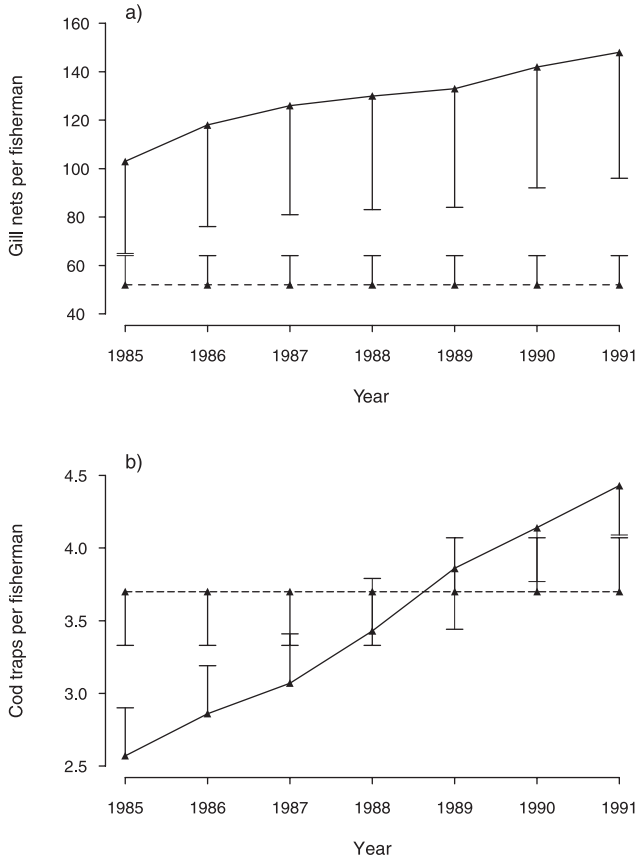
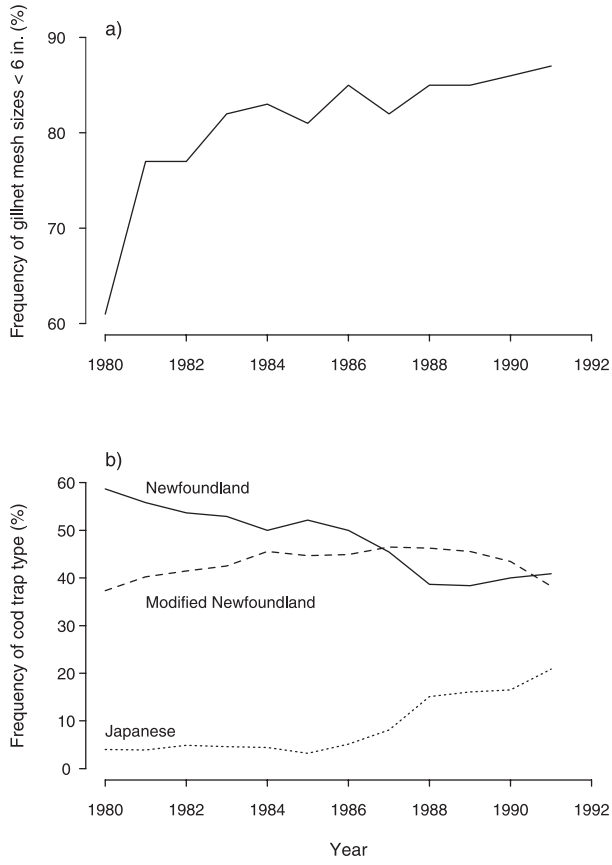


Fig. 4. Temporal changes in the frequency of (*a*) gillnet mesh sizes less than 6 in. and (*b*) cod traps of Newfoundland, modified Newfoundland, and Japanese design, as reported by fishermen engaged in the northern cod fishery between 1980 and 1991. See text for details of cod trap designs.



early 1990s (1991). Concomitant with this shift from Newfoundland to modified Newfoundland to Japanese design were changes to trap volume and trap mesh size. The median volume of Japanese traps was 58 and 35% greater than those of Newfoundland and modified Newfoundland traps, respectively, notwithstanding a considerable range in volumes within each trap design (Fig. 5*a*). Japanese traps were also characterized by considerably smaller mesh, the median mesh sizes of the sides and bottoms of Newfoundland traps (5 in.) exceeding those of Japanese traps (3.625 in.) by 28% (Figs. 5*b* and 5*c*). Larger trap volumes provided the opportunity for increased catch rates, while smaller mesh sizes increased both the gear selectivity for smaller fish and the retention probability of the catch.

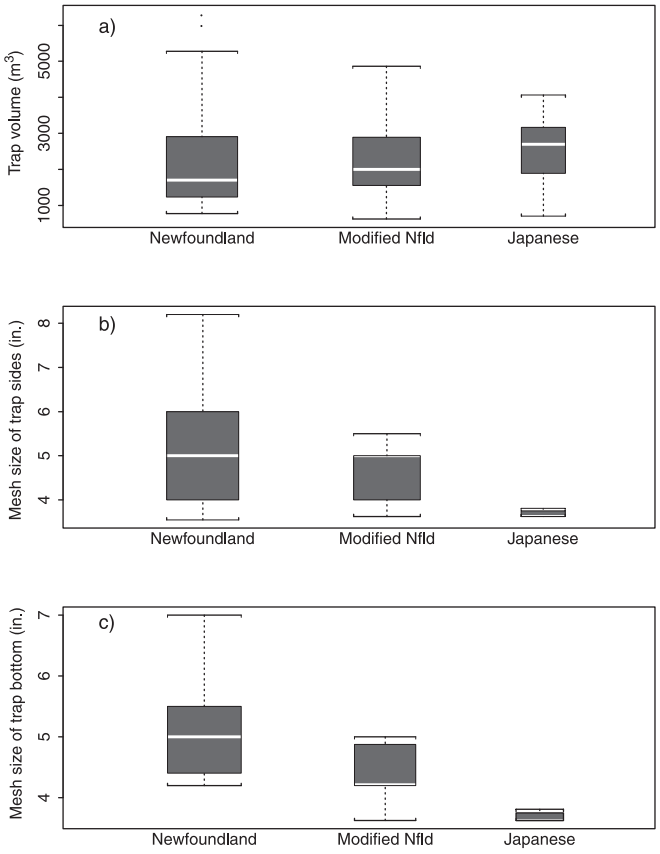
Unreported catches in the inshore fishery

Fishermen stated that unreported catches in the gillnet and trap fisheries occurred for three primary reasons. Cod captured by gill nets, but not reported in the catch statistics, included fish that were bruised, partially eaten by other organisms, or badly deteriorated. Unreported trap catches of cod were attributed to the discarding, or retention for household use, of fish too small for sale and to the dumping of partial or entire boatloads during comparatively short periods (usually over a period of less than 1 week of the 8- to 10-week trap season) when fish plant processing capacity had been exceeded.

To estimate the incidence of unreported catches in the trap fishery, fishermen were asked directly to estimate the proportion of their catch that would normally have been discarded, or let go, from each trap haul. Among all respondents who fished continuously from 1980 to 1991, average discard rates remained constant at 5% by weight (range 0–20%) from 1980 to 1984 before increasing through 1989, whereafter they remained constant at 12% (range 0–60%) (Fig. 6*a*). Among the 70% of fishermen who reported no change in discarding rates, unreported catches averaged 5% during the 1980s and early 1990s (Fig. 6*b*). Among those who reported a change in discarding, the incidence of unreported catches increased significantly from 5% in 1984 to 28% in 1989 (Fig. 6*b*).

To estimate temporal changes in unreported catches in the gillnet fishery, fishermen were asked to describe annual changes in typical soak times and to estimate how their unmarketable catches (percent by weight) would change as a function of soak time. This information allowed the incidence of unreported catches to be estimated indirectly. Between 1980 and 1991, average soak time increased more than 50% from 1.5 to 2.3 days, with most of the increase occurring between 1983 and 1989 (Fig. 7*a*). The range in aver-

Fig. 5. Box-and-whisker plots showing differences in the (*a*) volume and (*b*) side and (*c*) bottom mesh sizes of Newfoundland, modified Newfoundland, and Japanese cod traps in the northern cod inshore fishery. See text for details of cod trap designs. Medians are represented by white bars in each box, the lower and upper ends of each box represent the 25 and 75% quartiles, respectively, the whiskers represent lines extending from the top and bottom of each box to adjacent data no more than 1.5 times the interquartile range, with values beyond this range indicated by solid circles, and the width of each box is proportional to the square root of the number of traps represented in each sample.

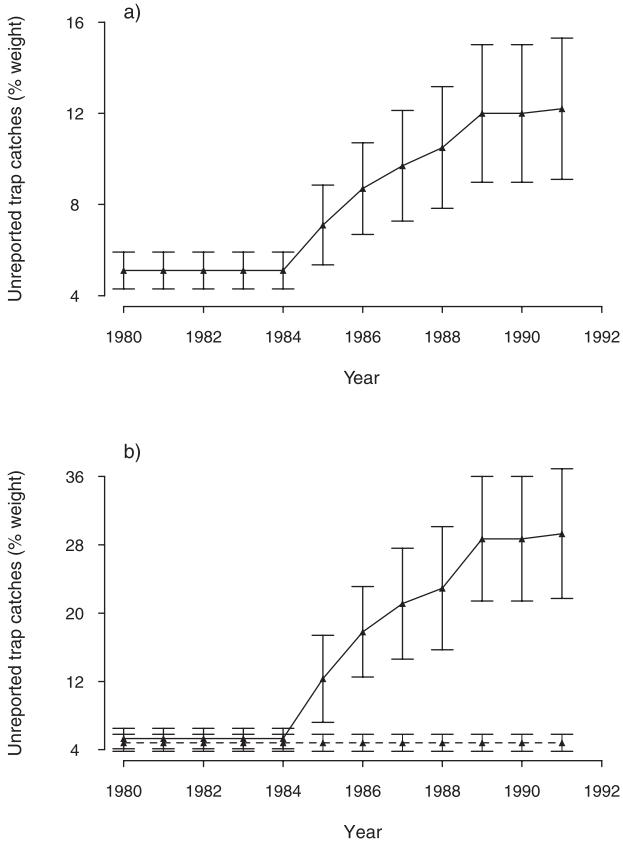


age soak times among individuals increased from 1–3 days in 1980 to 1–7 days in 1991. The percentage of catches deemed unmarketable was estimated by fishermen to increase from an average of 4%, by weight, after a 1-day soak period to 25% after a 3-day soak to more than 50% for gillnet sets that exceeded 3 days (Fig. 7*b*). Based on these data on soak times and unmarketable fish, unreported catches in the gillnet fishery were estimated to have increased from 6% in the early 1980s (1980–1984) to 19% in the late 1980s and early 1990s (1989–1991) (Fig. 8).

Discussion

Interview-based data on catch rates, fishing effort, and unreported catches in the inshore northern cod fishery from 1980 to 1991 suggest observations that pertain to the rate of decline of this stock prior to the 1992 commercial moratorium and to the magnitude of fishing mortality experienced by northern cod.

Fig. 6. Annual changes in the incidence (mean ± SE) of undisclosed northern cod trap catches (*a*) reported by all interviewed trap fishermen and (*b*) grouped by those whose unreported catches changed (solid line) and those whose incidence of unreported catches remained constant (dashed line) between 1980 and 1991.



Declining catch rates and increasing effort as metrics of stock decline

Inshore fishermen reported declining catch rates from the early 1980s through the early 1990s. Although the patterns of decline may have differed with gear type, being continuous with gill nets and more punctuated with cod traps, they are consistent with the hypothesis that the decline of northern cod was gradual, occurring over a comparatively long period of time (Hutchings 1996), rather than being precipitous, occurring over a single year (Lear and Parsons 1993).

The trends in catch rates reported here are similar to those previously estimated for vessels greater than 35 ft engaged in the inshore fishery for northern cod. For each of the five NAFO unit areas that encompassed the inshore fishery for Division 3L, Hutchings and Myers (1994) documented 37–82% declines in gillnet catch rate (as recorded on purchase slips between buyers and fishermen) between 1986 and 1990 compared with the 63% reduction during the same time period reported in the present study (86% of the catch rate data presented here were reported by individuals fishing in Division 3L). A reanalysis of the data used by Hutchings and Myers (1994), conducted for three of the same five inshore unit areas, reported 41–78% reductions in gillnet catch rates during the same time period (Murphy and Shelton 1997). Regarding cod trap catch rates, vessels greater than 35 ft in

Fig. 7. Temporal changes (mean ± SE) in (*a*) gillnet soak time and (*b*) the proportion of unmarketable catch as a function of soak time reported by gillnet fishermen (n = 25) engaged in the northern cod fishery between 1980 and 1991.

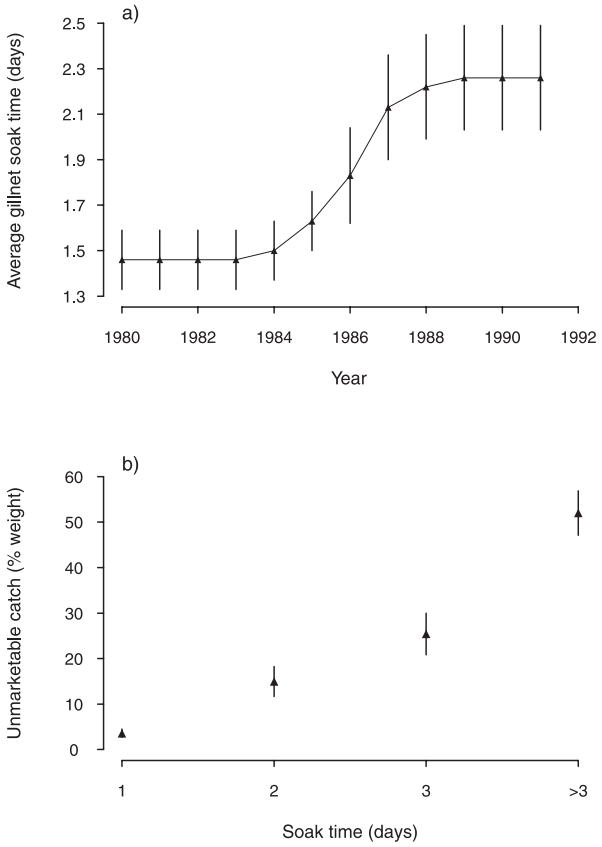
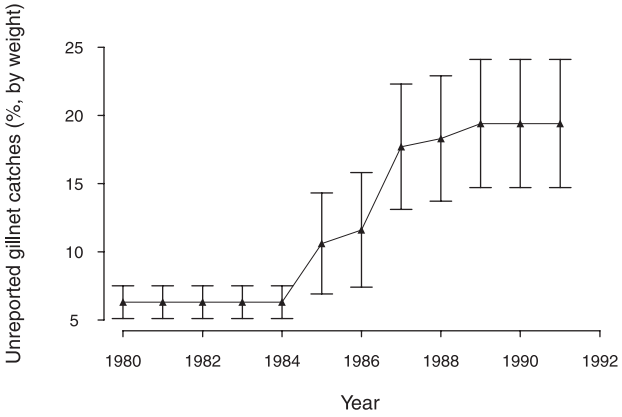


Fig. 8. Annual changes (mean ± SE) in the incidence of unreported gillnet catches, between 1980 and 1991, estimated from temporal changes in soak time and the association between soak time and unmarketable catch (see Fig. 7).



length experienced declines ranging from 30 to 73% in Division 3L between 1986 and 1990 (Hutchings and Myers 1994; Murphy and Shelton 1997) whereas the present study suggested a 14%, although statistically nonsignificant, increase during the same time period (88% of the trap catch rate data reported herein were obtained from individuals fishing in Division 3L). The apparent stability, and possible increase, in trap catch rates reported here in the late 1980s (Fig. 1) may be attributable to the greater than fourfold increase in the use of the larger-volume and smaller-meshed Japanese traps that occurred during the same time period (Fig. 4). In addition, stability, or increases, in trap catch rates might also be attributed to the comparatively strong 1986 and 1987 year-classes of northern cod (Lilly et al. 1998), which would have been recruited to the fishery, at age 3 years, in 1989 and 1990, respectively.

Declining catch rates from the early 1980s through the early 1990s were associated with increased inshore fishing effort. Numerically, between 1980 and 1991, the number of gill nets and cod traps increased more than 50%. But estimates of nominal effort almost certainly underestimate actual fishing effort and realized fishing power. For example, increases in gear deployment in the inshore northern cod fishery were also accompanied by declining gillnet and trap mesh sizes and by increased use of the modified Newfoundland and Japanese cod trap designs, changes that, according to fishermen, were intended to effect higher catch rates. Limited data from two studies conducted by DFO's Fisheries and Habitat Management Branch provide some support for the hypothesis that Japanese traps, and possibly modified Newfoundland traps, effect higher catch rates than traditional Newfoundland traps (Brothers and Hollett 1991; Brothers and Peddle 1991). Fished by the same crew at the same location in either 1990 or 1991, reported catch rates by Japanese traps were 3–29 times greater than those realized by Newfoundland traps (Table 1).

One interpretation of these trends in the inshore fishery is that declining catch rates reflected a declining abundance of cod, particularly larger and older cod, and fishermen responded to reduced catch rates by increasing the amount of gear that they fished, by increasing the ability of their traps to retain their catches, and by reducing gillnet and trap mesh sizes to increase the probability of capturing small fish. Our interpretation of the responses by fishermen to declining catch rates through the 1980s is supported by interviews conducted elsewhere in Newfoundland (Neis 1997). In addition to quantitative and qualitative changes in gear, increases in fishing effort were also evident from the reported increase in gillnet soak times, which reflected the increasingly greater distances from port at which fishermen were deploying their gear (Neis et al. 1999).

Despite the increases in fishing effort reported here, these changes may inadequately reflect fishermen's perception of the rate of decline of northern cod, possibly providing a conservative metric of the rate at which the stock was decreasing. This is because all fishermen do not have equal opportunities to increase nominal effort. Trap fishermen, for example, do not have the flexibility of gear location enjoyed by gillnet fishermen, whose gear deployment is usually not limited by depth or bottom type. In addition to financial limitations on an individual's ability to purchase gear, there are logistic constraints that restrict the maximum amount of gear that can be fished by any one crew.

These constraints may account for temporal differences in effort between those who increased their nominal effort during the last 6 years of the fishery and those who did not. Among gillnet fishermen, those who increased nominal effort between 1985 and 1991 were those who, in 1985, had the most gear in the water (Fig. 3*a*). If total amount of gear

Table 1. Comparison of catch rates from different types of cod traps, controlling for mesh size in the trap back, in NAFO Division 3K.

Location	Year	Trap design	Mesh size in trap back (mm)	Number of hauls	Catch rate ($kg \cdot haul^{-1}$)	Reference
Fogo	1990	Newfoundland	102	23	249	Brothers and Peddle 1991
	1990	Modified Newfoundland	102	22	278	
	1990	Newfoundland	92	28	123	Brothers and Peddle 1991
	1990	Japanese	92	15	376	
	1990	Japanese	92	9	669	
La Scie	1991	Newfoundland	89	19	68	Brothers and Hollett 1991
	1991	Japanese	89	23	400	
Conche	1991	Newfoundland	89	24	47	Brothers and Hollett 1991
	1991	Japanese	89	5	595	
	1991	Japanese	89	9	1372	

Table 2. Incidence of northern cod less than 18 in. (45.7 cm) in length in the trap catches of a Lower Island Cove, Conception Bay, fisherman, as recorded from detailed catch records, for six years between 1981 and 1991.

Year	Incidence of cod under 18 in. (%)
1981	4.1
1982	1.4
1983	2.5
1989	62.3
1990	76.7
1991	99.0

and size of vessel required to deploy that gear reflected a fisherman's monetary position, comparatively low finances and small vessel size may have prevented some fishermen from increasing their nominal gillnetting effort. Among trap fishermen, for whom vessel size was less likely to limit the number of traps that could be fished, those who did not increase their nominal effort between 1985 and 1991 may have reached the maximum number of traps that they were capable of fishing. Consistent with this hypothesis is the observation that those who did increase their effort were deploying fewer traps in 1985 than those for whom effort remained constant. Thus, the 44 and 72% increases in gill nets and traps, respectively, among those who increased their nominal effort might, because of their financial or logistic ability to increase harvesting power, better reflect fishermen's perception of the rate of stock decline than effort changes averaged among all fishermen.

Temporal increases in catch misreporting

Our interviews indicated that the incidence of unreported catches increased from the mid-1980s through the early 1990s. According to fishermen, the primary reason for increased catch misreporting was the declining average size of fish. A striking example of this decline was evident from the records of a trap fisherman in Lower Island Cove, Conception Bay (Division 3L), the only individual whom we interviewed who had recorded detailed length data for his catches. His records indicated that, in the absence of change to trap design and mesh size, the incidence of cod less than 18 in. (45.7 cm) in his annual catches increased more than 20-fold between the early 1980s and the late 1980s – early 1990s (Table 2).

In the trap fishery, these declines in average fish size were offset somewhat, depending on a fisherman's port of sale, by reductions in the minimum size of marketable fish. Prior to 1985, the minimum size of marketable cod reported by the fishermen interviewed herein was 16–18 in. (41–46 cm). However, in the late 1980s, fishermen reported that some plant owners were apparently purchasing cod as small as 12 in. (30 cm) in length. The increased catch misreporting estimated indirectly for the gillnet fishery can be attributed to increased soak times and the decline in marketable fish in the catches produced therefrom.

Increases in catch misreporting by inshore fishermen in the late 1980s and early 1990s are consistent with reported trends in discarding in other Northwest Atlantic cod stocks, e.g., northern Gulf of St. Lawrence (Palmer and Sinclair 1996), and with trends previously hypothesized for northern cod (Myers et al. 1997*a*). The increased selectivity for small fish effected by qualitative changes to gill nets and cod traps, coupled with a decline in availability of large fish, suggests that increases in catch misreporting by *weight* will underestimate the trend in catch misreporting by *number*, a more appropriate metric of trends in mortality attributable to fishing. As discussed elsewhere (e.g., Myers et al. 1997*a*), temporal trends in unreported catches can severely bias estimates of fishing mortality and stock abundance calculated by VPA.

The accuracy of our estimates of unreported catches probably differs by gear type. Among trap fishermen, who were asked directly to estimate their personal discard rates, there may have been a reluctance to disclose unreported catches. Such a negative bias on our estimates of undisclosed trap catches would have been exacerbated further by any failure

of fish plant owners to disclose to DFO their purchases of undersized cod. Such biases are presumably less evident in our indirect estimates of discard rates in the gillnet fishery, assuming that tendencies to over- and under-estimate gillnet soak times, and the influence of soak time on discard rates, were random among fishermen.

Summary

From a general perspective, the present study underscores the value and necessity of monitoring harvesting dynamics of which temporal changes in fishing effort are but one part (Hilborn and Walters 1992). This is particularly important when changes in catches (e.g., trap fishery for northern cod; Rose 1992) or catch rates (e.g., trawler fishery for northern cod; Baird et al. 1991), in the absence of information on effort, are used as metrics for changes in stock abundance, e.g., as a time series used for tuning the results of a VPA. But even when effort data are analysed as part of a catch rate analysis, such data are usually restricted to nominal effort data alone. This will almost certainly positively bias estimates of stock abundance when qualitative changes in fishing gear designed to increase fishing power are not documented.

Although we can suggest no substantive reason why fishermen should deliberately falsify catch rate and effort data given to individuals not involved in the regulation, management, or deployment of the fishery, interviews with DFO personnel may be more problematic. However, this need not hinder the collection of effort data by those actively involved in stock assessment or fisheries management. Indeed, these data would be readily available if a fisherman's annual license renewal was conditional on the reporting of the quantitative and qualitative status of the licensee's fishing gear.

Of specific relevance to the collapse of northern cod, the present study contributes to our knowledge of the inshore sector of the northern cod fishery in the 1980s and early 1990s, notably with respect to temporal trends in catch rates, fishing effort, and the incidence of unreported catches. The data are consistent with the hypothesis that the collapse of northern cod was neither sudden nor precipitous, at least not from the perspective of those whose livelihoods depended on the fishery. Through the 1980s, declining inshore catch rates precipitated increases in fishing effort. Associated with these gradual but significant changes to fishing power were increases in unreported catches that can be attributed to changes in size selectivity of fishing gear and declining availability of fish of marketable size. It seems reasonable to conclude that these temporal trends in fishing effort and catch misreporting contributed to the dramatic increases in fishing mortality in the late 1980s and early 1990s estimated by VPA (Lilly et al. 1998) and by mark–recapture studies (Myers et al. 1996, 1997*b*). Indeed, the concomitants of declining fixed-gear catch rate, increasing quantitative and qualitative fishing effort, increased selectivity for smaller fish, and increasing levels of unreported catches, as reported by inshore northern cod fishermen, may represent general correlates of imminent fish stock collapses.

Acknowledgements

We are particularly grateful to inshore fishermen and their families, past and present, whose experiences in the northern cod fishery contributed immeasurably to this research, noting in particular Robert and Jean Knapman of Lower Island Cove, Jack Temple, Eli, Jonathan, and Solomon Hutchings of Sunnyside, and Jim Smith and John Williams of Centre Cove. We also thank Wavey Hancock, DFO, Fisheries Management Branch, St. John's, Nfld., for the licensing data. Ram Myers, Barbara Neis, and Alan Sinclair contributed helpful discussion, while David Kulka, Ram Myers, Alan Sinclair, and two anonymous reviewers provided comments on earlier versions of the manuscript. The research was supported by monies received through DFO's Cod Mortality Partitioning Project and by a Natural Sciences and Engineering Research Council of Canada research grant to J.A.H.

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Appendix. Interview questionnaire from which the data reported in the present study were obtained

General

1. What is your name?
2. How old are you?
3. What is the name of the community you fish out of? Have you always fished out of this community? If not, what were the other communities you fished out of and when did you do so?
4. In what year did you begin fishing full-time? In what year did you stop fishing full-time?

Questions pertaining to cod traps

1. How much cod (by weight) did you catch in your traps each year from 1980 to 1991? (Refer to written documentation if available.)
2. How many traps did you fish each year from 1980 to 1991? (Distinguish between number of traps owned and number of traps actually fished in a given year.)
3. What kind of traps did you fish (e.g., Newfoundland, modified Newfoundland, Japanese) and what years did you fish them?
4. Why did you change your gear over time?
5. For each trap, and for each year the trap was fished: How big was your trap in the round, i.e., circumference? What mesh size(s) did you use in your traps (e.g., leader, wings, back, bottom, sides, bunt)? How deep were your traps?
6. At what depths would you set each trap?
7. How long would a typical trap fishing season last (specify approximate dates, e.g., start of May to end of June)?
8. In a typical fishing season, how many times a day would you haul your traps?
9. Do you own a sounder?
10. If yes, did having a sounder change how often you hauled your traps? More often, less often, or no change?
11. Did having a sounder allow you to fish more traps or fewer traps, or did a sounder not affect the number of traps you fished?
12. Did you ever have to dump cod because the plants would not buy them? If yes, in what year(s) did you dump cod and approximately how much cod did you have to dump?
13. What proportion of your catch would you normally have to discard, or let go, from each trap haul, perhaps because some of the fish were too small?
14. By weight, how much would this discarded catch amount to for each haul?
15. Comparing the early 1980s with the late 1980s, did you find you had to discard, or let go, more or less of your catch?
16. What was the smallest size of fish you would keep from your catches for sale?
17. What was the smallest size of fish that the buyers would take?
18. Did this minimum size change over the years?
19. On average, what percentage of the fish that were discarded, or let go, do you think would live?
20. Did you ever find that you needed to use a liner in your cod trap?
21. Do you know of anyone who used liners in their traps?

Questions pertaining to gill nets

1. How much cod (by weight) did you catch in your gill nets each year from 1980 to 1991? (Refer to written documentation if available.)
2. How many gillnets did you fish each year from 1980 to 1991 (distinguish between number of gill nets owned and number of gill nets actually fished in a given year)?
3. Why did you change your gear over time?
4. What were the mesh sizes of the nets that you fished each year from 1980 to 1991?

5. How many fleets of gill nets did you set in your first gillnetting season?
6. How many gill nets were there in each fleet?
7. Did you ever change the number of fleets you would set?
8. Did you ever change the number of gill nets you would have in each fleet?
9. How deep would you set your gill nets? Why did you set your nets at those depths as opposed to deeper or shoaler depths?
10. Did you change the depth at which you set your nets over the years?
11. When you first started gillnet fishing, how far from shore would you usually set your nets?
12. Did the distance you set your nets from shore change over the years? Did you tend to set them further from shore or closer to shore?
13. In a typical fishing season, how many weeks would you be fishing gill nets? What would your typical gillnet season be (e.g., early August to end of September)?
14. After setting your gill nets, how long would you leave your nets in the water before hauling them (e.g., less than 1 day, 1–2 days, etc.)?
15. Comparing the early 1980s with the late 1980s, did you tend to leave your nets in the water for a longer or a shorter period of time before hauling them?
16. Did you ever lose any gill nets? How many would you usually lose in a typical fishing season?
17. In your opinion, what are the most important factors that affect the quality of fish taken by gill net (e.g., soak time, depth of set, water temperature, presence of crabs)?
18. What percentage of your catch from each haul would you let go while you were on the water because of fish deterioration or damage?
19. How often would a buyer not purchase some of your catch because of poor fish quality (e.g., never, once a season, one to five times a season, 5–10 times a season, etc.)?
20. When this happened, what percentage of your day's catch would the buyer not buy from you?
21. As a rule of thumb, from a gillnet haul, what percentage of your catch would you not be able to sell if the nets were left in the water overnight? Two days? Three days? More than 3 days?

General

1. When the fishery reopens, do you think there should be any modifications made to the kinds of gear used to fish cod? (These changes might include, among others, increases in mesh size, thickness of trap twine (fish tend to mesh less with thicker braids), changes in amount of gear per person, changes to gillnet material to one that deteriorates with time to prevent ghost-fishing.)
2. More specifically, for each of the following types of gear, specify the changes to that gear that you think ought to be made if that gear is to be used in any future fishery for northern cod: draggers, cod traps, gill nets, and line trawls (include handlines).