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An Assessment of the Cod Stock in NAFO Divisions 2J+3KL

by

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Abstract

The structure of the 2J+3KL cod stock is reviewed, with emphasis on the extent to which cod currently in the inshore may be distinct from cod which formerly migrated between the offshore and the inshore. The status of the 2J+3KL cod stock is updated based on an additional year of data from commercial bycatch, research bottom-trawl surveys, prerecruit surveys, acoustic surveys in specific areas, sentinel surveys and a brief food fishery. A new source of information is an index fishery of about 3000 t conducted in the inshore and the offshore. Also new are descriptions of cod distribution and migrations based on returns from recent tagging studies, and estimates of population size in the inshore based on those returns. Estimates of the consumption of cod by seals are revised and updated.

1 Introduction

Historically, many of the cod in NAFO Divisions 2J+3KL (the “northern cod”) migrated between overwintering areas in deep water near the shelf break and feeding areas in shallow waters both on the plateau of Grand Bank and along the coasts of Labrador and eastern Newfoundland (Fig. 1a). Some cod remained inshore throughout the winter in deep water both within the bays and off the headlands. For several centuries various nations pursued the cod while they were in the shallow areas, first with hook and line and later with nets which evolved by the late 1800s into the highly effective Newfoundland cod trap. The deep waters, both inshore and offshore, remained refugia until the 1950s, when longliners designed to exploit populations of cod in deep coastal waters were introduced to eastern Newfoundland and distant water fleets from Europe started to employ bottom-trawlers to fish the deeper water of the outer banks, first mainly in summer/autumn but later in the winter and early spring when the cod were highly aggregated. Landings increased dramatically in the 1960s as large numbers of bottom-trawlers targetted the overwintering aggregations on the edge of the Labrador Shelf and the Northeast Newfoundland Shelf. At the same time, the numbers of large cod in deep nearshore waters are thought to have declined quickly as the longliner fleet switched to synthetic gillnets. Additional details on the history of the northern cod fishery, including changes in technology and temporal variability in the spatial distribution of fishing effort, may be found in Templeman (1966), Lear and Parsons (1993) and Hutchings and Myers (1995).

The number and individual size of the fish declined through the 1960s and 1970s and the stock reached a very low biomass by the mid-1970s (Baird *et al*. 1991). Following Canada’s extension of jurisdiction to 200 miles in 1977, the stock began to recover as a consequence of smaller catches, entry of the strong 1973-1975 year-classes and an increase in the growth rate of individual fish. Fishing effort by an expanding Canadian trawler fleet increased dramatically following extension of jurisdiction and this fleet took a large portion of the total allowable catch, which almost doubled between 1978 and 1984. It became clear in retrospect that the stock size was overestimated during this period. Fishing mortality was much higher than the $F_{0.1}$ target level. In addition, the 1976-1977 year-classes were weak and individual growth rate declined. The 1978-1982 year-classes were moderate to strong but the 1983-1985 year-classes were weak. The spawner biomass did not increase after about 1982 and the 3+ population size peaked in 1984-1985.

Reasons for the overestimation of stock size are complex and not fully understood (see review by Shelton and Lilly (submitted)). They include changes in the method by which the sequential population analysis (SPA) was calibrated and the "retrospective" problem, a phenomenon whereby adding additional data on each year-class results in downward revisions of population size. A third cause of overestimation is misinterpretation of anomalously high survey estimates, the most problematic of which occurred in 1986. It was recognized in 1988-1989 (Baird *et al*. 1991; Lear and Parsons 1993) that the 1986 value had contributed to severe overestimation of stock size. The catch predicted for an $F_{0.1}$ fishing mortality in 1989 was much lower than the TAC's and catches of recent years, and the fixed fishing mortality approach was suspended in favour of an approach that reduced quotas more gradually in hopes of avoiding undue hardship to the fishing industry. Fishing mortality was allowed to esculate. Simulations indicate that the change in the approach to setting the quota turned what might have been a severe stock decline under a fixed fishing mortality rate into a collapse (Shelton 1998).

By the early 1990s much hope was placed on the 1986 and 1987 year-classes, which appeared to be strong in the research vessel surveys and initially contributed strongly to commercial catches. However, in concert with older year-classes, these two year-classes appeared to decline very rapidly. Fishing mortality was very high but reported landings including documented discards were insufficient to account for the abrupt decline observed in the research vessel indices in 1990-1991. The stock was closed to Canadian fishing in July 1992. The research vessel index showed a further large decline in autumn 1992. It was thought that there might have been a substantial increase in natural mortality, especially during the first half of 1991 (Lear and Parsons 1993; Atkinson and Bennett 1994). Research vessel indices continued to decline in the absence of a Canadian fishery and reached a very low level by 1994. There was no sign of recovery in the 1995-1997 surveys.

Controversy continues regarding the time course and causation of the collapse. Some analyses found no support for a sudden increase in natural mortality in 1990-1991 (Myers and Cadigan 1995) and attributed the decline to fishing mortality alone (Hutchings and Myers 1994; Hutchings 1996; Myers *et al*. 1996a,b; Myers *et al*. 1997a,b). However, in the late 1980s and early 1990s the stock underwent several changes that may not have been related to fishing. For example, the distribution during the autumn was increasingly concentrated toward the outer edge of the banks (Lilly 1994; Taggart *et al*. 1994), the distribution during the winter was increasingly toward the south and to deeper water (Baird *et al*. MS 1992b; Kulka *et al*. 1995), the inshore fishery started late (Davis MS 1992) and fish experienced a pronounced decline in growth, condition and age at maturity, especially in the north (Taggart *et al*. 1994). In addition, declines in abundance and changes in distribution were experienced by many other groundfish, both commercial and non-commercial (Atkinson 1994; Gomes *et al*. 1995). The changes in the lightly exploited American plaice in Divisions 2J and 3K parallel many of the changes in cod (Bowering *et al*. 1997). Capelin, the dominant pelagic species in the area and the major prey of cod, almost disappeared from Division 2J, increased in abundance in areas where they were previously uncommon (Flemish Cap and eastern Scotian Shelf), became inaccessible to acoustic surveys conducted at traditional times, arrived late in the inshore for spawning, and experienced low growth rates (Lilly 1994; Frank *et al*. 1996; Nakashima 1996; Carscadden *et al*. 1997; Carscadden and Nakashima 1997). Arctic cod, a cold water species, appeared to increase in abundance and expand its distribution (Lilly *et al*. MS 1994; Lilly MS 1996a). Changes were observed in salmon (Narayanan *et al*. 1995) and several other pelagic species, especially migrants from the south (Montevecchi and Myers 1996). These changes in cod and many other species may have been related to the prolonged period of low water temperatures starting in the early 1980s and to a particularly cold period in the early 1990s (Narayanan *et al*. 1995; Drinkwater 1996; Colbourne *et al*. 1997), but causal links between changes in water temperature and changes in fish biology remain to be established in many cases, especially for the cod (e.g. Lilly 1994). Although much of the published literature concludes that fishing was the major and even the sole cause of the collapse of the 2J+3KL cod during the late 1980s and early 1990s, the possible impacts of factors such as water temperature, the abundance and availability of prey (especially capelin) and predation by seals require additional study.

A thorough review of all analyses relating to the decline of cod in 2J+3KL from the mid-1980s to the early 1990s is beyond the scope of this paper. However, one specific aspect may be mentioned as illustrative of the degree of uncertainty. Various analyses have been presented in support of the hypothesis that the cod shifted southward (Kulka *et al*. 1995; Wroblewski *et al*. 1995), possibly in response to a decline in water temperature (deYoung and

Rose 1993; Rose *et al*. 1994; Atkinson *et al*. 1997), and that this shift increased the vulnerability of the cod to both Canadian and non-Canadian fleets (Rose *et al*. 1994; Atkinson, *et al*. 1997). Other analyses find no support for this hypothesis (Hutchings and Myers 1994; Hutchings 1996; Myers *et al*. 1996a). There can be little progress in determining what caused the deaths of the fish until there is better understanding of where and when the deaths occurred.

Uncertainty about the time course of the decline lies at the heart of the inability to reconcile catches and the autumn research vessel index. One may class the various possibilities for the discrepancy into three groups. First, the decline may have been more gradual than indicated by the surveys. Under this scenario, the survey index had positive year effects for several years in the late 1980s and early 1990s. These effects may have been associated with the increased degree of aggregation toward the shelf edge at the time of the surveys. Hutchings (1996) has conducted a modelling exercise which he suggests demonstrates how aggregations could cause overestimation in a random stratified survey. Second, the survey indices may not have been severely anomalous. Instead, catches were grossly underestimated because landings were under-reported and the discarding of small fish was seriously underestimated (Hutchings 1996; Myers *et al*. 1997a). Third, there may have been an increase in natural mortality. If the survey index reflects accurately the change in population abundance, then the increase in natural mortality must have occurred rather suddenly. However, if the survey index had positive year effects, then an increase in natural mortality may have been less acute and severe but of longer duration. Shelton and Lilly (submitted) concluded that the major cause of the failure of the SPA model to fit the survey and catch data is probably misreporting in the early 1990s and that in the absence of accurate removals it will not be possible to quantitatively determine the contribution of other factors, such as changes in natural mortality and survey catchability, to the lack of model fit. Events that co-occurred with the collapse suggest that, while fishing mortality was ultimately the major cause, changes in the spatial pattern of fish abundance and changes in weights at age also contributed (Shelton and Lilly submitted).

The inshore region has recently gained a greatly increased degree of prominence in the assessment of 2J+3KL cod. By the autumn of 1994 there appeared to be very few cod left within the boundaries of the 2J+3KL stock complex. In spring 1995 a research vessel unexpectedly found a dense aggregation of cod in Smith Sound, Trinity Bay, and during summer/autumn of 1995 participants in the new sentinel survey program experienced good catch rates over much of the area from central 3K to southern 3L. These reports of cod in the inshore indicated that the stock was not as severely depleted as might be deduced from the offshore alone, and called into question the adequacy of the offshore survey as an index of total stock abundance.

A narrative of the assessment process for 2J+3KL cod from extension of Canadian jurisdiction in 1977 to the moratorium in 1992 has been compiled by Bishop and Shelton (1997). This paper provides details of the annual assessments, including the data and methods used to determine stock status and the results of the assessments, including TAC projections in terms of the standard requested reference points. The origin and evolution of the important databases such as catch at age, catch rate indices, and research survey data are discussed. Topics related to the assessments, such as the various committees and commissions that were struck to provide advice on scientific aspects of the assessments, and important issues such as the “retrospective problem”, are also given attention. Documentation supporting assessments in 1993-1997 may be found in Bishop *et al*. (MS 1993; MS 1994; MS 1995a,b), Shelton *et al*. (MS 1996) and Murphy *et al*. (MS 1997). Reports of the Canadian assessment meetings during 1993-1996 may be found in Sinclair (1993), Shelton and Atkinson (1994), Shelton (1996) and Evans (MS 1996). NAFO deliberations are documented in NAFO Scientific Council Reports.

The most recent assessment (Lilly *et al*. MS 1998b) concluded that there was no indication that the 2J+3KL cod stock had begun to recover in the offshore. The size of cod aggregations in the inshore was very uncertain. The present paper updates the stock status based on an additional year of data from commercial by-catch, the research bottom trawl surveys, prerecruit surveys, acoustic studies in specific areas, sentinel surveys and a brief food fishery. A new source of information is the index fishery conducted in the inshore and the offshore. Also new are descriptions of cod distribution and migrations based on returns from recent tagging studies and an estimate of population size based on those returns. Consumption of cod by seals is discussed. Proceedings of the 1999 assessment meeting are in Rivard (1999).

Because there has been considerable interest in conducting fisheries in the inshore, the evidence for the existence of distinct inshore stocks within the 2J+3KL cod stock complex will be reviewed, and information from the inshore will be presented separately from that from the offshore where practical.

2 Stock structure

2.1 Definitions of inshore and offshore

The terms "inshore" and "offshore" have created some confusion within assessment meetings in the past. There was a request during the 1998 cod zonal assessment meeting for clear and unambiguous definitions. This may not be possible. It is recognized that a cod trap set within a few metres of land is in the inshore and a trawler fishing on the outer edge of Funk Island Bank is in the offshore. However, there is no distinct dividing line between the two. For example, a 55 foot vessel might set gillnets at a depth of 40 m close to shore adjacent to gillnets set by a 30 foot vessel, at 250-300 m some 25 nautical miles northeast of Cape Bonavista, or at 40 m on the plateau of Grand Bank near grounds fished by large otter trawlers. Which of these fishing operations are inshore and which are offshore?

For many years it was the custom within the documentation of the 2J+3KL assessment to refer to all landings from fixed gear (traps, gillnets, and various types of hook and line) as inshore and landings from mobile gear (otter trawls) as offshore. The terms were also used in quota allocation, whereby there was for many years a quota for the stock as a whole, but the "inshore" was given an allocation which it was permitted to overrun. In this context, only vessels less than 65 feet in length were considered to be part of the inshore fleet. (It may be noted that in some contexts there is additional classification by vessel size, so that one may see vessels less than 35 feet referred to as "inshore", vessels 35-65 feet as "nearshore" and vessels 65-100 feet as middle distance.) The definition by gear type would not be a problem if fixed gears were deployed only close to the coast. However, longliners had been introduced to eastern Newfoundland waters in the early 1950s to exploit the aggregations of cod found in the deep water off the headlands, such as off Cape Bonavista. In these waters they overlapped the fishing areas of distant water trawler fleets. Definition by gear type became much more problematical in the mid-1980s as the longliner fleet (which became predominantly a gillnet fleet in the 1960s) started to move further offshore, especially onto the plateau of Grand Bank. The inshore component was then clearly overlapping areas that had been fished with otter trawls for decades, and some of the catch in the inshore allocation was actually coming from far offshore. (It is worth recalling that, in an historical context, the plateau of Grand Bank was fished with longlines for centuries, and dory vessels continued to fish the plateau of the bank into the 1960s.)

In attempting to differentiate the fixed gear catch into inshore and offshore, landings have sometimes been aggregated by statistical unit areas (Fig. 1b). Those unit areas that abutted the coast (areas 2Jd,m, 3Ka,d,h,i, and 3La,b,f,j,q) were considered to be inshore. This was helpful in getting a fuller understanding of that portion of the gillnet catch that was being taken beyond the traditional grounds as the gillnetters expanded their fishing areas after the mid-1980s. However, the definition was arbitrary because the "inshore" unit areas vary considerably in the distance to which they extend away from the coast and they do not correspond to any physiographic features.

The terms inshore and offshore have recently been used with respect to the geographic coverage by the research trawl surveys. When the stratification scheme was established, it was decided that the strata would not include the 12-mile coastal zone (Doubleday 1981; p. 24). Starting in the autumn of 1996, new strata were established closer to shore and within the bays of Divisions 3K and 3L. These new strata have been referred to as being inshore, to distinguish them from the older strata that are referred to as offshore.

The terms inshore and offshore have also been used with reference to distribution and diet composition of harp seals. As will be discussed later, in the present paper the inshore area for harp seal distribution is a band 25 km from the coast.

Thus, there is no correspondence between the inshore as defined for allocating quota, inshore as sometimes employed in assessments for aggregating the fixed gear catch, inshore as used in discussing the research surveys and inshore as used for discussing harp seal distribution. The terms "inshore" and "offshore" are widely used within the fishing industry and are convenient terms of geographic reference in general discussion, but at present their usage is not consistent among all contexts.

2.2 Observations of cod in the inshore

Cod in Divisions 2J+3KL (the "northern cod") historically migrated on a seasonal basis between a summer-autumn feeding area in shallow water along the coast of southern Labrador and eastern Newfoundland and an overwintering area offshore, primarily near the shelf break. However, not all cod moved offshore in the winter. Some remained near the coastal shelves in deep water below the Cold Intermediate Layer (CIL) of the Labrador Current, and some remained within the bays of eastern Newfoundland, often in narrow fjord-like environments. In recent years the quantity of cod caught during autumn research bottom-trawl surveys in offshore waters has been very low, but there have been numerous reports of cod in shallow coastal waters, catch rates have been good to excellent in sentinel surveys from White Bay south, and dense aggregations of cod have been found and studied in deep inlets in the inner reaches of Trinity Bay. There is much uncertainty and speculation regarding the stock affinities of these cod that are now found in inshore waters.

Linking the inshore to the offshore

Several studies in the 1960s demonstrated a close association between the cod caught in inshore waters and the cod caught on the outer shelf. The most compelling information was the pattern of returns from tagging studies in both the offshore and the inshore in the early to mid-1960s (Postolakii 1966; Templeman 1974) but there were also analyses of catch rates, fish size and growth rate. Fleming (1965), Hodder (1965) and May (1967) showed that the catch per fisher in the inshore declined as catches by distant water fleets increased in the offshore in the late 1950s and early 1960s. Referring to sampling during 1955-1962, Hodder (1965) concluded: "The decreased abundance of fish older than 6 years in the inshore trap fishery is attributed to the decreased abundance of these older ages on the offshore fishing grounds as a result of increased effort by trawlers in all areas off the east coast of Newfoundland and southern Labrador in recent years." May *et al*. (1965) used random samples of research vessel trawl catches and catches by various gears in the inshore commercial fishery in 1960-1962 to calculate mean length-at-age of cod in ICNAF Divisions from 2H to 3Pn. They found that von Bertalanffy growth curves "... derived from the offshore data provide an adequate representation of the inshore material as well, lending evidence to the hypothesis that there is no inshore-offshore stock separation in the areas concerned." It should be noted, however, that the inshore samples came from communities on headlands and exposed coasts, and may have been dominated by migrating fish.

Cod in deep waters off headlands

The presence of cod in deep water off the coastal shelves of eastern Newfoundland has been recognised since exploratory longlining in the early 1950s (Templeman and Fleming 1956, 1963). Not all the cod in these areas, just below the depth at which the Cold Intermediate Layer of the Labrador Current impinges on the bottom, arrived from near the shelf break following spawning. In the 1980s the fishery in the deep water started each spring very soon after the disappearance of the ice, and often long before the sudden increase in landings toward the middle or end of June in adjacent shallow waters (unpubl. data). In addition, research trawling off Cape Bonavista and in the mouth of Trinity Bay has yielded good catches in February-April (Lilly 1982; unpubl. data). Thus, some cod are in this deep-water coastal environment months before the migration of cod from the offshore. Templeman (1962) presented several arguments in support of a suggestion that "... each large shelf region, such as the Bonavista Shelf, the Fogo Shelf and the St. Anthony Shelf, projecting seaward with deep water on each side has a basic stock of its own, some of which it loses temporarily in the summer by coastal or pelagic feeding migrations and in the winter by movements in the deep water, while receiving some migrants from other areas."

As reported by Hutchings *et al*. (1993), there is evidence of spawning in the deep water off Cape Bonavista. Cod caught in the commercial gillnet fishery northeast of the Cape in 275-350 m were sampled weekly in 1983 and 1984. A plot of a gonad-somatic index versus time illustrates that there were many cod with relatively large gonads when the first samples were collected (May 11 in 1983 and May 30 in 1984), and that the proportion of cod with elevated indices, and the maximum values of the indices, declined to a minimum by the middle or end of July (Lilly MS 1996b). The decline in gonad indices provides only circumstantial evidence that cod spawn in deep water off the Bonavista Shelf. The cod with low gonad indices could have spawned elsewhere before migrating into the area, and cod with large gonads may have moved elsewhere to spawn if they had not been caught.

Cod in eastern bays

Reports of the presence of cod in spawning condition in the bays of eastern Newfoundland may be found in the scientific literature as early as the 1890s, when Neilsen described how he obtained fish in spawning condition for the Dildo Island Marine Hatchery in May-June in Trinity Bay. In discussing an early run of cod at the head of Trinity Bay in 1894, Neilsen (1895) was of the opinion that the "... early occurrence of fish seems clearly to indicate that those fish do not enter the bay from the outside, but that they are *local-bred* fish, which keep in deep water during winter, and on the first opportunity in the spring, seek the shoaler waters in the head of the bay ...".

Additional evidence of the presence of spawning cod within eastern bays may be found in unpublished trip reports (Marinus 67-1, 68-1, 68-2) which describe the maturity of cod caught during experimental gillnetting in the deep water of Trinity and Bonavista bays. These data have been summarised by Hutchings *et al*. (1993). Cod were caught with 6- and 7-inch mesh monofilament gillnets off Tickle Harbour Point and the Horse Chops in Trinity Bay and near Little Denier and Cabot Island in Bonavista Bay in April-June of 1967 and 1968. All gillnet sets were made in deep water with the nets usually running from cold water into the underlying warmer water. In 1967 many of the cod were in spawning condition or close to it (Fleming MS 1967), and in 1968 the cod were in maturity stages indicating spawning was soon to occur (Fleming MS 1968). Fleming (MS 1968) thought that the gillnet experiments were sampling "... a segment of the stock which ... consists of large old cod which have escaped other gears, and which spawn in the coastal areas and bays in contrast to the younger fish being caught by traps and handlines which spawn before arriving in the coastal areas in the spring."

It is interesting to note that Templeman (1962) considered his Avalon-Burin stock to be "... an inshore stock ... extending from the outer coast of the Avalon Peninsula into Fortune Bay". In concluding his discussion of the Labrador-Newfoundland stock, he stated: "Very likely in the future enough differences will be found to indicate a number of north-south and inshore-offshore sub-stocks ..." (Templeman 1962). However, Templeman did not present evidence of inshore stocks north of the Avalon Peninsula (other than the coastal shelf "sub-stocks" discussed above), and he did not speak of "bay stocks".

Cod in fjord-like environments

Cod have for many years been caught through holes cut in the ice in sheltered inlets and embayments of the east and northeast coasts (e.g. Neis *et al*. MS 1996). The only such areas that have been studied extensively using scientific techniques are the three fjord-like arms near Random Island on the western side of Trinity Bay.

Most attention in the late 1980s and early 1990s was focused on the two southern arms (Northwest Arm and Southwest Arm) where DFO and especially the Fisheries Oceanography Group at Memorial University of Newfoundland conducted tagging experiments (see paragraphs on tagging in Section 2.3) and documented various aspects of the biology of cod that overwintered inshore, including their movements and spawning (Wroblewski, *et al*. 1994, 1995; Smedbol and Wroblewski 1997).

The focus shifted to Smith Sound following discovery of a large and dense aggregation of cod in spring 1995 (Rose MS 1996; Brattey 1997; Morgan and Brattey 1997; Brattey and Porter MS 1997; Porter *et al*. MS 1998) There is much evidence that cod have always overwintered in this area, but the recent winter/spring aggregations appear to be much larger than people were aware of in the past. There seems to be a general pattern of cod aggregating in the Sound in the winter and moving out sometime in spring, but the timing of these movements is not well understood. In addition, there may be annual variability in the movements (S.J. Walsh, Department of Fisheries and Oceans, St. John's, pers. comm.). Sounder surveys during the winter of 1997 did not detect any concentrations on February 14-19 or February 24, but a large aggregation was present on February 27 and remained at least until late March. In contrast, in the winter of 1998 a large aggregation was already present on January 27 and remained at least until mid-February.

Results of tagging experiments, genetic studies and acoustic surveys in the three arms of western Trinity Bay will be described in later sections.

Cod in the shallow-water fishery

Cod in shallow water along the coast of southern Labrador and eastern Newfoundland supported a fishery with hook and line for centuries. Since the late 19th century this fishery has been strongly augmented by the use of the cod trap, and since the 1960s by the use of synthetic gillnets. The geographic pattern of the catch in 1947-1949 does not support the supposition that "bay stocks" made important contributions to the total inshore catch. Templeman (1958) stated: "Within the east coast area, cod are most abundant near the projecting island and headland areas such as the Cape Bauld - St. Anthony, Fogo Island, Cape Freels, Cape Bonavista, Bay de Verde - Grates Point areas and in the areas to the east of the Avalon Peninsula. … As a rule far fewer cod are available in the deep inlets and warmer water at the heads of the east coast bays than at the headlands."

In years prior to the collapse, areas of largest catch had in common a closeness to the schools of cod migrating toward the coast from their offshore overwintering areas. If all cod caught in the inshore shallow-water fishery arrived from the offshore, then the earliest landings would be expected at the headlands. However, substantial landings occurred in the inner parts of Bonavista and Trinity Bays several weeks prior to the big increase in landings at the tips of the headlands. See Lilly (MS 1996b) for some preliminary analyses of these patterns based on purchase slips. These patterns appear to correspond to the descriptions of herring fish and capelin fish as reported by fishers (Anon MS 1987, p. 28-29; Neis *et al*. MS 1996). Additional research is required to determine if the early landings (prior to about mid-June) in the inner parts of Bonavista Bay and Trinity Bay were supported by cod which remained within the bays throughout the winter and the later landings were supported by cod which migrated into the coastal areas from farther offshore.

It is tempting to speculate that cod taken in the early landings belong to "bay stocks". It would be of interest to determine if cod taken in the early landings differed from cod taken from later landings with respect to length-at-age, relative year-class strength, otolith structure, and other biological characteristics Unfortunately, the data required to conduct these analyses may not have been collected prior to the 1990's. Most routine sampling of inshore catch was conducted on the outer shores and headlands after mid-June. The early catch in the inner parts of the bays may have been rarely sampled.

Recent observations of cod in shallow water

A surprising aspect of the cod currently in coastal waters is the large number of reports of cod being seen near the surface (Neis *et al*. MS 1996; Davis MS 1996; numerous personal communications to scientists; communications in public media, such as the Evening Telegram, St. John's, NF, 25 May 1996, p.4) and cod being caught in shallow-water gear, including gillnets set for herring, lumpfish and black-back (winter) flounder. Cod have even been caught in lobster pots.

Reports of cod in shallow water became frequent in the winters of 1997-1998 and 1998-1999. These reports came primarily from two areas: Notre Dame Bay on the northeast coast and southwestern Bonavista Bay on the east coast. Reports from Notre Dame Bay included the following. On December 30-31, 1997, cod up to 3 feet (91 cm) in length were reported frozen in ice at Baytona, a community in the inner reaches of the bay. Observers noted the presence of smelt in the area. On January 6-7, 1998, cod were seen in ice near the Twillingate Causeway, which is further out in the bay. Harp seals were reported in the area. From January 11 to approximately January 16, 1999, cod were found dead and dying in and below ice in Virgin Arm, again in the outer part of the bay. It was estimated by Fishery Officers, who interviewed divers and other people who harvested the fish, that perhaps 200,000 lbs (91 t) of cod died. A sample (n=193) of these fish, obtained by divers, had a mean length of 59 cm (range 35-95 cm). The fish were to all appearances healthy and in good condition. Harp seals were reported in the area and some of the larger cod in the sample had bites taken from their bellies. In early February, 1999, a small number of cod were found frozen in the ice at Virgin Arm. Seals were in the area.

Reports from southwestern Bonavista Bay are similar but include more observations of predation by harp seals. On December 30, 1997, cod were observed chasing herring very close to shore in Cannings Cove. In early February, 1998, many dead cod were observed in Southern Bay Reach. Many harp seals were reported in the area. From February 28 to March 3, 1998, cod were seen swimming with fins above the surface, and 200 lbs of cod were found dead on the shore. Seals were reported in the area and an observer reported seeing a seal taking a bite out of a cod's belly. On January 11-13, 1999, many cod were observed swimming near the surface at Cannings Cove and Jamestown. Seals were again seen in the area and an observer reported seeing seals with cod in their mouths, shaking the cod and tearing out the guts. On January 20, 1999, an observer saw a very large number of seals near Deer Island (at the headland between Goose Bay and Sweet Bay) coming to the surface with cod in their mouths. They would take a clean cut out of the belly, taking the liver but leaving the gonad. As reported by The Telegram (St. John's, NF, February 23, 1999), in February 1999 seals were observed preying on cod in a small cove on Deer Island. The seals would shake the cod "and the gut would stay in the mouth and the fish would fly off". The presence of large numbers of dead cod on the bottom was confirmed by a diver. One cod recovered with a large bite from its belly was reported to be about 3 feet (91 cm) long. Divers harvesting sea urchins have reported seeing large numbers of dead cod on the bottom in many parts of southwestern Bonavista Bay during the past 3-4 winters.

Most observers say that the appearance of cod in shallow water in winter is a new phenomenon. From the reports obtained in the past two winters, the observations appear to be highly localized within the eastern half of Notre Dame Bay and southwestern Bonavista Bay. A few of the reports indicate that the cod may have been chasing prey into shallow water. Most reports indicate that seals were in the area and observers felt that the cod were fleeing from seals. Some observers were of the opinion that the seals herded the cod into shallow water in coves. It is possible that in some cases the cod entered shallow water in pursuit of prey and the seals followed the cod. Cod have been dying in these situations, due both to direct predation by seals and to exposure to the cold and ice.

2.3 Stock relationships of cod in the inshore

Did some migrating cod from offshore remain inshore?

It has been suggested that some of the cod that at one time migrated between the offshore and the inshore remained in the inshore in the early to mid-1990s, contributing to the dense aggregation first found in Smith Sound, Trinity Bay, in 1995 and to the high catch rates experienced by participants in the sentinel surveys. There have been several variants of this hypothesis.

Dr. George Rose (Memorial University of Newfoundland) has been quoted as noting that there were almost no older fish in the northern cod population by 1992, and that it is possible that the survivors, mainly younger fish, came inshore and remained there (The Evening Telegram, St. John's, NF, 24 March 1996, p. 13; Kurlansky 1997, p. 203).

Taggart (1997) noted that an aggregation of cod that had been found in the North Cape area of Division 3L each year during the autumn research bottom-trawl surveys was last detected in 1993 and that the large aggregation of cod in Smith Sound was first detected in spring 1995. Based on these observations and the results of genetic and parasite studies, Taggart (1997) hypothesized that "the large aggregations of cod observed in recent years in the Random Island region of Trinity Bay may be those that would normally aggregate offshore in the North Cape region but for some reason have ceased their normal migration pattern to offshore for winter." He noted that this hypothesis could be tested by sampling the large aggregation in Smith Sound and comparing it genetically with fish sampled in the offshore.

Winters and Brattey (MS 1998, p. 13) proposed that "a major progressive change in migration behavior occurred in the early 1990's resulting in cod remaining inshore during the entire year." As evidence they referred (p. 3) to the decline in offshore research survey indices in the early 1990s and the high catch rates inshore in the sentinel surveys.

The above three variants of the altered migration hypothesis differ with respect to timing. The change could have occurred in the early 1990s when most fish disappeared from the autumn research surveys, about 1992-1993 when cod disappeared from the migration corridor east of Bonavista Bay as recorded during spring-summer acoustic studies, or about 1994 when the last aggregation of cod disappeared from the autumn research surveys. If the change occurred early in the 1990s, then a very large quantity of cod could have been involved and these cod should have been comprised largely of the 1986 and 1987 year-classes. With increasing delay in the change, the quantity of cod available to remain inshore would decline and the age classes would be more recent.

The data available for testing the altered migration hypothesis are limited. The only sources of information on commercial size cod in the inshore between 1991 and 1995 are the small fishery in 1992 prior to declaration of the moratorium on July 2, food fisheries in 1992-1994, bycatch in fisheries directed at other species, and the research being conducted in the arms of western Trinity Bay.

As noted above, autumn bottom-trawl surveys in the late 1980s were dominated by the 1986 and 1987 year-classes, which seemed to disappear very rapidly in 1991 and 1992. If these cod migrated to the inshore and remained there, then inshore catches and catch rates might be expected to be high and dominated by these year-classes. The 1991 inshore fishery, which was the last fishery to be unrestricted, was indeed dominated by the 1986 and 1987 year-classes, but the total catch declined dramatically from the 1990 level, especially north of Division 3L (Baird *et al*. MS 1992a). The decline was not consistent with a large quantity of fish remaining inshore. In 1992 the inshore catch, taken mainly by a "recreational fishery" using jiggers or baited hooks, was small and composed of mainly the 1985-1987 year-classes, with the 1987 year-class dominant (Bishop *et al*. MS 1993). "In both 1991 and 1992 there were some indications, based on the commercial and recreational fisheries, that cod may have remained in inshore waters later than usual and in significant numbers. During the autumn surveys, time was allotted for limited coverage (using the bridge sounder to detect fish and trawling where possible) of those areas which are not normally included in the regular survey area. The results indicated that very few cod were encountered in the inshore areas surveyed" (Bishop *et al*. MS 1993, p. 3). It may be noted, however, that experience in the late 1990s showed that cod may be shoreward of the area that can be surveyed by large vessels.

In 1993 there was a food fishery with no restrictions on season or quantity of fish taken. There is considerable uncertainty about how much fish was taken. The catch from recreational fishing and by-catch was mainly of the 1987-1989 year-classes, with the 1989 year-class at age 4 comprising 45% by number (Bishop *et al*. MS 1994). In 1994 there was a food fishery of just 1300 t. Based partly on the poor results of the 1993 food fishery (and to prevent large amounts of fish being taken) (Kulka *et al*. MS 1995), the 1994 food fishery was limited to five Friday/Saturday periods in August and September. Most participants considered the food fishery to be a failure and it was closed a week early because of small fish and low numbers in the catches (Bishop *et al*. MS 1995a; Kulka *et al*. MS 1995). The catch from the recreational and by-catch fisheries in 1994 was mainly from the 1989 and 1990 year-classes, with the 1989 year-class at age 5 comprising 43% by number (Bishop *et al*. MS 1995a). One should not place much weight on the performance of food fisheries, since much of the effort was by non-professionals and the gear was restricted to hook and line. Nevertheless, the poor results in the 1993 and 1994 food fisheries and the dominance of the 1989 and 1990 year-classes (rather than the 1986 and 1987 year-classes) are not consistent with the hypothesis that the fish that disappeared from the offshore moved inshore and remained there.

In 1995 much more information became available from surveys in Smith Sound and catches from the sentinel surveys. The 1990 year-class was dominant in Division 3K, whereas the 1989 and 1990 year-classes were both strong in Division 3L, with the 1989 year-class more prominent toward the south (Davis MS 1996; Brattey 1997; Lilly *et al*. MS 1998a). These results indicate that the high catch rates in the sentinel surveys were not supported by the fish that disappeared from the offshore surveys in approximately 1990-1992. It is possible, however, that there was a change in migration pattern somewhat later as postulated by Rose and Taggart (as cited above). However, once again the match in year-classes is not correct. The bulk of the fish inshore in the mid-1990s was represented by the 1989 and 1990 year-classes, both of which had been weak at age 3 in the offshore bottom-trawl surveys (see later section on survey results). There remains the possibility that individuals of the 1989 and 1990 year-classes found inshore in the mid- and late 1990s were recruited from offshore spawning and failed to migrate offshore after spending their first few years inshore.

<u>Tagging</u>

Inshore tagging experiments prior to the late 1980s were conducted during the summer and autumn (Templeman 1974, 1979), and thus are not helpful in testing the hypothesis that there are inshore components that are distinct from components that migrate to the inshore from offshore. Recoveries from these experiments came from both the inshore and the offshore.

To our knowledge, the first attempt to locate cod overwintering inshore and to determine by tagging and biological sampling if they were resident fish occurred in March 1988, when a bottom-trawl survey was conducted in Conception and Trinity Bays. The only aggregation found was in Southwest Arm in western Trinity Bay. (Smith Sound was not surveyed.) Tags were applied to fish taken mainly in 220-240 m. Additional tagging experiments were conducted in the same area in March 1990 and January 1991. A very high proportion of the returns were taken close to the tagging site, even three or more years after release, consistent with the concept of local residency (Taggart *et al*. 1995, p. 9). A small proportion of the fish were recaptured offshore. Additional tagging studies were conducted in Southwest Arm in June 1992 and both April and June 1993.

Broader scale tagging studies were initiated in late 1995. From December 1995 until autumn 1997 a total of 12,235 cod were tagged with spaghetti t-bar tags and released at various inshore locations in Divisions 3KL from the Northern Peninsula southward to St. Mary's Bay (Brattey MS 1999). Most tagging was conducted during summer and autumn and the spatial extent of coverage varied among years. A total of 501 of these tagged cod have been reported as recaptured, all from inshore areas. Most fish were apparently taken during sentinel surveys and recreational fisheries in summer and autumn and during the 1998 autumn inshore index fishery. The recaptures of tagged fish from these experiments, in conjunction with those described by Brattey *et al*. (MS 1999), suggest that a substantial portion of cod caught in southern 3L during summer and early autumn are migrant cod from 3Ps. Recaptures from inshore tagging in 3KL during 1995-1997 further suggest that most of the cod from approximately western Trinity Bay northward, including those found in Smith Sound in winter, are local cod that reside in northern 3L or southern 3K throughout the year. These cod do not appear to move into southern 3L to an appreciable extent. There appears to be considerable exchange of cod along the inshore between the Fogo area in 3K, Bonavista Bay, and western Trinity Bay. There are also indications of a seasonal migration pattern among cod from this area. Many of the recaptures during 1998 were from the fall index fishery and were north of the release location, suggesting some northward movement in summer. Any inshore-offshore movement of tagged cod during the period 1996-1998 could not be detected due to the lack of offshore fishing activity associated with the moratorium.

Genetics

Is there evidence that the cod currently inshore are genetically distinct from cod in the offshore? Studies during the 1990s have employed two techniques; analysis of sequence variation in the cytochrome *b* region of mitochondrial DNA and analysis of allele length variation in microsatellite nuclear DNA. Results with the former do not support the existence of distinct inshore components whereas results with the latter provide support for considerable but not absolute distinction.

Carr *et al*. (1995) used the mitochondrial DNA technique to examine samples from the northern Grand Bank (June 1988), Flatrock on the eastern Avalon Peninsula (June 1989) and three samples from Trinity Bay (Chance Cove, April-May 1990; Random Island, January-April 1991; Heart's Ease Ledge, July 1993). The Flatrock sample was thought to be mostly if not entirely offshore cod. The Chance Cove and Random Island samples were representative of over-wintering bay cod and the Heart's Ease Ledge sample was representative of cod spawning in the bay. Carr *et al*. (1995) said: "Cod over-wintering in Trinity Bay are not genetically distinct from offshore cod. In combination with tagging and physiological studies, these data suggest that there is sufficient movement of cod between bay and offshore locations to prevent the development or maintenance of independent inshore stocks. Adult cod that over-winter in Trinity Bay appear to represent an assemblage of temporarily nonmigratory fish that have become physiologically acclimated to cold-water inshore environments."

The nuclear DNA technique has been used to compare samples from the inshore and the offshore, and indeed has been used to compare some of the same samples studied by Carr *et al*. (1995). The first series of samples were collected in 1992-1995 and were compared using a suite of five microsatellite loci (Bentzen *et al*. 1996; Ruzzante *et al*. 1996, 1997, 1998; Taggart *et al*. 1998). A pool of samples collected within Trinity Bay, and particularly those fish exhibiting high antifreeze content (indicative of a prolonged period in cold water, presumably inshore), were genetically distinguishable from those overwintering offshore both on the Northeast Newfoundland Shelf and on the northeastern and eastern slopes of Grand Bank. It is notable, however, that the Trinity Bay samples were not distinct from the cod collected somewhat closer to shore in the St. Anthony Basin and in the Notre Dame Channel (Division 3K) in June 1994 (Ruzzante *et al*. 1998). It is noted that the analyses presented in the papers cited above are complex, for they utilize several measures of genetic differentiation and include by necessity careful attention to details of fish characteristics and the time and place of sampling.

Additional samples were collected from three inshore bays (Notre Dame, Bonavista, and Trinity) in 1996-1998 and analysed for the same five microsatellite loci and an entirely different seven loci. Only the results from the latter study (Beacham *et al*. MS 1999) are presently available. They reveal no distinction among samples collected in the three bays. A comparison between the inshore samples and four pooled samples from the Northeast Newfoundland Shelf and the northeastern edge of Grand Bank indicated that the inshore fish were distinct from the offshore fish. When the results were examined in finer detail, it was seen that the inshore samples were distinct from three of the offshore samples but could not be distinguished from the fourth, which was collected on the northern Grand Bank.

A detailed review of all the genetic studies would be complex and beyond the scope of this paper. There does appear to be support for the existence of inshore components, but the inshore samples are not distinct from all offshore samples. In addition, it is not clear at this time if all cod currently inshore belong to inshore components. Further consideration of the samples already analyzed together with those additional data expected from the sampling in 1997-1998 and new sampling in 1999 will benefit from a continuance of careful attention to details of sampling such as time, location, depth, temperature and the size of the cod aggregation from which the sample is drawn, and biological characteristics such as size and age, spawning state, parasite burden and the level of thermal hysteresis.

Summary

Several sources of information are consistent with the hypothesis that there are distinct inshore or bay stocks along the east coast of Newfoundland. The information includes the presence of cod inshore in the winter, the historic existence of spring fisheries in the inner reaches of Bonavista and Trinity bays before cod arrived at the headlands from the offshore, the occurrence of spawning within the bays, the paucity of returns offshore from cod tagged inshore in the winter and genetic distinction between samples of cod taken inshore and most samples taken offshore. It is not clear whether all cod currently inshore belong to the inshore stocks identified in those genetic analyses employing nuclear DNA.

3 Catch and catch at age

3.1 Landings

Nominal catch

The following description is based on landings only. Estimates of discards are available for trawlers directing for cod and shrimp (Kulka 1997; Kulka MS 1998), but these data have not been included in the following description of catch and were not included in the analyses conducted in 1998 (Lilly *et al*. MS 1998b). Discards were estimated to average 3,400 t between 1980 and 1992, with a peak at 9,000 t in 1986. There are no estimates of discards from trawl fisheries directed at species other than cod and shrimp and there are no estimates for fixed gear (which would include cod, capelin and squid traps). There are also no estimates for other categories of mortality associated with fishing, such as those cod that fall out of gillnets before the gear is hauled onboard.

Landings from this stock increased during the late 1950s and early 1960s and peaked at just over 800,000 t in 1968 (Table 1; Fig. 2). Landings then declined rapidly to a minimum of 139,000 t in 1978, increased to a plateau of approximately 250,000 t in the mid- to late 1980s and then declined very quickly in the early 1990s. The portion of the landings coming from each of the Divisions changed over time. During the 1960s, when the fishery was primarily by non-Canadian fleets (Fig. 3), landings were taken mainly from Divisions 2J and 3L (Fig. 4). Division 3K became prominent in the mid-1970s. Landings from Division 2J were relatively small in the mid-1980s. Division 3L dominated from the mid-1980s until the moratorium in 1992.

The fixed gear landings (Table 2; Fig. 5) increased from just 41,000 t in 1975 to a peak of 113,000 t in 1982, declined to 74,000 t in 1986, and increased again to a peak of 117,000 t in 1990, just 2 years before declaration of the moratorium. There was a substantial decline to 61,000 t in 1991. The commercial fishery was closed in July 1992 and only 12,000 t were landed that year. Some of the increase in the late 1980s was due to a resurgence of gillnet landings in southern Division 2J and trap landings in Division 3L, but much was due to an expansion of the gillnet fishery to the Virgin Rocks and other offshore areas in Division 3L (see Table 3 of Shelton *et al*. MS 1996).

Landings have been small since 1992. In 1993 a recreational fishery together with by-catches accounted for 11,000 t. In 1994 a limited (10 d) food fishery during August and September, together with by-catch, accounted for about 1,300 t. In 1995 there was no recreational or food fishery but a sentinel survey was introduced to provide catch-effort information from fixed gear fished in a manner similar to a commercial fishery. Reported landings were only 330 t. In 1996 the sentinel survey continued and a food fishery was allowed on two consecutive 3-day weekends. These two fisheries together with by-catch landed approximately 1,700 t. In 1997 there was no food fishery. Sentinel surveys accounted for about 70% of the total landings of 500 t.

In 1998 there was a quota of 4000 t, divided among by-catch (275 t), sentinel surveys (375 t), and a new index fishery, which was itself divided into an inshore component (3000 t) and an offshore component (350 t). The preliminary reported catches were 398 t from by-catch, 388 t from sentinel surveys, 3019 t from the inshore index fishery, and essentially zero from the offshore index fishery. In addition, there was a 3-day food fishery that is estimated to have taken 696 t (Inkpen and Kulka MS 1999). There is evidence of removals in excess of sentinel surveys and legal fisheries, but the magnitude of these removals cannot be estimated.

A detailed accounting of the commercial and food fishery catch by unit area, gear and month is provided in Table 3. Most (55%) of the catch was taken in Division 3L, 45% was taken in Division 3K and less than 1% was taken in Division 2J. An accounting of the catch from sentinel surveys, by unit area, gear and month, is provided in Table 4.

Most (68%) of the catch was taken in Division 3L, 31% was taken in Division 3K and less than 1% was taken in Division 2J.

3.2 Catch and weight at age

A summary of the sampling used to estimate the catch at age in 1998 is given in Table 5. A total of 207,000 fish were measured and 6300 fish were aged. Sampling represented fairly well the distribution of landings by Division, gear and month. Sampling was intense compared to the level prior to the moratorium when there was a substantial commercial catch.

The age composition and mean length-at-age of the landings were calculated as described in Gavaris and Gavaris (1983). The following relationship was applied in deriving average weight-at-age:

$$\log(\text{weight}) = 3.0879*\log(\text{length}) - 5.2106.$$

In terms of numbers of fish, the catch in 1998 was dominated by gillnet (49%), followed by handline (35%), linetrawl (15%) and trap (2%) (Table 6). The proportion of the catch numbers at age varied among gears (Table 6; Fig. 6). Gillnet landings were mainly of ages 5-8, with age 6 (the 1992 year-class) dominant. Handline landings were mainly of ages 4-8, with ages 5 and 6 prominent. Linetrawl landings were mainly from ages 3-8, with ages 4-6 prominent. Trap landings were mainly from ages 4-8 with age 6 most prominent. The combined catch came mainly from ages 4-8, with age 6 dominant.

The numbers at age, mean weight-at-age and biomass at age for fish in the reported landings from 1962 to 1998 are presented in Tables 7-9. The 1990 year-class was the most important contributor to the catch in 1995-1997 and was still an important contributor in 1998.

The mean weights-at-age calculated from mean lengths-at-age in the landings have varied over time (Table 8; Fig. 7). There was an increase in the late 1970s and early 1980s, followed by a decline through the 1980s to low levels in the early 1990s. There has been substantial improvement in the latter half of the 1990s, and for some age-groups (eg. ages 4-6) the weights-at-age calculated for 1998 were at or near the highest levels in the timeseries. Interpretation of changes in the weights-at-age is difficult because of changes in the relative contributions of the various gear components and changes in the location and timing of catches from each gear component. For example, much of the landings prior to the moratorium came from otter trawling offshore early in the year, whereas since the moratorium most of the catch has come from fixed gear inshore in the second half of the year. In particular, the high proportion of landings coming from gillnets in 1998 will tend to increase the mean weight-at-age of the younger ages. There are clearly problems with the 1993 weights-at-age that remain to be resolved. See Lilly (MS 1998) for additional information regarding this time-series.

4 Research vessel surveys

4.1 Survey design

Research vessel surveys have been conducted by Canada during the autumn in Divisions 2J, 3K and 3L since 1977, 1978 and 1981 respectively. No survey was conducted in Division 3L in 1984, but the results of a summer (August-September) survey have been applied for some analyses. The 1995 autumn survey continued into late January 1996. Spring surveys have been conducted by Canada in Division 3L during the years 1971-1982 and 1985-1998. Surveys in Divisions 2J and 3K were conducted by RV Gadus Atlantica (up to 1994) while those in Division 3L were conducted by RV A.T. Cameron (1971-1982) and RV Wilfred Templeman or its sister ship RV Alfred Needler (1985-1998 for spring and 1983-1998 for autumn). The autumn surveys in Divisions 2J and 3K in 1995-1998 were conducted mainly by RV Teleost, although RV Wilfred Templeman surveyed part of Division 3K. In the autumn 1995 survey both ships used for the first time the Campelen 1800 shrimp trawl with rockhopper footgear, replacing the Engels 145 Hi-rise trawl that had been used since the start of the surveys in 2J and 3K and since the change to the RV Wilfred Templeman in Division 3L. In addition, the Campelen trawl was towed at 3.0 knots for 15 min instead of 3.5 knots for 30 min. The selectivities of the two nets were found through comparative fishing experiments in 1995 and 1996 to be markedly different, with the Campelen being far more effective at catching small cod (Warren 1997; Warren *et al*. MS 1997). Conversion of Engels catches to Campelen equivalent catches is reported by Stansbury (MS 1996, MS 1997).

The survey stratification scheme, illustrated in Fig. 8-10, is based on depth contours (Doubleday 1981; Bishop MS 1994). The strata used in 1996 were similar to those in previous years except that the survey was extended to 1500 m and 25 new strata were added to the inshore in Divisions 3K and 3L to obtain an estimate of the cod landward of the standard survey area. The survey in 1997 was similar to that in 1996, except that some of the new inshore strata were modified and one stratum was added. The survey in 1998 was as in 1997. Prior to 1988, set allocation was proportional to stratum area, with the provision that each stratum be allocated at least 2 sets. In 1989 and 1990 an "adaptive design" was introduced in an attempt to minimize variance. It was found that this method introduced a bias and the additional sets fished during the second phase of these surveys have been excluded from analyses. In 1991-1994, additional sets were allocated in advance to certain strata based on past observed stratum variance (Gagnon 1991). In 1995-1998, set allocation was based once again on stratum area alone. To account for incomplete coverage of some strata in some years, estimates of biomass and abundance for non-sampled strata were obtained using a multiplicative model. This correction was not applied after 1991 because of changes in cod distribution, a change in the stratification scheme introduced in 1993 (Bishop MS 1994) and the change in vessel and trawl gear in 1995.

4.2 Autumn surveys in Divisions 2J, 3K and 3L

4.2.1 Abundance and biomass

Abundance and biomass have been estimated by areal expansion of the stratified arithmetic mean catch per tow (Smith and Somerton 1981). Estimates for the autumn surveys from 1978 (Divisions 2J and 3K) or 1981 (Division 3L) to 1994 may be found in Tables 12-19 of Shelton *et al*. (MS 1996). The data from 1983 to 1994 have been converted to Campelen equivalents and are presented along with the actual Campelen data from 1995-1998 in Tables 10-12 for Division 2J, Tables 13-15 for Division 3K and Tables 16-18 for Division 3L. Note that data for 1993-1998 are presented separately from earlier years for Divisions 2J and 3K because of the change in stratification scheme introduced in 1993 (Bishop MS 1994). Because there have been changes over time in the depths fished, annual variability in the abundance and biomass of cod has been monitored for those strata that have been fished most consistently since the start of the surveys. These "index" strata are those in the depth range 100-500 m in Divisions 2J and 3K and 55-366 m in Division 3L. The new inshore strata are not included. Changes in abundance and biomass in the index strata are shown by Division for the years 1983-1998 in Fig. 11. In Division 2J there was an irregular decline over time with a strong positive year effect in 1986. In Division 3K there was again a sharp positive year effect in 1986 but also a very sharp increase in 1989 followed by declines in 1990 and 1991. In Division 3L there was a gradual decline over time with a positive year effect in 1990. The abundance and biomass have remained at extremely low levels in all Divisions since 1993. The abundance and biomass estimates for the new inshore strata in 1996-1998 (Table 19) are less than estimated for the offshore but are relatively high given the much smaller area of the inshore strata. The total abundance and biomass of all strata fished in 1983-1998 are provided by Division and year in Table 20.

The abundance and biomass for index strata, deep offshore strata and inshore strata are provided in Table 21 by Division and year for the four years since introduction of the Campelen trawl. Abundance in index strata was highest in 1995, declined in 1996 and 1997 and increased a little in 1998. Biomass in index strata increased from 1995 to 1997 and remained unchanged in 1998. The biomass in index strata in 1997-1998 was about 16,500 t, which is about 1.4% of the average biomass of 1,200,000 t (in Campelen equivalents) in 1983-1988 (excluding 1986).

The mean number caught at age per tow during autumn surveys from 1979 (1981 in Division 3L) to 1994, and the mean number per tow for Divisions 2J, 3K and 3L combined, may be found in Tables 3-6 of Bishop *et al.* (MS 1995b). The data from 1983 to 1994 have been converted to Campelen equivalents and are presented along with the actual Campelen data from 1995-1998 in Table 22 for Divisions 2J, 3K and 3L separately and for all three Divisions combined. Mean catch per tow has continued to be very low for each age in each Division during the past few years when compared with many years in the 1980s and early 1990s. In Division 2J in 1998 the mean catch per tow was highest for fish of age 4 (the 1994 year-class). The 1994 year-class has been the dominant year-class in Division 2J since 1995. In Division 3K in 1998, the 1997 year-class at age 1 experienced the highest catch per tow. The 1995 and 1996 year-classes were both more strongly represented than the 1994 year-class. In Division 3L the 1998 year-class at age 0 experienced the highest catch per tow, followed by the 1995 year-class at age 3.

Population numbers at length, calculated by areal expansion of the stratified arithmetic mean catch at length (3-cm groupings) per tow, are illustrated for 1995-1998 in Fig. 12. There were very few cod longer than 50 cm in any year. A strong mode at 19 cm in Divisions 2J and 3K in 1995 moved to 28-31 cm in 1996, to the upper 30s and lower 40s in 1997 and to the upper 40s by 1998. A comparison with the age samples reveals that this mode represented the 1994 year-class in 1995, but by 1997 and again in 1998 it was a combination of the 1994 and 1995 year-classes. The size composition in Division 3K in 1998 was strongly bimodal. The mode of larger fish was mainly 3 and 4-year-olds, as indicated above, and the mode of smaller fish was mainly 1 and 2-year-olds. The strong separation between the age 2 fish and the age 3 fish is surprising. The 1998 frequency from Division 3L has a distinct mode at about 9 cm (young of the year). In all three years Division 3L had more large fish than Divisions 2J and 3K.

4.2.2 Distribution

The distribution of cod at the time of the autumn surveys has been illustrated in numbers per standard tow (Shelton *et al*. MS 1996; Murphy *et al*. MS 1997) and in weight (kg) per standard tow (Lilly 1994, MS 1995). The catch from each tow in the period 1983-1994 has been recalculated to Campelen equivalents, and plots of these recalculated catches for 1985-1994 are shown together with the actual catches in 1995 and 1996 in Fig. 13. For the period 1981-1988 catches were wide-spread over the survey area. The first indication of the big changes to come occurred in 1988, when almost no fish were caught in the area of Harrison Bank in northwestern Division 2J. Commencing in 1989 the fish in Divisions 2J and 3K became increasingly concentrated toward the edge of the bank. By 1991, concentrations on Hamilton Bank and the plateau of Grand Bank disappeared, leaving fish in inner Hawke Saddle and in the saddles between Belle Isle Bank and Funk Island Bank and between Funk Island Bank and Grand Bank. In 1992, only the concentration between Funk Island Bank and Grand Bank remained. This concentration was smaller in 1993 and disappeared in 1994.

A few additional comments should be made regarding these distribution plots. First, the scale used in Fig. 13 does not give sufficient emphasis to the very large catches. The largest symbol size represents catches exceeding 1000 individuals. In the 1983-1994 period, 103 catches exceeded 1000 individuals, 35 exceeded 2000 individuals, and 11 exceeded 4000 individuals (see Table 21 in Lilly *et al*. MS 1998b). Of those that exceeded 4000 individuals, three occurred in 1986, the year in which the survey index was anomalously high, and seven occurred in 1989-1991, when the cod were becoming increasingly aggregated toward the edge of the shelf. Five catches exceeded 6000 individuals and three of these, including the two largest at 7354 and 8048 individuals, occurred in 1991 during the latter stages of the decline. The second comment regarding the new distribution plots is that the patterns look somewhat different from those seen in earlier plots based on the actual numbers of cod caught (Shelton *et al*. MS 1996; Murphy *et al*. MS 1997) or the weight (kg) of the cod caught (Lilly 1994, MS 1995). This is particularly so in 1989 and 1990 when the cod appear to be less concentrated toward the edge of the shelf than they did in the earlier plots, particularly those based on the weight of the catch. The difference is partly because the adjustment to Campelen equivalents has moved many additional sets into the largest bin (> 1000 individuals) used in the plots, and partly because the adjustment applied to each catch depends on the size distribution of the cod in that catch, so that some catches were increased very little while others were increased 10-fold and even 30-fold. The median increase in catch (number) per standard tow in the conversion from Engels catches to Campelen equivalents for all sets (not just those greater than 1000 individuals) was about 2.3 times in 1983-1984, about 2.0 times in 1987-1988, 2.8 times in 1989, 3.1 times in 1990, and about 3.0 times in 1991-1994. The relatively large increases in 1989-1994 are probably attributable first to the recruitment of the initially strong 1986 and 1987 year-classes and then to the disappearance of the larger fish.

Because catches in recent years have been very small, the distributions in 1995-1998 have been presented in Fig. 14 with the scale reduced by an order of magnitude compared with Fig. 13. In each of the four years, the larger catches were broadly spread over the southern Labrador and Northeast Newfoundland Shelf. Catches on the plateau of Grand Bank tended to be small, with the larger catches occurring near the Virgin Rocks and the Eastern Shoals. Some relatively large catches were obtained in the new inshore strata since fishing in these areas started in 1996.

4.2.3 Lengths, weights and condition

The lengths-at-age and weights-at-age of cod sampled during the autumn surveys confirm the general pattern of a decline in the 1980s and early 1990s as observed in commercial weights-at-age. The research survey data (Tables 23, 24; Figs. 15, 16) illustrate that the changes varied with Division; there was a strong decline in Division 2J, a lesser decline in Division 3K, and little or no decline in Division 3L. These Divisional differences are more apparent in Fig. 17, which focuses on changes in mean lengths and weights of cod of ages 4 and 6. Superimposed on the long-term decline are periods of relatively quicker or slower growth associated with changes in water temperature (Shelton and Lilly MS 1995; Shelton *et al*. MS 1996). The trend toward very low mean lengths and weights-at-age in the early 1990s appears to have been reversed, but sample sizes at ages greater than age 4 have been very small in recent years (Lilly MS 1998), so the accuracy of these estimates is poor.

Condition, as measured by both gutted body weight (Fig. 18) and liver weight (Fig. 19) relative to fish length, declined in Division 2J in the early 1990s. Gutted condition has since returned to approximately normal whereas the liver index has improved but not fully recovered. In Division 3K gutted condition declined and has since improved whereas liver index has changed little. In Division 3L gutted condition has remained relatively unchanged over time whereas liver index increased considerably in the early 1990s and has since declined. The historic trends in condition indices are complex and poorly understood (Lilly MS 1996c, MS 1997).

4.2.4 Maturity at age

The observed proportions mature at age for female and male cod in Divs. 2J+3KL combined from 1982 to 1999 as recorded during autumn surveys in 1981 to 1998 are shown in Tables 25 and 26, together with the parameters for a probit model with a logit-link function, the estimated A50 and the upper and lower 95% confidence intervals. The model estimates for A50 are illustrated in Fig. 20. In the early portion of the time series from 1972 until the mid to late 1980s the A50's were higher and fluctuated irregularly between 5.8 and 6.2 for females and 4.8 to 5.3 for males. From the mid to late 1980s until the present the A50's declined in both sexes and are currently at or close to their lowest values in the time series, at 5.25 for females and 3.84 for males. The most recent portion of the time series shows considerable year to year variability for both sexes suggesting that the declining trend may have halted.

4.2.5 Year-class strength

The weakness of recent year-classes is emphasized when mean catch at age per tow is plotted for the 1976-1997 year-classes at ages 1-3 (Fig. 21). The 1994 year-class at age 1 was relatively large compared with actual catches of earlier year-classes, but it looks very weak compared to previous year classes following conversion to Campelen equivalent numbers. The 1992-1995 year-classes at age 3 look weak even when compared with unconverted catches of some of the year-classes from the early and late 1980s.

4.2.6 Estimates of total mortality

Based on SPAs (eg. Lilly *et al*. MS 1998b), fishing mortality on fully recruited age groups was relatively stable at about 0.5 from 1977 to 1987, but increased rapidly to 1989. Fishing mortality rose above 1.0 in 1990 and continued to increase until the moratorium was declared in 1992.

If the autumn research vessel index at age is proportional to the population abundance at age then these data can be used to calculate total mortality (Z) for those ages that are fully recruited to the survey by means of the equation

$$Z_{a,y} = \ln\left(\frac{RV_{a+1,y+1}}{RV_{a,y}}\right).$$

For those ages that are not fully recruited to the survey, the relative Z values provide an indication of possible changes in total mortality, although not reflective of the actual mortality. The calculated Z's for ages 1 to 14 over the period 1983 to 1997 are plotted in Fig. 22. This plot demonstrates the big increase in total mortality that took place in the late 1980s and early 1990s. Total mortality remained very high for two years following declaration of the moratorium in mid-1992. Total mortality declined during the mid-1990s, but values for most fully or near-fully recruited ages appear to have remained well above 0.2, the value normally assumed for natural mortality. There is some indication of a decrease in Z on ages 4 and 5 in the most recent years. The extremely truncated age composition of recent surveys limits the usefulness of the analysis to some degree.

4.3 Spring surveys in Division 3L

Abundance and biomass of cod in Division 3L in the spring have been estimated by areal expansion of the stratified arithmetic mean catch per tow. Estimates for the surveys from 1978 to 1995 may be found in Tables 20-21 of Shelton *et al*. (MS 1996). The data from 1985 to 1995 have been converted to Campelen equivalents and are presented along with the actual Campelen data from 1996-1998 in Tables 27-28. The indices declined very rapidly from 1990 to 1994 and have remained very low in subsequent surveys. Fishing in waters deeper than 200 fathoms started on a regular basis in 1991 (Table 29). In some years a large portion of the total estimated abundance and biomass was caught outside the index strata in the deeper water. Trends in total estimated abundance and biomass are presented in Fig. 23.

5 Recruitment surveys and observations

Information on the relative strength of incoming year-classes is available from pelagic juvenile fish surveys, which capture fish at an age of a few months before they settle to the bottom; beach seine surveys, which capture 0-group and age 1 fish in shallow water along the coast; and the bottom-trawl surveys, which capture some 0-group fish during the autumn but are most useful for fish of ages 1 and older.

Pelagic juvenile fish surveys have been conducted in August-September 1994-1998 in inshore and offshore waters of Divisions 2J, 3K and 3L (Anderson *et al*. MS 1999). Over the five years of surveying, abundance declined from 1994 to 1996 and then increased. However, the 1997 and 1998 values remain below those measured in 1994 and 1995. In 1998, a large contribution to the index for 2J+3KL came from Division 3L. The index within Divisions 3NO was much higher than seen in any previous year, and it is suspected that the juvenile cod on the plateau of Grand Bank in Division 3L came from spawning in Divisions 3NO. The index in the offshore of 2J3K was relatively low in 1998. The index was higher in the bays, particularly White Bay and Notre Dame Bay. Bonavista Bay was not surveyed in 1998, but the index there has historically ranked among the highest.

A beach seine survey, referred to as the Fleming survey in honour of the scientist who conducted very similar surveys in 1959-1964, was conducted at the same sites from St. Mary's Bay in southern Division 3L to western Notre Dame Bay in central Division 3K during September-October 1992-1997 (Schneider *et al*. 1997; Methven *et al*. MS 1998). There was a decline in year-class strength from 1994 to 1996 but the 1997 survey yielded the highest mean catch of 0-group cod since 1992. Although this high mean was associated with high confidence limits, it was predicted that this year-class would be strong at age 1 in 1998 and would contrast with the weaker 1996 year-class. There was no broad-scale beach seine survey in 1998, but information is available from a survey over a much more limited spatial range within Newman Sound in southwestern Bonavista Bay (Gregory *et al*. MS 1999). Sampling was conducted in Newman Sound in 1995-1996 and 1998. Relative year-class strengths were shown to be consistent between the Fleming survey and the Newman Sound sampling. In both surveys, the 1996 year-class was weak. The prediction from the 1997 Fleming survey that the index for age 1 would be high in 1998 was supported by the Newman Sound survey. In addition, the Newman Sound survey yielded an age 0 index that was the highest in the short 3 year data set. Together, the Fleming survey and the Newman Sound sampling suggest that the 1997 and 1998 year-classes are stronger than the 1995 and 1996 year-classes.

It is notable that the pelagic survey and the beach seine survey were in agreement on the relative strengths of the 1994-1996 year-classes, but the 1997 and 1998 year-classes appear stronger in the beach seine survey than in the pelagic survey.

As noted above, the 1994 year-class appeared strong relative to adjacent year-classes in the offshore catches of the autumn bottom-trawl surveys, but all year-classes born in the 1990s appear weak compared to most year-classes in the 1980s.

6 Acoustic surveys

<u>Hawke Channel</u>

The Hawke Channel region of Division 2J was surveyed acoustically in June of 1994-1996 and 1998 and January 1998-1999 (G. Rose, Memorial University of Newfoundland, St. John's; pers. comm.). In June of 1994, the number of cod within the survey area was estimated at 18 million. The 1989 year-class was dominant, but there were also good numbers of the 1988 and 1987 year-classes. In June of 1995, most of the older fish were not found, and the 27 million fish were mainly of the 1991-1993 year-classes. In June of 1996, there were 35 million cod, most of which were younger than age 5. In June of 1998, there were approximately 28 million cod, mainly of the 1994 year-class. There was direct evidence of spawning in Hawke Channel in 1994, but there has been little spawning activity there since.

Smith Sound

A dense aggregation of cod was first found in Smith Sound, Trinity Bay (Division 3L) in spring 1995. Acoustic surveys of this Sound have produced biomass estimates of 13 thousand tons in early May 1995, 0.2 thousand tons in April 1996 and 21 thousand tons in April 1997 (Table 30). Surveys in other areas of western Trinity Bay in April 1997 and southern Bonavista Bay in June 1997 detected relatively small quantities of fish, so that the total biomass estimated for surveyed areas in spring 1997 was 23 thousand tons. A survey in Smith Sound in June 1998 produced an estimate of 14 thousand tons, and a survey in January 1999 produced an estimate of 15 thousand tons. The fish found in June 1998 were larger and older than those found in January 1999 (G. Rose, Memorial University of Newfoundland, St. John's; pers. comm.), so the number and quantity of cod using Smith Sound during the period from June 1998 to January 1999 may have been greater than was found during either individual survey.

Inshore 3K,3L in 1998

An intensive acoustic survey covered waters landward of the research vessel bottom-trawl survey from Cape St. Mary's at the southwestern limit of Division 3L to Great Harbour Deep in White Bay (Division 3K) in October-December 1997 (Anderson *et al*. MS 1998). This was after the time of the traditional offshore cod migration but at the same time as the traditional bottom-trawl survey which covered the offshore and the deeper waters of the bays. The acoustic survey gave a biomass estimate of 18 thousand t, of which 60% was in Trinity and Bonavista bays.

The problem of some cod being very close to the bottom in an acoustic "dead zone" was recognized by Anderson *et al*. (MS 1998) but not quantified. D.S. Miller (Focus Technologies, St. John's, NF, pers. comm.) estimated the quantity of fish within the dead zone by examining the fine scale distribution of acoustic signals in the zone from detected bottom to 5 m above bottom and extrapolating density estimates into the 'dead zone' with an exponential model. Revised estimates of biomass for 6 of the 7 survey areas indicated that biomass was underestimated in the original calculations by from 1.45 to 2.59 times. The revised biomass estimate for the entire survey area increased from 18 thousand t to 34 thousand t. At the zonal assessment meeting it was noted that alternate mathematical models gave different estimates, which could be lower or much higher than the estimate from the exponential model. Other ways of looking at the quantity of fish in the dead zone were also discussed. It was decided that more information about the acoustic dead zone was required. No new estimate for the quantity of fish in the dead zone was accepted by the meeting.

7 Sentinel surveys

Sentinel surveys were conducted in the inshore of Divisions 2J, 3K and 3L at various times from summer 1995 to autumn 1998 (Davis MS 1996). The primary goal of these surveys was to determine catch rates on traditional fishing grounds, primarily with linetrawls and gillnets, but also to a much lesser extent with traps. In addition, cod sampled from these surveys provide biological information on fish that are landward of the sampling conducted during the standard research bottom-trawl surveys.

7.1 Sentinel survey catch rates – exploratory analyses

Evaluation of the sentinel survey data for use in a quantitative manner in stock assessments, for example as a potential calibration index in SPA's, required a number of years data to be available. Now that the program has been running for 4 years the data can be evaluated, particularly in terms of being a potential index of stock size.

The survey design for sentinel comprised selecting fishermen from around the coast (Fig. 1d) to fish in a standard manner at consistent times and locations each year. Time and location for fixed sites were chosen to reflect the optimum fishing pattern with respect to each fishermen and were expected to remain invariant over the years. In addition to fixed sites, "experimental sites" were also fished providing more flexibility to the program. Only the fixed site data are considered further below.

From the available data recorded on log sheets and from biological sampling of the catches, catch rates were calculated in one of two ways, depending on the information available. If a catch weight is not recorded on the log sheet, the length frequency is nevertheless usually available and using a standard length – weight relationship, the weight of the catch can be estimated. If the catch weight has not been reported, this predicted catch was used to fill in the missing values where possible. In order to standardize the data, catch rates were calculated as kgs per net per day for gillnets and as kgs per thousand hooks per day for linetrawls. The linear correction for soak time is an approximation that may not apply to longer soaktimes because of gear saturation and other effects. However, most values fall in the linear or near-linear part of the function. Data are being accumulated from the scientific logbooks which would allow the functional form of the gear saturation curve to be modelled and such a model would be preferential to the linear approximation. However, in the interim it is considered necessary to account for soak time in some manner.

Three analyses were applied to sentinel catch rates from line trawls and gillnets. Handline catches are included in the first and third analysis only. Trap catches are not considered in any of the analyses because catches are only estimated and the fish are released, so that they may contribute to subsequent catches.

In the first analysis (Fig. 24), the square root of the catch rates for each fishermen were plotted individually for the period 1995 to 1998 to allow visual inspection of the data. Gillnet catch rate data are available for 3 sites in 2J, 23 sites in 3K and 27 sites in 3L. Linetrawl data are available for 2 sites in 2J, 12 sites in 3K and 12 sites in 3L. Handline data are available for 4 sites in 2J, 3 sites in 3K and 1 site in 3L. Gillnet catch rates for 2J are quite sparsely distributed over the years. Only at Williams Harbour and Spear Harbour are all four years of the sentinel survey represented, and in the case of Williams Harbour, only one set was made in 1998, in the case of Spear Harbour, only one set was made in 1996 and in the case of Cape Charles, only one set was made in 1996. Although sparse it appears that gillnet catch rates in 2J were lower in 1995 compared to other years. Linetrawl data for 2J are also very sparse and are only available for the last three years. There do not appear to be any trends in the data.

Gillnet data for 3K show that most sites that were fished in 1995 recorded relatively low catch rates with subsequent years being higher. Visual inspection of the data do not indicate clear trends at most sites for the subsequent years. There is evidence of a seasonal trend at some sites, for example a declining trend from the end of June to the end of September at Jackson's Cove. Linetrawl data for 3K is also low in 1995 at most sites and was low at Goose Cove and Coachman's Cove in the last one to two years. There is not much evidence of a seasonal signal in the data. There appear to be little in the way of trends in the data after the 1995 to 1996 increase. Data from handlines for 3K are quite sparse and no trends can be seen.

In 3L, gillnet data indicate relatively low catch rate values in 1995 and higher values in subsequent years. There is evidence of seasonality at some sites, such as Little Catalina. There is a lot of spatial variability within the division, for example between catch rates at Little Catalina (high) and Thornlea (low). Some gillnet data in 3L are quite sparse, for example Calvert. Linetrawl catch rates in 3L are low in 1995 at most most sites, increase in 1996 and then remain fairly constant. Some sites suggest more of an increasing trend, such as Calvert. Considerable handline data are avilable for Petty Harbour. Again catch rate values for 1995 are low but subsequently there is no evidence of a trend.

In summary, the plots for the individual sites for the three gear types indicate that catch rates were lower in 1995 throughout 2J3KL but with no clear trend thereafter. There is evidence of a seasonal cycle at some sites and some evidence of year to year differences in the timing of fishing which could impart a spurious signal (depending on when the sentinel fishing at the site took place relative to the seasonal cycle). In some cases the series for the site is very short because of fishermen entering or leaving the program, or contributing few sets in some years, making it difficult to determine whether trends in catch rates exist at these sites.

In the second analysis the mean and the 90th, 75th 50th, 25th and 10th percentiles are plotted across years for the sentinel catch rate distribution within cells formed by unit area, year, month, for linetrawls and gillnets (Fig. 25). A historical reference based on the median catch rate for vessels larger than 35ft for the period 1987 to 1992 is included but the shortcomings of these data are noted. Linetrawl data north of Notre Dame Bay are too sparse to draw any conclusions. From Notre Dame Bay south there is evidence of seasonality in several unit areas, for example an increase in the fall at Fogo Island in both 1995 and 1996. However, the duration of the fishery is too short in most instances to see the seasonality that probably exists at all sites. Some of the unit areas suggest that an increase has taken place over the time period. For example, on the Southern Shore catch rates are higher in 1997 and 1998 than they are in the previous two years. However the adjacent unit area, St Mary's Bay shows a decrease in 1998 and decreases also appear to have occurred in Conception Bay, Bonavista Bay and Fogo Island in 1998.

Gillnet catch rates for most unit areas were relatively low in 1995 compared to subsequent years. Subsequently there is evidence of an increasing trend in Notre Dame Bay and Fogo Island, and evidence of higher values in the final year compared to previous years in Trinity Bay and Conception Bay. Several areas show strong seasonal signals in catch rates, for example Bonavista Bay, Trinity Bay, Southern Shore and St Mary's Bay.

In the third analysis, sentinel catch rates were subjected to statistical tests to determine whether or not there has been a significant increase from one year to the next. In order to do this a non-parametric test for ranked data was applied. A two-tailed Kruskal-Wallis test was used to indentify sites for which there has been a shift in location of the distribution of catch rates between the two years being compared. This test only informs as to which sites have observed a statistically significant change in catch rates, and does not provide the direction of the shift between years. To obtain information on the direction of change, a general linear model was fit to ranked catch rate data. Comparison of means for sites observing statistically significant change in catch rates provides an indication whether the central tendency of the distribution of catch rates has increased or decreased over the years under examination. It is important to note that although sites are grouped by division, the comparison is done by sentinel fishermen, so that the change in catch rate by individual fishermen over time is being evaluated and then the results of this evaluation are summed to give an outcome for the whole division. The outcome of these tests are summarized in Table 31.

For 2J gillnets, at the $\alpha = 0.05$ level, there is little evidence of an increase over the time period. For linetrawls and handlines in 2J there are very little data. There is no support for an increase in catch rates over the time period of the sentinel for either gear in 2J. For 3K gillnets, most sites showed a significant increase when comparing subsequent years to 1995. In comparing years 1996 to 1998, more sites decreased from 1996 to 1997 and 1996 to 1998 than increased whereas in 1998 all sites that had a significant difference between 1997 and 1998 showed an increase (6 out of 22). For 3K linetrawls, most sites showed a significant increase in subsequent years when compared with 1995. However the catch rates at all sites for which there was a significant change, catch rates were lower in 1998 compared to either 1996 or 1997. Handline data for 3K are sparse.

For 3L gillnets, most sites showed a significant increase between subsequent years and 1995. Out of 22 sites common to both 1997 and 1996, 8 showed a significant difference and for 3 of the 8 this represented an increase from 1996 to 1997. Most gillnet sites in 3L for which there was a significant difference between 1998 and either of the previous two years, showed that there was an increase. For linetrawls in 3L nearly all sites showed that 1996-1998 were significantly higher than 1995. Comparing 1998 with 1996, 1 site was significantly lower and 1 site was significantly higher. Of the two sites that showed a significant difference between 1997 and 1998, both showed a decrease. Comparative data for 3L handline are available for only two sites and there was no significant difference between 1998 and 1997.

In summary, a number of conclusions can be drawn regarding sentinel catch rates in 2J3KL. Firstly, there is a distinct seasonality in catch rates for some gear type – location combinations, particularly in the case of gillnets. Therefore, changes in the distribution of sentinel fishing effort with time, as can be observed from the daily plots for individual fishermen, could impart a spurious signal into the sentinel catch rate data. Sentinel catch rates in 2J3KL were generally significantly higher after 1995 but thereafter some sites showed further increases, several sites suggested no significant change and several sites indicated decreases. In several areas there is an indication that linetrawl catch rates were relatively lower in the most recent year. Clear trends in the sentinel catch rate data for 2J3KL cannot be inferred at this stage. It seems likely that the combination effects of gear selectivity and seasonality will have to be disentangled from the age-disaggregated data on a site by site basis to gain further insight into variability. This exercise will be made more difficult by the entry and exit of sites into the program and the temporal variability of fishing effort relative to the seasonal cycle in local fish abundance. If there is a trend in real stock size for 2J3KL cod over the time period of the sentinel program, then the contribution of this signal to the age aggregated index is relatively weak compared to the other sources of information. However, if the stock size has been relatively constant then this would be compatible with the data. Although sentinel catch rates are generally high at most locations during the four year period compared to pre-moratorium values, there is no way to scale this to stock abundance.

7.2 Sentinel survey catch rates - standardized

Annual trends in sentinel survey catch rates were explored using an Analysis of Variance to account for effects associated with month and sentinel enterprise. For each of the two major gears (5.5 inch gillnet and linetrawl) the following model was fit:

Ln(sum of catch/sum of effort) = Year + Month + Enterprise

where the years were 1995-1998, the months were July to November for gillnets and August to November for linetrawls, and the enterprises were all those in Divisions 3K and 3L that fished with that specific gear in any of the above years and months. (Each enterprise was assigned a unique number.) Results of an earlier model had shown no significant difference between Divisions, so data from the two Divisions were combined. Catch per unit effort was expressed as number of fish caught per net (gillnet) and number caught per hook (linetrawl). Catch rates were not standardized for soak time, but only records with soak times between 18 and 24 hours were selected for the gillnet analysis and only those less than or equal to 12 hours were selected for the linetrawl analysis. In the gillnet data, there were no instances in which the catch within a cell (year, month, enterprise) was zero. However, in the linetrawl data there were 11 instances of zero catch. Two analyses were conducted for linetrawls; one in which cells with zero catch were eliminated and one in which zero values in the catch were replaced by a value of 1.

In the gillnet analysis, all main effects were significant (Table 32). The standardized gillnet catch rate increased from 1995 to 1996, remained steady in 1997, and increased in 1998 (Table 32; Fig. 26). In the linetrawl analyses, month was not significant in either of the two runs. The standardized linetrawl catch rate showed relatively little change from 1995 to 1996, increased from 1996 to 1997, but declined in 1998 to approximately the 1995 level (Tables 33, 34; Fig. 26). Reasons for the annual changes in catch rates were not explored at this time.

7.3 Sentinel survey age compositions

To explore annual variability in the age composition of the sentinel catches, catch at age was calculated by Division, gear and year as described in Appendix 1 of Lilly *et al*. (MS 1998a). To keep the information comparable among years, the catch included only cod caught at control sites within a specified period of the year, but excluded those fish frozen for detailed study in the laboratory. For gillnets, only the catch from 140 mm nets was included. The samples for aging came only from the appropriate Division, gear, year and time of year, with the exception that any age samples from gillnet mesh sizes other than 140 mm were not excluded. The time period was July 16 to September 30 for gillnets and August 16 to September 30 for linetrawls. This represents the time of most frequent deployment of these gears across the many sentinel sites (B. Davis, Department of Fisheries and Oceans, St. John’s, NF, pers. comm.).

The age compositions are provided in Table 35. At the bottom of each age composition are the number of fish caught, the number of fish assigned an age when the age-length key is applied to the length composition and the number of fish aged. In several instances the number of aged fish was small. In almost all instances there were individuals of a length not represented in the age sample and therefore not assigned an age. This usually occurred toward either end of the length frequency. Therefore, the age compositions may underrepresent and possibly even miss ages toward either end of the range. This highlights the difficulty with attempting to determine catch at age from small samples.

The relative strength of the 1990 year-class was most apparent in Division 3K. The 1989 year-class was more strongly represented in Division 3L than in Division 3K. These age compositions include older fish than were found offshore in the same years. For example, age compositions from linetrawls in Division 3K in 1995-1998 included ages that were not even recorded in the aging of cod from the autumn research vessel survey in Division 3K (Fig. 27). This was particularly notable in 1996 and 1997.

8 Index fisheries

The Fisheries Resource Conservation Council (1998; p.32) recommended that “an index program be established to provide additional information to supplement sentinel programs and to add confidence, inshore and offshore, in cod population estimates” and that “as part of this program catches … be spread over the full range of the stock area and over time”. The program put in place involved an inshore component and an offshore component.

8.1 Inshore index fishery

Participation in the inshore index fishery was made available to all Level I and Level II Professional Fish Harvesters who held a groundfish licence for a vessel <65 feet. The fishery was conducted on an IQ basis with each eligible enterprise licenced for 2700 lbs (round weight). The fishery was open from September 24 to October 16, 1998. All licence holders were required to complete logbooks. A total of 2813 enterprises landed 3139 t.

Logbooks were not required for vessels less than 35 ft prior to the moratorium and catch information was inferred from purchase slips and other sources. No measure of fishing effort is available for the less than 35 ft vessels for the pre-moratorium period. Vessels greater than 35 ft were required to complete logbooks prior to moratorium. These historic data have been examined by Murphy and Shelton (MS 1997) and found to be extremely sparse and unreliable.

A new science logbook was introduced as a condition of license for vessels less than 35ft for the commercial “index” fishery in 1998. Catch rates have been derived for cod-directed sets from the data provided by fishermen. A sample is considered to be the catch rate for each "set", irrespective of the number of nets or hooks deployed, for either gillnets or line trawls in a specified unit area, month and year. Catch is expressed in kilograms. Gillnet effort was standardized to net per day and linetrawl effort was standardized to 1,000 hooks per day.

Arithmetic means were considered as a possible statistic for making comparisons; however, the distributions of sample values within area/month/year cells tend to be skewed with long tails representing a small number of high catch rates. To illustrate possible trends in the data from the commercial fishery in 1997 and 1998, the mean, median 90th, 75th 25th and 10th are shown to examine how the distributions may have changed over time or space. Emphasis is placed on the median as an indicator of central tendency in the comparisons below.

Spatial differences in gillnet and linetrawl catch rates for the index fishery in 1998 are illustrated by plotting the percentiles and the mean by unit area (Fig. 1b) arranged sequentially around the coast in Fig. 28. Data for the 3Ps cod stock are included for comparison purposes. The number of sets that occurred in each area are tabulated below the graphs. Fogo represented 40% of the linetrawl sets made in 2J3KL in 1998, and Trinity Bay represented 25% of the sets. Linetrawl catch rates were relatively low near the Strait of Belle Isle, area 3, only 3 sets), relatively constant from White Bay to Fogo (area 4 to area 6) at about 1,000 kgs per thousand hooks per day, highest in Bonavista Bay (area 7) with the median over 2,000 kgs per thousand hooks per day and about 600 to 800 kgs per thousand hooks per day from Trinity Bay to St Mary’s Bay (area 8 to area 11). Linetrawl catch rates were higher in 3Ps (areas 12-14) than all areas in 2J3KL with the exception of Bonavista Bay.

Spatial differences in gillnet catch rates indicate that, with the exception of Labrador, where there are few data, there is a steady increase from about 20 kgs per net per day in White Bay (area 1) to over 50 kgs per net per day in Bonavista Bay (area 7). Gillnet catch rates were a little lower in Trinity and Conception Bays (areas 8 and 9), but rose to about 65 kgs per net per day for the Southern Shore (area 10) and to a peak value of over 200 kgs per net per day for St Mary’s Bay (area 11), although only 34 sets were made in this area. In comparison to 2J3KL, gillnet catch rates in 3Ps are relatively low (10-30 kgs per net per day).

Spatial differences are examined on a finer scale by calculating the mean catch within statistical sections for each gear (Fig. 29). By reference to the map illustrating statistical sections (Fig. 1c), it may be seen that catch rates tended to be highest from eastern Notre Dame Bay to western Trinity Bay. Gillnet catch rates were also high along the eastern side of the Avalon Peninsula and especially in St. Mary’s Bay.

8.2 Offshore index fishery

An offshore index fishery was conducted by Fisheries Products International Limited in Division 3L during November 16-26, 1998. The initial plan was to spend the first few days searching the area with the ship's sounder to find concentrations of cod, and then to delimit aggregations by passing over them repeatedly and to fish them in a regular commercial manner, with the exception that the quota would be spread among several aggregations.

The initial period of searching during the first three days yielded no aggregations. The ship then adopted a strategy of fishing in areas where fish would have been expected at this time of year. A total of 26 tows were made at various locations in Division 3L. The largest catch was 600 lb in the vicinity of the Virgin Rocks – Eastern Shoals. All other catches combined yielded an additional 200 lb. The catch rates were considered by the company to be extremely low. The 600 lb catch (at 46 22 N; 50 47 W) comprised 76 fish, mainly in the 75-90 cm range.

9 Food fishery

A food fishery was permitted for 3 days (August 28-29 and September 19). Participants were restricted to a maximum of 10 fish per day. Only baited or feather hooks and lures were permitted. It is estimated that 696 t were landed. Average catch rates varied widely from 0.73 fish per hook per hour in Conception Bay to 4.6 in Bonavista Bay (Inkpen and Kulka MS 1999). The overall average was lower than in 1996, the last time that a food fishery was open in 2J+3KL. Mean size and range of fish size increased from Division 2J to 3K to 3L (means of 45, 54 and 59 cm, respectively).

10 Population analysis

<u>Analytical assessment</u>

An analytical assessment was not attempted. The inability to reconcile reported catches and the research vessel index in the late 1980s and early 1990s has not been resolved.

If this were the only problem, then there would be value in proceeding with sequential population analysis, as had been done in the previous assessment (Lilly *et al*. MS 1998b), in order to conduct a tentative risk analysis. It was felt, however, that the research vessel bottom-trawl index, the only long-standing fishery-independent index available for this stock, may no longer be representative of the stock as a whole. It is thought that the index is adequently reflecting the status of the stock in the offshore, which constitutes the vast bulk of the stock area, but is not reflecting the status of cod found on traditional inshore fishing grounds (depths less than 50-60 m) from White Bay to St. Mary's Bay. For example, the size range of the cod in the inshore includes much larger fish than are found in most of the offshore. Large fish were seen in catches of the sentinel survey and index fishery, among fish dying in ice and among the carcasses remaining from belly-feeding by harp seals. In the offshore, large fish have been found only in small numbers in a few areas of Division 3L in both the research survey and the offshore index fishery. In addition, age compositions in sentinel surveys look very different from those in the research survey, although it is acknowledged that the research survey has higher selectivity for young fish. By way of example, it is noted that the 1990 year-class is recognized as being relatively strong in the inshore. It has been an important contributor to sentinel survey catches since the surveys started in 1995 and it contributed to catches in the 1998 inshore index fishery. In contrast, the 1990 year-class is weak offshore in both the autumn bottom-trawl survey and in the June acoustic studies in Hawke Channel. It was caught in only very low numbers in Divisions 3K and 3L during the autumn research survey in 1998.

It was decided that an analytical assessment of the inshore alone was not possible because inshore catches prior to the moratorium could not be apportioned into those coming from inshore components and those coming from components that migrated into the inshore from the offshore. It is thought that most of the historic inshore catch came from the latter.

Because of the interest in harvesting those cod that reside in the inshore, attention was focused on obtaining a biomass estimate for that "component" alone.

Mark-recapture experiments

Estimating the abundance of inshore cod in 2J+3KL is difficult because the complexity of both near-shore topography and fish behaviour make it very difficult to use either bottom-trawling or acoustics. However, mark-recapture experiments where tagged cod are returned from commercial fisheries can be used to estimate the abundance of inshore cod, provided the experiments are carefully designed. The rate of tag returns is related to the exploitation rate of the fishery, but the design must be planned so that parameters such as tag loss, tagging mortality, reporting rate, and migration can also be taken into account.

Cadigan and Brattey (MS 1999a, b) used tag returns from 21 tagging experiments conducted in Placentia Bay and inshore 3KL during 1997-1998 and developed a model to estimate the migration rates between these regions and the exploitation rates within the regions. They estimated that 7% of Placentia Bay cod migrate into southern 3L seasonally and that those that survive exploitation return to 3Ps. Migration rates between southern 3L and adjacent areas were more complex. Many fish tagged in southern 3L were in fact Placentia Bay cod.

Estimates of exploitation rates for 3Psc, where there was a commercial fishery, ranged from 0.4% in the first six months of 1998 to 9.7% in the latter half of 1998 and were consistent with reported landings. Exploitation rates for 3K and 3L throughout 1997 and the first six months of 1998 were very low (0 to 1.1%). Reported landings for these periods were very small because of the moratorium.

The number of tags returned from 3KL increased considerably in the second half of 1998 as the sentinel surveys, a food fishery and a new index fishery were conducted. The information was used to estimate exploitation rates and stock size for the 1998 index fishery. Because of the pattern in tag returns (see Section 2.3) estimates were made for two areas; (1) 3K and northern 3L, including Bonavista and Trinity bays and (2) southern 3L from Conception Bay to St. Mary's Bay. The exploitation estimate for 3K and northern 3L was 6.2%. The estimate for southern 3L was quite variable, but a reasonable lower bound on exploitation in this region was 5%. Using the reported commercial landings in 1998 for these regions, the exploitation rate estimates suggest that 52,000 t of cod were available to the index fishery in 3K and northern 3L, with a 95% confidence interval of 36,000 – 135,000 t. The analysis suggests that no more than 15,000 t of cod were available to the index fishery in southern 3L. Some of these cod had migrated into southern 3L from Placentia Bay in Subdivision 3Ps.

Extrapolation of sentinel survey catch rates

During the 1998 assessment meeting the biomass of cod in the inshore of divisions 3KL in 1997 was estimated by (i) calculating the ratio between sentinel gillnet catch rates in Placentia Bay (Subdivision 3Ps) and a mark-recapture estimate of biomass in that bay and then (ii) applying that ratio to sentinel gillnet catch rates in 3KL. The methodology is given by Winters and Brattey (MS 1998). As stated in the Stock Status Report for 1998: "This estimate is subject to many uncertainties, including the accuracy of the estimate of biomass in Placentia Bay and the comparability between Placentia Bay and coastal areas in divisions 3KL with respect to fishing behaviour by the sentinel fishers and the size composition of the fish. In addition, the extrapolation may be biased because of uncertainty in the relationship between gillnet catch rates and fish abundance. High catch rates can be maintained over a wide range of fish densities; ideally multiple measures of catch rate over a wide range of densities are required."

During the zonal cod assessment meeting (Rimouski, 1-12 March 1999), authors of the present paper were instructed by the Chair to apply the methodology of Winters and Brattey (MS 1998) to data collected in 1998. The details of that calculation are provided in Appendix 1.

11 Consumption by seals

Quantity of cod consumed

The quantity of cod consumed by harp seals in 2J3KL was estimated using a model that incorporates information on the numbers at age of harp seals in the Northwest Atlantic, energy requirements of individual seals (based on an allometric relationship with body weight), the seasonal distribution of seals in 2J3KL, and geographical and seasonal variations in the proportion of cod in the diet (Stenson *et al*. MS 1999a). The basic model is described in Stenson *et* *al*. (1997) and Hammill and Stenson (MS 1997). However, a number of the inputs were revised by Stenson *et al*. (MS 1999a), including estimates of the numbers at age, residency time in 2J3KL, the proportion of the population in offshore areas and the proportion of cod in the diet.

Numbers at age were obtained using the methods described in Stenson *et al*. (MS 1999b). The population model described in Shelton *et al*. (1996) was updated by incorporating revised estimates of catches in Greenland, additional information on recent harvest levels, the age structure of catches and current reproductive rates. As recommended by the National Peer Review Committee (February, 1999), a form of the model was used that assumes pup mortality was three times that of older seals and that the level of unreported catches is 5% for young of the year taken off Canada and 50% for all other seals. Using this model, the total population of harp seals in the Northwest Atlantic in 1998 was estimated to be approximately 5.15 million and relatively stable since 1996.

The assumptions made to estimate the seasonal distribution of harp seals in 2J3KL were revised in Stenson *et al*. (MS 1999a). Based on Kapel and Rosing-Asvid (1996) and Sergeant (1991), 20% of the individuals in all age-groups were assumed to remain in the Arctic. By tracking the movements of harp seals using satellite telemetry, Stenson and Sjare (MS 1997) determined the average residence time of seals in 2J3KL. This period (Nov. 21 to July 6), used by Stenson *et al*. (MS 1999a), is very similar to the residency period assumed in previous studies (228 d vs 212 d). The largest change in the assumed distribution of harp seals between Stenson *et al*. (MS 1999a) and earlier studies (Stenson *et al*. 1997; Hammill and Stenson MS 1997) is in the proportion of energy obtained from offshore and inshore areas. In previous studies 55% of the energy requirements were assumed to be obtained from areas represented by the offshore diet. This was obtained by assuming that seals were randomly distributed between the coast and the 400m depth contour. Stenson *et al*. (MS 1999a) assumed that 89% and 86% of the energy required in summer and winter periods, respectively, were obtained in offshore areas. They obtained this estimate by plotting the locations of seals in 2J3KL obtained from the satellite tracking study described in Stenson and Sjare (MS 1997) and determining the proportion of positions present within a 25 km band of the coast. This band was chosen to represent the areas where the inshore diet samples were obtained (primarily by small boat sealers and inshore fishermen within the bays and headlands). Increasing the width of this band appeared unlikely to increase the proportion of seals in the inshore areas significantly.

The proportion of cod in the diet of harp seals in 2J3KL was estimated based on the reconstructed stomach contents of seals collected from both inshore and offshore areas. The basic methods used to reconstruct stomach contents were similar to those used previously. However, Stenson *et al*. (MS 1999a) modified the methods described in Lawson *et al*. (1995) and Lawson and Stenson (1997) to reflect recommendations of the Seal Consumption Workshop (December 1998, Halifax, N.S.). In order to account for unidentified prey (primarily invertebrates) the total reconstructed prey weight was adjusted upward by 10%. Also, different regression equations were used to estimate the wet weight of Atlantic cod from otolith measurements. In previous studies (e.g. Lawson *et al*. 1995; Lawson and Stenson 1997) wet weights were estimated using regressions presented by Ross (1993). Stenson *et al*. (MS 1999a) used the relationship developed by Lidster *et al*. (1994) to estimate the length of cod from the otolith measurements and the standard length/weight equation used in groundfish assessments in the Newfoundland Region to estimate the wet weight from body length. Comparing the two methods indicates that although the lengths of cod consumed by seals are similar, the weights of cod consumed differ greatly, especially for cod greater than 30 cm.

In previous studies (Stenson *et al*. 1997; Hammill and Stenson MS 1997) the proportion of cod in the inshore diet during the winter (October – March) and summer (April – September) seasons was assumed to be the average of samples collected in 1982, 1986, 1990, 1991, 1992 and 1993. Stenson *et al*. (MS 1999a) included additional samples from nearshore areas for the years 1987-89 and 1994-96. As a result, they were able to estimate the proportion of cod in the diet of inshore harp seals during the winter and summer seasons for the years 1982 and 1986 - 1996. Incorporating the additional data, particularly the higher level of cod in the summer diet in recent years, resulted in higher estimates of the average proportion of cod in the diet during the summer (5.08% vs 2.76%, Hammill and Stenson MS 1997), but a lower proportion of cod in the winter (2.99% vs. 4.9%).

In previous estimates the proportion of cod in the offshore diet was obtained by combining all samples collected during each season. In order to be consistent with the way in which the inshore data were treated and to provide an estimate of uncertainty in this component of the diet, Stenson *et al*. (MS 1999a) averaged the annual proportion of cod in the diet over years for which samples were available. The proportion of cod in the diet of offshore harp seals used by Stenson *et al*. (MS 1999a; 2.12% summer, 0.96% winter) was significantly lower than that used previously (9.46% summer, 1.26% winter; Hammill and Stenson MS 1997). Although averaging the samples reduced the estimate slightly, the primary reason for this difference was the methods used to estimate the wet weight of cod consumed, particularly for the summer offshore samples which contained a number of large cod (>30 cm). The wet weight of cod obtained using the relationship presented in Ross (1993) is double that estimated using Lidster *et al.* (1994) and the standard groundfish length/weight relationship for cod 35 cm in length and is almost triple for cod 45 cm long. Given the small sample sizes available for offshore areas and the larger fish present, these differences are highly significant.

The various changes in the proportion of cod in the harp seal diet are summarized in the following text-table.

	Previous calculations		New calculations	
	Winter	Summer	Winter	Summer
Inshore	4.90	2.76	2.99	5.08
Offshore	1.26	9.46	0.96	2.12

Using the average proportion of cod in the diet, approximately 50,000 tonnes of cod were estimated to have been consumed in 1998. The uncertainty associated with this number was estimated by applying the 95% confidence interval in the proportion of cod in the annual diets for each area and season. This is a minimum estimate of uncertainty since it does not incorporate variation within annual diet estimates and assumes that all other components of the model (numbers at age, residency, energy requirements, etc) are known. Efforts are underway to incorporate these sources of uncertainty in the model.

In addition to estimating consumption using an average diet, consumption was also estimated using annual estimates of the nearshore diet. An average was used for the offshore area due to the lack of annual data. For this run, the diet in years for which data were not available was assumed. For the period 1974-81, the proportion of cod in the diet was assumed to be the same as in 1982 while an average of the 1982 and 1986-90 data was applied to the 1983-85 period. Considering the increased cod seen in the diet in recent years, an average of the last two years for which data were available (1995 and 1996) was used for 1997 and 1998. Based upon these assumptions, approximately 65,000 tonnes of cod were consumed by harp seals in 1998.

The present estimate of the quantity of cod consumed by harp seals is approximately 50% of the estimate given one year ago. The magnitude of this change illustrates the uncertainty involved in these calculations. As described above, there were numerous changes in the calculations. The major reason for the lower estimate of consumption is a revision in the weights of individual cod consumed by the seals as calculated from the sizes of cod otoliths found in seal stomachs. The second most important factor in the decline is a change in the proportion of the seal energy requirement estimated to be coming from the inshore. The previous estimate of 45% in both summer and winter was revised to 14% in winter and 11% in summer. This is partly a consequence of defining a more narrow inshore zone (the zone in which inshore stomach samples were collected), but the primary reason for the change was the additional data obtained from monitoring seal movements using satellite telemetry tags. The previous estimate assumed that seals were randomly distributed from the coast to the shelf break, whereas the data now available suggest that harp seals are more common in offshore areas (>100 km from the coast). It must be noted that in the Stock Status Report it is stated that “the reduction in the proportion of energy coming from the inshore caused a decline in the estimate of cod consumed because the proportion of cod in the harp seal diet is higher in the inshore than in the offshore.” The changes in the diet are more complex than that, as described above.

Observations of seals consuming cod bellies

For several years there have been reports of seals biting just the bellies from cod and leaving the head and musculature uneaten. As noted in the section on recent observations of cod in shallow water (see Section 2.2), there have been numerous observations during the past two winters of seals biting the bellies out of cod and leaving the remainder of the body, including the head. Commercial sea urchin divers have reported seeing large numbers of dead cod with their guts bitten out.

A sample of 5 cod was obtained by a diver in the Jamestown area of Bonavista Bay during the first week of January 1999. These fish ranged from 49 cm to about 80 cm. Each fish had a large hole in its abdomen. The hole tended to be centred ventrally and to be semi-circular when viewed from the side. The vertebral column was intact. None of the organs could be seen where the hole was. However, when the abdominal wall was cut anterior and posterior to the hole, one could find the esophagus and sometimes the anterior part of the stomach, the posterior part of the intestine and all or part of the gonad. In 3 animals the ovaries were intact. The ovaries were small and completely posterior to the edge of the hole. In all cases, the liver, most or all of the stomach, and most of the intestine were gone. The remaining organs or organ parts were in good condition. The appearance of the fish is consistent with the reports of those who have seen seals feeding on large cod.

Numbers at age eaten by harp seals

The revised estimates of the quantity of cod consumed by harp seals were used to estimate numbers of cod (at age) consumed by the seals using the methods described in Stansbury *et al*. (MS 1998). The revised estimates were calculated only to 1995. The data required to extend the consumption at age to 1998 are still being prepared and are not available for this assessment.

A total of 438 of the seal stomachs examined from 1986 to 1995 contained Atlantic cod otoliths. From these stomachs 1,547 otoliths were recovered. Length frequencies were derived from the otolith length – fork length regression found in Lidster *et al*. (1994). Data were originally separated into quarterly time periods for each year for inshore and offshore. In the current analysis, the inshore and offshore were combined because of the paucity of the data from the offshore. In addition, the quarters were combined into the first half and the second half of the year.

The length frequencies reconstructed from otoliths in the stomach samples were compiled into half-yearly length frequencies for each year (Fig. 30). Although otoliths from the seal stomachs have been aged, the data may not be extensive enough to be used to break down the annual length frequencies by half year. For this reason age sampling from the spring 3L research surveys using the Campelen trawl in 1996-1998 were combined to give a key for the first half of the year (Table 36) and sampling from the autumn surveys in 2J,3K and 3L using the Campelen in 1995-1997 were combined for the second half of the year (Table 37). These keys were applied to the seal length frequencies on a half-yearly basis for each year to give the numbers at age.

Mean weights at length were calculated from the standard weight-length regression and used in conjunction with the length frequencies and the estimates of biomass consumed to calculate numbers of cod. Proportions at age were calculated by applying the semi-annual age-length keys to the semi-annual length frequencies in each year.

The annual estimates of numbers of cod at age consumed by seals are provided in Table 38 and Fig. 31 and the biomasses at age consumed are in Table 39. In the early years most of the predation was on ages 0-2, with the bulk occurring on age 1. In 1992 , 1993 and especially 1995 there was a greater proportion of older cod (ages 3-5) in the diet. The change in age composition results in a trend of fewer (but older) cod being consumed in recent years (except 1994), even though total consumption in weight has been increasing.

In the absence of a sequential population analysis for the cod stock (see Section 10), the importance of seal predation to the dynamics of the cod stock was not explored further.

Additional uncertainities

Information regarding the population size, distribution and feeding behaviour of seals increases each year and leads to changes in estimates of the number, size and age of cod and other species consumed by the seals. Changes in perception can be large, as illustrated by the considerable reduction in the cod consumption estimates from last year to this year. Much of the uncertainty associated with the consumption of cod in particular arises because cod is a minor prey of the harp seal. The population of harp seals is large, so slight changes in the proportion of cod in their diet can lead to large changes in the quantity of cod which they are estimated to consume.

There are many sources of potential bias in the estimates (Stenson *et al*. MS 1999a). Only a few that received particular attention during the assessment meeting are discussed below.

The proportion of cod in the diet of harp seals in the inshore has increased in recent years. The harp seal stomach samples are obtained from collectors who may not necessarily be sampling in a random manner. It is possible that a disproportionate number of the samples is coming from seals that are aggregated around the cod aggregations. If this is the case, then the estimates of the proportion of cod in the diet may be too high.

On the other hand, the predation by harp seals on just the bellies of cod may be biasing the proportion of cod in the diet because the soft parts would not be recognized and taken into account in the diet reconstructions. It is recognized that the weight of cod killed by belly-feeding is much higher than the weight consumed. The feeding on bellies also causes the size composition of the cod killed to move toward larger sizes compared with a size composition based solely on otoliths. At this time there is little information on the proportion of the seal population engaging in this form of predation, the number of days on which it happens and how many cod each of these seals kills per day. There is also no information on what proportion or what components of the cod stock are subject to this predation.

During the zonal assessment meeting it was suggested that perhaps the proportion of the seal herd occupying the inshore, as estimated from the satellite telemetry, was underestimated if a high proportion of the seals inshore are young animals and the tags had been applied only to older animals. In the Stock Status Report it was reported that “the tags had been applied to younger and older seals in the same proportions as the occurrence of these two groups in the population”. This statement is in error. Tags were applied only to older seals. However, the diet samples from the inshore came from both younger and older seals and the age structure of the samples is consistent with the proportions of younger and older seals estimated in the population. This suggests that, in general, younger seals are not more strongly represented in the inshore.

12 Outlook

The risk of fishing the 2J+3KL cod stock at various catch levels cannot be quantified because the current stock size is poorly measured. It is clear however that the size of the stock as a whole remains low relative to levels in the 1980s and very low compared to earlier decades. Even during the peak of partial recovery in the mid-1980s the stock was characterized by low abundance, truncated age distribution and poor inshore catches compared with levels prior to the huge removals offshore in the 1960s and 1970s.

The prospects for recovery of cod in the offshore based on regeneration by those cod currently there appears to be dismal in both the short and medium term. The spawning biomass continued to decline after imposition of the moratorium and has for several years been extremely small, especially north of Division 3L. All year-classes born in the 1990s have been small and have experienced high mortality.

The status of cod in the inshore remains uncertain. It is important to recognize that the inshore fishery historically was highly dependent on fish arriving from the offshore and will not return to its former prominence until such time as a substantial biomass of cod builds up in the offshore and resumes its summer feeding migration to the inshore. The risk associated with fishing those aggregations of cod in the inshore from White Bay in the north to St. Mary’s Bay in the south cannot be quantified because the biomass currently inshore remains uncertain. Acoustic estimates for Smith Sound in Trinity Bay in 1995-1999 at times when cod aggregations were present have ranged from 13,000 to 20,000 t. Additional aggregations exist in Bonavista and Notre Dame bays, but the number and size of these aggregations are not known. The exploitation rates calculated from tag return data indicate a population in Division 3K and northern Division 3L in autumn 1998 of 52,000 t, with a broad 95% confidence interval of 36,000 – 135,000 t. An additional biomass of no more than 15,000 t of cod was available to the index fishery in southern 3L. Some of these fish had overwintered in Placentia Bay (Subdivision 3Ps) and had migrated into Division 3L during the spring-autumn period. Catch rates during the sentinel survey and the index fishery were good to excellent, but the biomass to be inferred from these catch rates is not clear.

It remains difficult to estimate the impact of harp seals on cod. Although the number of cod consumed by seals was estimated, it was not possible to proceed further at this time because of the lack of an analytical model of the cod population. However, the estimates of removals of cod based on reconstructed diets of seals are high relative to most indicators of the size of the cod stock and these estimates do not incorporate the mortality caused by seals feeding on cod bellies alone. It appears that predation by seals has been an important source of mortality of cod since the start of the moratorium. There is also the possibility that predation by seals is retarding the recovery of the cod stock, not simply because considerable numbers of cod are being consumed but also because some of those cod are large and have already recruited to the spawning population.

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Tables and Figures for this document were unable to be supplied by the authors.
Consequently they are not available electronically.

Appendix 1. Extrapolation of 3Ps tagging estimates to 3KL using sentinel catch rates

The following calculations were conducted on instruction from the Chair of the Cod Zonal Assessment meeting.

Cadigan and Brattey (MS 1999) provided a mark recapture estimate for Placentia Bay (3Psc) of 70,000 tons for 1998. Winters and Brattey (MS 1998) carried out an extrapolation of the 1997 tagging estimate for Placentia Bay in an attempt to estimate the biomass of cod in 3KL. Their approach is repeated on the 1998 tagging estimate for Placentia Bay using the 1998 sentinel gillnet catch rate data for Placentia Bay and 3KL. Following their approach the Q for the summer gillnet fishery (week 24-40) in Placentia Bay is calculated and applied to the bay by bay sentinel CPUE data for inshore (<120m) 3KL to compute the estimate.

Tagging estimate	UNITAREA	SQ/KM <120METERS	Q	CPUE	Calculated Biomass
70000	3PsC	3840	0.000546	9.9565	69999
	3Lq	2427		31.3631	139362
	3Lj	841		31.5778	48622
	3Lf	1016		51.3333	95488
	3Lb	2039		55.7585	208154
	3La	2178		40.5172	161567
	3Ks (3Kh,i)	4045		27.9184	206759
	3Kn (3kd)	995		12.6071	22966
Extrapolated 3KL Biomass					882,920

According to Winters and Brattey (MS 1998) the estimate should be an underestimate since it excludes cod north of White Bay and any cod at depths greater than 120m which did not contribute to sentinel catch rates.

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