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Spatial and temporal variation in Atlantic salmon abundance in the Newfoundland-Labrador region with emphasis on factors that may have contributed to low returns in 1997

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Abstract

Salmon populations commonly experience fluctuations in abundance. At times, fluctuations can be quite severe and occur commonly over wide geographic areas and this, apparently, is what happened in Newfoundland in 1997. With few exceptions, total returns of small salmon to monitored Newfoundland rivers declined by 45% or more over 1996 in a number of areas (Exploits, Gander, Northeast Placentia, Humber, Torrent, and Western Arm Brook), while other stocks experienced declines of 20 to 40% (Terra Nova, Middle Brook, Campbellton, Northeast Trepassey, and Conne). For the most part, declines were not expected. Substantive increases in spawning escapements in northeast and northwest coast rivers beginning in 1992, high smolt production in 1996, increasing trends in smolt survival, improved ocean climate indices, and early smolt run timing were all suggestive of improved adult salmon returns for 1997. This report summarizes historic trends in Atlantic salmon abundance in Newfoundland and Labrador, along with an overview of the status of stocks in 1997. It also provides a review of various factors that may have contributed to the low returns in 1997. Factors examined that could possibly have contributed to low returns were legal and illegal fisheries, marine environmental conditions, predation, disease, parasites, and others such as delayed maturation. Most evidence points to increased mortality at sea, but no single factor was identified that could conclusively explain the cause of the low returns.

Résumé

L'abondance des populations de saumon présente assez souvent des fluctuations. Il arrive que ces fluctuations puissent être très importantes et couvrir de grandes superficies. Il semble qu'un tel phénomène se soit produit à Terre-Neuve en 1997. À quelques exceptions près, les remontées totales de petits saumons dans les rivières de Terre-Neuve faisant l'objet d'un contrôle ont diminué d'au moins 45 % en 1996, cela dans diverses régions (Exploits, Gander, Northeast Placentia, Humber, Torrent et Western Arm Brook) tandis que d'autres ne subissaient des baisses que de 20 % à 40 % (Terra Nova, Middle Brook, Campbellton, Northeast Trepassey et Conne). Ces déclins n'étaient généralement pas prévus. Des augmentations appréciables des échappées de géniteurs dans les rivières des côtes nord-est et nord-ouest depuis 1992, une production élevée de saumoneaux en 1996, une tendance à la hausse de la survie des saumoneaux, de meilleurs indices pour l'environnement océanique et une descente hâtive des saumoneaux portaient tous à croire à une amélioration des remontées en 1997. Le présent rapport donne un sommaire des tendances de l'abondance du saumon de l'Atlantique à Terre-Neuve et au Labrador ainsi qu'un aperçu de l'état des stocks en 1997. On y trouve aussi un examen des divers facteurs qui ont pu contribuer aux faibles remontées de 1997. Les facteurs examinés sont les pêches légales et illégales, les conditions de l'environnement marin, la prédation, la maladie, le parasitisme et d'autres, comme une maturation retardée. La plupart des faits indiquent une augmentation de la mortalité en mer, mais il a été impossible d'identifier un facteur unique pouvant expliquer le déclin des remontées.

Contents

Introduction

Concern over the health of Newfoundland and Labrador Atlantic salmon, *Salmo salar*, stocks, and management programs instituted to assist in rebuilding depressed stocks, have a long history. For example, over the past several decades, drift-net fisheries off the south coast of Newfoundland were closed (Chadwick 1993; May 1993), restrictions affecting angling and commercial fishing seasons were introduced in 1978 (Chadwick et al. 1978), and the 1984 salmon management plan implemented. The latter initiative was primarily designed to rebuild depressed stocks in mainland Canada and southwestern Newfoundland by reducing the interception and exploitation of large, mainly multi-sea-winter (MSW) salmon (O'Connell et al. 1992a. The 1984 management plan was not specifically designed to assist in rebuilding Newfoundland grilse populations, although it was expected that some improvements would result. Cautions expressed concerning the declining abundance of Newfoundland salmon stocks resulted in the introduction of commercial fishery quotas in 1990 followed by the most significant measure to date, the moratorium on the Newfoundland commercial Atlantic salmon fishery which began in 1992 (O'Connell et al. 1993), with a small commercial fishery remaining in Labrador.

Despite the numerous management measures that have been taken with the common goal of increasing salmon returns, improved escapements often have not materialized. O'Connell et al. (1992a) concluded that salmon escapements overall to Newfoundland rivers through 1988 were not consistent with the 1984 salmon management plan expectations. Salmon abundance in a number of rivers including Exploits, Middle Brook, Biscay Bay, Northeast Brook Trepassey, and Conne River continued to decline from the mid-to-late 1980's through 1991 (Dempson et al. 1997a). This pattern reversed, beginning with the commercial salmon moratorium, as Atlantic salmon returns doubled or tripled in a number of stocks on the northeast and northwest coasts during the period 1992 - 1996 in comparison with 1989 - 1991. Clearly, there were expectations for even higher returns beginning in 1997, as a direct result of the added spawners beginning in 1992 (O'Connell et al. 1997a). This, however, only applied to those areas where increased spawning escapements occurred during the moratorium years, mainly northeast and northwest coast rivers while south coast and southwest coast rivers remained the exception. For example, salmon stock sizes in south coast rivers decreased during the moratorium by amounts that could realistically range from about 30 to 70% by comparison with pre-moratorium levels (Dempson et al. 1997a), and consequently adult salmon returns were not anticipated to increase in 1997 (O'Connell et al. 1997a). The exception was in those south coast rivers where smolt production in 1996 was at, or near record levels. In this case, even with marine survival approximating that of the previous year, somewhat of an improvement over 1996 returns could have been expected but still below historic escapements.

Despite cautious optimism for increased salmon returns to some areas beginning in 1997, managers maintained a conservative approach as recommended by Science for the 1997 season (DFO 1997). This was due in part to continued stock problems in Salmon Fishing Areas (SFAs) 1, 2, and 14B Labrador (Fig. 1), and Bay St. George (SFA 13) (Fig. 1), the relative uncertainty of projections given the variable nature of salmon abundance, and in consideration that the first life cycle of salmon from the increased spawners in 1992 would not be complete until 1998. In retrospect, this approach was the correct one. With few exceptions, salmon returns in 1997 were low; in fact returns of small salmon decreased by over 45% in comparison with the previous year (1996) in a number of rivers (Exploits, Gander, Northeast Placentia, Humber, Torrent, Western Arm Brook) while other stocks declined by 20-40% (Terra Nova, Middle Brook, Campbellton, Northeast Trepassey, Conne). This phenomenon was not restricted to Newfoundland. Indeed, returns of small Atlantic salmon were less than 50% of the previous year (1996) in almost 40% of the monitored rivers throughout eastern Canada (DFO 1998).

The unexpected dramatic decline in salmon abundance in 1997 necessitated a thorough review of various factors that could have contributed to the low returns and not just in some rivers, but as indicated above, over a wide geographic area. However, 1997 cannot be looked at in isolation of past events. Has history repeated itself? Just how anomalous was 1997?

In this paper we: 1) provide an overview of historic trends in salmon abundance in the context of events that occurred in 1997; 2) review reasons why low returns were unexpected; 3) summarize the current status of stocks in 1997; and 4) evaluate various factors that may have contributed to the apparent low salmon returns in 1997.

Overview of historic trends in salmon abundance

> *"One of the characteristic features of Pacific salmon stocks is the large degree of interannual variation in the number of adults returning to spawn in coastal rivers and streams. ... it is common for the number of mature adults in a stock to vary by more than an order of magnitude between years and at the same time show, at least superficially, no clear temporal regularity in adult stock size."*

The above statement by Noakes et al. (1990) highlights the reality that salmon populations, including Atlantic salmon, are exceedingly variable. Given the apparent decline in 1997 then, how does this compare with past events? Have similar declines occurred previously and over a wide geographic area? Does a single year represent a trend? In a review of factors that contributed to the demise of Atlantic salmon in Lake Ontario, Huntsman (1944) reported that following a rapid increase in salmon numbers from 1869 to 1878, there was:

> "*a catastrophic decline from 1878 to 1880. A similar fluctuation in salmon abundance during that period characterized the whole Atlantic coast ...*".

To place events associated with the apparent decline of salmon in 1997 in perspective then, we briefly review historic information on salmon landings in Newfoundland, Labrador, and the Maritime region as indicators of salmon abundance. Primary sources of information on historic landings were Huntsman (1931) and Taylor (1985), while recent catch data for Newfoundland were extracted from O'Connell et al. (1992b, 1997a). It was obvious at the outset that, similar to the long history of management measures associated with managing salmon populations, there is also a long history of trying to understand the variable nature of Atlantic salmon populations (for example, see Huntsman 1937, 1944). More recently, Dempson and Reddin (1995) reviewed eleven factors that could have contributed to the decline in returns of adult salmon to Conne River, Newfoundland. While no single factor was identified that could have individually explained the decline, several factors were shown to be related to the decreased returns. This is the reality of salmon life history.

Newfoundland and Labrador: pre 1910

As illustrated in Figure 2, historic landings in the Newfoundland and Labrador salmon fishery have been highly variable. Indeed, this is one of the main features that characterizes the Newfoundland salmon fishery over an interval of more than 100 years (1803 - 1909). Data pertinent to the historic Labrador fishery while sporadic, equally illustrates the variable nature of the fishery. Owing to many incomplete years prior to 1860, we examined the Labrador data from 1860 - 1909. Given the virtual absence of restrictions that would have affected these historic fisheries, the catch data in all likelihood reflects actual variation in annual salmon abundance.

We arbitrarily chose a decline of 40% or more from one year to the next as a reference level relative to fluctuations in relative salmon abundance. Declines of this magnitude occurred in the Newfoundland salmon fishery in 1804-05, 1810-11, 1817-18, 1863-64, 1870-71, 1879-80, 1891-92, and 1901-02 (Fig. 2). In Labrador, declines of ≥ 40% occurred in 1863-64, 1865-66, 1875-76, 1877-78, 1879-80, 1881-82, and 1905-06. In several instances, parallel declines occurred in both Newfoundland and Labrador (1863-64; 1879-80) (Fig. 2). While the declines were dramatic in some years, they did not necessarily represent total fish stock collapses and stocks rebounded in subsequent years.

The Maritime Region: 1870 - 1930

As observed in the historic Newfoundland and Labrador data, large fluctuations in salmon abundance have also characterized Maritime areas (Fig. 3). Similarly, declines of ≥ 40% from one year to the next were not uncommon. Several systems (Saint John, Restigouche) were occasionally characterized by declines of over 60% (Fig. 3) but low apparent abundances could also be followed by high catches in the subsequent year.

Noteworthy among the variations observed is the temporal consistency among regions. Substantive declines in the years 1874-1876 and 1879-1881 were common among the Restigouche, Miramichi, and Saint John systems. Recall that Newfoundland and Labrador similarly experienced major declines in salmon in 1879-80, while salmon abundance in both Newfoundland and the Restigouche county area also declined by about 50% from 1870 to 1871.

There is an additional feature besides the common fluctuations in abundance that characterizes the historic Atlantic salmon resource among the Maritime and Newfoundland regions as well as the long departed salmon resource of Lake Ontario. Put quite simply, both users and abusers of the resource often contributed to the decline and destruction of stocks well before there were any formal government agencies involved with the specific management of the salmon resource. For example, Huntsman (1944) provides the following statement by M. H. Perley regarding the Kennebecasis tributary of the Saint John River, New Brunswick:

> "*The inhabitants appear to be actuated by an insane desire to destroy every salmon which appears in these rivers; and no sooner is it reported, that salmon have been seen, in any particular pool, than the whole neighbourhood is in commotion, with preparations for their destruction - the fish are pursued with untiring zeal, until all are captured, except a very few, which, perhaps escape to some place of shelter and safety*".

Taylor (1985) provides a number of references to Newfoundland rivers being completely barred with nets, and inferences relating to concern over salmon stocks as early as the mid-to-late 1880's. In a statement included in Taylor (1985), Adolf Nielsen wrote in regards to the Gander River that:

> "*the baring of the river with stake-nets, the numerous nets employed in and outside the estuary ... have caused this excellent stream to be ... almost entirely depleted of salmon ...*".

Concern over the possibility of salmon on the west coast of Newfoundland becoming exterminated was expressed in the early 1870's (Taylor 1985). Taylor (1985) also provides a statement written by A. Murray around 1874 about the Bay St. George area:

> *"At each of these places small communities are formed, varying in number from fifty to two hundred individuals, who assume to possess an exclusive right ... to the whole vallies of their respective rivers; and moreover they even further claim absolute right to the river itself ... [including] the supposed prescriptive right of salmon poaching".*

The point of the above references is to illustrate that given the almost complete destruction of some salmon stocks, populations displayed a high resilience and continued to persist. In a recent review of factors associated with ecological extinction, McKinney (1997) states that: *"Species with large body size, high trophic level, specialised habitat needs and poor dispersal are among the most consistently extinction-prone ..."*. Where does this place Atlantic salmon?

Newfoundland and Labrador: 1974 - 1991 the recent past

An examination of the recent series of commercial catch data similarly displays annual variability (Fig. 2). Declines of ≥ 40% occurred in Newfoundland in 1977-78, and again from 1987-88. With respect to Labrador, there were no occasions when commercial landings fell from one year to the next by ≥ 40%. Both regions experienced a decline in commercial landings from 1981-84 (Fig. 2). However, following a brief increase around 1986 - 1987, landings in both areas went into decline in part due to management measures (e.g. quotas in 1990 and 1991), but also in view of an overall trend for continued lower abundance.

Summary

Historic as well as recent information suggests that salmon populations are characterized by fluctuations in abundance. Fluctuations can be quite severe, similar to that which may have occurred in 1997. In the past, fluctuations have also occurred commonly over wide geographic areas. At times, the decline and even destruction of the salmon resource in some areas was caused through ignorance of the damage being done to the long-term conservation of the resource. Salmon populations have in the past, at least, displayed a high resilience that have allowed them to survive and persist for subsequent generations.

Why low returns were unexpected

Increased spawning escapement

In Newfoundland, adult Atlantic salmon have been routinely monitored at 14 sites in years prior to and continuing through the moratorium (Humber River via mark-recapture). This includes obtaining complete counts of salmon from two of the three largest rivers in Newfoundland (Exploits and Gander rivers). Direct estimates of returns unequivocally provide the best information possible to infer changes in salmon abundance. We note that escapements have also been monitored on other Newfoundland systems but either on an irregular basis (e.g. Highlands River, Grand Bank Brook) or beginning only in more recent years (e.g. Campbellton River). A summary of Atlantic salmon returns to fish counting facilities is provided in O'Connell et al. (1997a).

In the first year of the commercial salmon fishery moratorium (1992), total returns of both small and large Atlantic salmon to northeast coast rivers (SFAs 4-5) increased dramatically. Similarly, corresponding conservation egg deposition levels rose by 87 to 228% over the previous year (Table 1). The substantive increase in egg deposition levels created, in effect, a salmon 'baby boom'. This continued for the next five years through to 1996 with escapements having increased, on average, by a factor of 2 or 3 times. Modal smolt age in these populations is 3+ years. Thus adult salmon production resulting from increased spawning escapements should have first appeared in 1997, with continued optimism for subsequent years.

Increased spawning escapements also occurred in some west (Humber) and northwest coast rivers (SFAs 13-14A) (Table 1). However, the northwest coast populations are characterized by a modal smolt age of 4+ years. Consequently, the first year of expected new production resulting from increased spawning in 1992 would not occur until 1998. As mentioned earlier, south coast stocks declined in abundance during the moratorium.

High smolt production

The census or surveying of smolt populations can provide a direct index of freshwater production and survival. In Newfoundland, information on smolt abundance is currently available from six rivers: Western Arm Brook (1971-97); Northeast Brook Trepassey (1986-97); Conne River (1987-97); Rocky River (1990-97); Campbellton River (1993-97); and Highlands River (1980-81; 1993-97). Smolt production in 1996 was either the highest on record (Conne River; Rocky River; Campbellton River), or was above the previous long-term averages (Northeast Brook Trepassey; Western Arm Brook) (Fig. 4). One exception was Highlands River where the 1996 smolt run was the highest in three years, but still below levels recorded in 1980 and 1981. Thus even on several south coast rivers, where, as previously indicated, adult salmon returns actually fell during the moratorium years, smolt production was still exceptionally high. Increased egg-to-smolt survival has occurred in some systems (see below) and the 1997 smolt production has exceeded record levels of 1996 in five cases.

Increasing sea survival

Following periods of either declining (Conne River; Northeast Brook Trepassey) or stable sea survival (Western Arm Brook), survival had started to increase in several populations in recent years (Fig. 5). Coupled with higher relative smolt production, a rate of marine survival consistent with the 1996-1997 period would have yielded an increase in adult salmon returns in 1997. As illustrated in Figure 5, marine survival fell dramatically in most rivers.

Marine thermal habitat, smolt run timing, and smolt condition

Analyses of Conne River smolt and adult population characteristics showed that there was a high association between an index of marine thermal habitat and subsequent sea survival, and a similar association between smolt run timing and survival (Fig. 6) (Dempson and Furey 1997). Higher condition of smolts also tended to coincide with better marine survival. Marine thermal habitat conditions in early 1997 were among the 'best' to date (see below), while an early smolt run was also characteristically associated with improved returns. Smolt runs were the earliest on record for Conne River, Northeast Brook Trepassey, Rocky River, and Campbellton River, while at Western Arm Brook, 1996 marked the earliest smolt run since 1989 (Fig. 7).

Summary

Substantive increases in spawning escapements in northwest and northeast coast rivers beginning in 1992, high or record high smolt production in 1996 from those stocks where smolts were monitored, improved sea survival in recent years, in conjunction with suitable ocean climate indices and early smolt run timing, were all suggestive of improved adult salmon returns for 1997.

Current status of stocks in 1997

Status of stocks in 1997 can be examined relative to past returns of salmon to rivers, i.e. spawning escapements, or in relation to the adjusted total population size. Adjusted population size is corrected for salmon removals in marine fisheries (legal or illegal) in years prior to the moratorium and provides an indication of what the total stock size was prior to fish being exploited at sea. Recently, Dempson et al. (1997a) estimated average minimum marine exploitation rates, separately for small and large salmon, on a number of individual Newfoundland salmon stocks for the period 1984 to 1991. An estimate of the average exploitation rate on small salmon was 44.0% (95% C.I. = 35.0 - 53.1%), while large salmon exploitation was estimated at 74.9% (95% C.I. = 67.4 - 82.5%) (Table 2).

When individual river-specific values were available, adjusted total population sizes were estimated for 1984 - 1991. In cases where river-specific values could not be estimated, respective upper and lower confidence intervals were used to illustrate realistic bounds associated with the total population size. We note that estimates of adjusted population sizes can also provide more accurate indications of changes in marine survival rates on those stocks where smolt data are available.

Salmon returns in 1997 contrasted with other years

Total returns of small Atlantic salmon to various Newfoundland rivers for the period 1984 - 1997 are illustrated in Figures 8, 9, and 10 for the northeast, south, and west coasts, respectively. Large salmon returns for the same coastal areas are shown in Figures 11, 12, and 13. Dashed lines on graphs represent the stock size adjusted for marine exploitation. As observed in either historic (1803 - 1910) or recent (1974 - 1991) commercial catch data for Newfoundland, returns of small Atlantic salmon to rivers also fluctuates among years.

Notwithstanding the drop in returns of small salmon from 1996 to 1997, declines of ≥ 40% in other years were not uncommon (Figs. 8 - 10). Indeed, the paired years of 1988-89 and 1990-91, 1986-87, and 1993-94, follow in sequence from 1996-97 with respect to having the most number of stocks experiencing a drop in total returns of ≥ 40%. Nor was the magnitude of the decline from 1996 to 1997 necessarily the greatest.

Similar fluctuations in large salmon returns also occur among years (Figs. 11 - 13). Recall that in Newfoundland, most large salmon are repeat spawning grilse. Yet in contrast with small salmon, it appears that a decline in large salmon from 1996 to 1997 is the exception rather than the rule. Whereas virtually all stocks, with the exception of Rocky and Lomond rivers, declined in small salmon numbers, a drop in large salmon numbers was limited to five systems: Exploits, Campbellton, Northeast Brook Trepassey, Humber, and Lomond rivers.

Salmon Abundance in Bay St. George

Salmon in four rivers in Bay St. George were counted during the last week of August in 1996 and 1997 by snorkeling down each river. The text table below compares counts in 1996 adjusted for unobserved fish, to the adjusted counts in 1997. It is apparent from these data that the abundance of both small and large salmon were greater in 1997 than in 1996. This is consistent with the observations of the numbers of salmon entering Highlands River and Pinchgut Brook, tributary of Harry's River. Thus, it appears that the abundance of salmon in Bay St. George (SFA 13) did not decline as did populations in other SFAs in insular Newfoundland.

River	Small salmon (<63 cm)		Large salmon (>63 cm)	
	1996 adjusted	1997 adjusted	1996 adjusted	1997 adjusted
Crabbes R	844	1121	239	346
Barachois R	805	1044	36	182
Robinson R	768	1017	120	172
Flat Bay Bk	1233	1282	132	167

Salmon abundance in Europe

The question of how widespread geographically low returns of salmon were in 1997 can assist in providing direction for possible explanations as to the cause(s). It appears that declines were widespread in North America but Atlantic salmon are also found in Europe. Assessment biologists in Ireland, Scotland, Iceland and Finland were polled for their views on 1997 stock sizes. In most cases, while there were declines in some stocks there were sufficient examples of increased returns for others to disprove the hypothesis of a pandemic decline. The only exception is in Scotland, where returns of only the spring salmon component were poor. However, spring 2SW salmon are of particular relevance to issues affecting North American salmon as they migrate to the northwest Atlantic more so than other European stock components. Thus, it seems that the lower returns in Europe only occurred consistently with the spring Scottish salmon stocks.

Natural marine survival

During moratorium years, estimates of marine survival from smolts to adult small or one-sea-winter (1SW) salmon are believed to represent natural survival rates. Despite major changes to fisheries and corresponding reductions in marine exploitation, marine survival rates are still less than 10% although this level has been achieved in both Conne River and Western Arm Brook during periods when commercial and other bycatch fisheries were in operation. Conne River and Northeast Brook Trepassey have experienced their lowest marine survival rates during the period of time that the Newfoundland commercial salmon fishery has been closed. Ocean survival in both of these stocks was falling throughout the late 1980's and early 1990's (Fig. 5); adjusted marine survival rates only serve to highlight the difference even more.

In an experiment where wild Conne River smolts from the 1995 smolt class were grown-out at an aquaculture sea cage site in Bay d'Espoir, Newfoundland, a sea survival of approximately 20% was obtained (Dempson et al. 1997b). In contrast, wild 1SW survival from the same smolt class was 5.8% (Dempson and Furey 1997). Thus, by intervening in such a manner as to provide protection from predators and an ample food source, the results indicated that the capability to achieve moderately high survival in a marine environment still exists.

Following a brief period of increasing survival in recent years, the Conne River and Northeast Brook Trepassey stocks, along with Western Arm Brook, Rocky, and Campbellton rivers, experienced a substantive decline in survival of the 1996 smolt class (Fig. 5). Highlands River in Bay St. George was an exception as survival to small salmon actually doubled over the previous year and was the highest reported for small salmon returns.

In contrast with the smolt survival information, at Campbellton River we also have data on kelt survival from those fish that are monitored leaving the river during the spring and ocean survival has been: 1994 = 26%; 1995 = 35%; 1996 = 39%, and 1997 = 39%. The similar rates in 1997 to those of earlier years suggests that summer conditions for adult salmon were satisfactory, and that the causes for low returns likely occurred prior to the return of adult salmon to coastal waters.

Significance of low returns in 1997

Given the characteristic variability associated with returns of Atlantic salmon, and past years with similar or even greater proportionate decline in returns, one may be tempted to question the undue concern over the drop in small salmon returns in 1997; salmon abundance fluctuates and similar declines have occurred in the past.

While much of the attention has been focused around the substantive decline in 1997 returns, mostly, of small salmon, little attention has been directed towards the lack of improvement of returns to monitored rivers on the south coast stocks after the closure of the commercial fishery in 1992, the exception being Rocky River. Low returns again in 1997 simply highlights a prolonged problem. It is only because of the increased smolt production in some rivers in recent years that stocks have not fallen to even lower levels.

What we see in our rivers now, for the most part reflects the total population size given the absence of directed fisheries on salmon in the marine environment that would affect grilse returns. Thus, 1997 does not just represent another 'low' year, but in a number of cases when compared against conservatively estimated adjusted returns (adjusted for marine exploitation) for 1984 - 1991, reflects either the lowest (Terra Nova and Gander rivers), or among the lowest (Middle Brook, Northeast Brook Trepassey, Northeast Placentia River, Conne River, Humber River, Western Arm Brook) stock sizes that have been recorded or estimated (Figs. 8 - 10) since 1984. Biscay Bay River was not monitored in 1997, but it too has shown a long term decline in total population abundance (Fig. 9).

Generalization to Newfoundland

One may ask whether the above information on low returns to monitored rivers is representative for all stocks, or just those on which we have specific information. We believe the data are reflective of a broader situation affecting most Newfoundland rivers.

Table 3 is a matrix of Spearman correlation coefficients of Atlantic salmon returns to Newfoundland rivers, 1984 - 1997. Small salmon values are shown above the diagonal with large salmon values below. Statistically significant values are highlighted in a larger bold font. As shown in the table, northeast and west coast stocks (SFAs 4, 5, 13, 14A) (Fig. 1) appear to have a high degree of congruence among trends in abundance for both small and large salmon (Table 3). Not only are there many significant correlations among stocks within a region, but also between the SFA 4-5 (northwest coast) and SFA 13-14A (west coast) stocks.

South coast stocks, again, are the exception. Here there seems to be little conformity among those south coast stocks for which we have total salmon return data. Thus in these cases, trends for low salmon abundance may only be indicative for the rivers that are monitored. However, in view of the overall failure of any consistent response to increased salmon returns during the moratorium years, we feel that this is not the case, and generalization about the state of low overall salmon stocks on the south coast is warranted.

Generalization to North American salmon stocks

If marine climate has an impact on survival of salmon while they are at sea, then salmon returns over wide geographic areas should be correlated. In order to test for coherence in salmon abundance for North American salmon stocks, a set of adult abundance information was obtained for six stock groupings from Anon. (1997). The six stock groupings used were Labrador, Newfoundland, Quebec, Scotia-Fundy, Gulf of St. Lawrence, and USA. Coherence in returns for salmon stocks was tested using estimates of both 1SW and 2SW salmon covering the entire range of salmon in North America (Anon. 1997).

For 1SW salmon from North America, there were 8 out of a possible 15 statistically significant correlations at the 5% or less level of significance (Table 4). All significant correlations were positive. For the six stock complexes tested, the northern stocks from Labrador and Newfoundland were correlated with each other; whereas, the more southerly origin stocks were correlated with each other but not with Newfoundland and Labrador. For 2SW salmon from North America, there were 7 out of a possible 15 statistically significant correlations at the 10% or less level of significance (Table 5). For 1SW salmon, correlations with abundance over time were significant for only Quebec and USA. For 2SW salmon, correlations with abundance over time were significant for only Gulf of St. Lawrence and Scotia-Fundy. Although not significant, all trends over time for 2SW salmon stocks were negative indicating the possibility of declines in overall population size over the period of 1982-96.

The widespread coherence in trends of North American salmon in return estimates for both 1SW and 2SW salmon are shown in the results from correlation analyses. The two more northerly stock complexes based on their significant positive correlation, i.e. Labrador and Newfoundland, appear to form a cohesive unit. The four more southerly stock complexes of Quebec, Gulf of St. Lawrence, Scotia-Fundy, and USA, while being somewhat dissimilar from the northerly ones, are similar to each other based on the pattern of significant correlations. There were no significant declining trends for 1SW stocks and two stocks were increasing. For 2SW stocks, five out six were in decline and two of these significantly so. The strong similarity of the pattern of returns suggests that common events are influencing the production of North American salmon over the northwest Atlantic. These common events influence production and abundance over a large area despite variable fishing effort, different gear, and different management practices applied to the various stock components. The apparent widespread nature of these events suggests climate as a possible cause. Additional analyses of common trends in Atlantic salmon abundance throughout eastern Canada can be found in a Department of Fisheires and Oceans (DFO) Stock Status Report (DFO 1998).

Summary

As observed among commercial catch statistic information, salmon returns to Newfoundland rivers have been highly variable. Decreased returns from one year to the next, similar to that experienced in 1997, have occurred in the past on a number of occasions. Some south coast stocks, however, show clear evidence for a continual long-term decline in production. Based on the high smolt production in many rivers, the apparent differential impact on large salmon returns in 1997, and consistent marine survival of previous spawners, the information suggests that the decline in salmon returns in 1997 is likely the result of factors that affected the 1996 smolt class while at sea. Geographically, the low returns in 1997 are fairly widespread throughout insular Newfoundland. The one exception are returns to rivers in Bay St. George where increased returns or at least average returns were observed. There were no counting facilities in SFAs 1 and 2 in Labrador in 1997 with which to compare returns to those of previous years. Comparison of returns for small and large salmon indicated that declines in large salmon were not consistent with or proportionate to declines in small salmon. The evidence on hand suggests that low returns of salmon in 1997 appear related to factors that likely affected the 1996 smolt class.

Review of factors that may have contributed to low salmon returns

Consider fate of a smolt; either it survives at sea and returns to spawn, or it does not survive. If it does not survive, there are a multitude of factors that could be examined (assuming data exist) that potentially, at least, could have contributed to its particular fate. These factors are such that they could affect the smolt at, or immediately following their migration to sea, during the initial 'post-smolt' period, say, two to three months post-migration, or later during the fall, winter and spring, prior to the onset of maturation and return to natal rivers. These factors could be associated with: 1) environmental conditions (temperature, salinity, etc.); 2) removals in fisheries (commercial, recreational, aboriginal, bycatch, illegal); 3) predation (cod, seals, sea birds etc.); 4) diseases or parasites (bacterial, viral, sea lice, etc.); or 5) a suite of other factors that could include changes in biological characteristics of stocks (e.g. delayed sea-age at maturation), effects of escaped aquacultured salmon, measurement error, etc.

Recruitment variability in anadromous salmonids can be partitioned separately into those effects arising from their life in fresh water and in the sea. The task of tracking the events controlling survivorship of Atlantic salmon becomes more complex after postsmolts leave fresh water and enter the marine environment. With other marine fish species the task is one of characterizing the fate of large numbers of larval fish in a relatively small area. Whereas with salmon, we are faced with the task of characterizing the fate of small numbers of fish over a wide area. European and North American salmon inhabit a major part of the north Atlantic and migrate widely in it (Friedland et al. 1993). In order to examine the declines in salmon stocks, several aspects of returns and total production or recruitment for various stocks and areas in Newfoundland and their possible relation to sea-surface temperature (SST) are examined.

Characterizing the fate of fish that have died to causes unknown in freshwater or in the sea is difficult because it is rare to actually see dead fish and the source of their mortality. Consequently, there are many potential sources of mortality that cannot be examined due to a lack of quantitative information (Table 6). Also, to be a candidate for a cause associated with the decline of adult 1SW salmon returning in 1997, the cause must have occurred between entry of the smolts into the sea during the spring-summer of 1996 up to their return as grilse in 1997. Specifically, we will try to evaluate the reasons for the lower returns in 1997 based on the following questions:

1. *Did fisheries, either aboriginal food, commercial, recreational and/or illegal fisheries increase sufficiently to reduce returns of adult salmon in 1997?*

2. *Did environmental factors, e.g. water temperature, etc. either in freshwater or in the sea cause the low returns of salmon in 1997?*

3. *Did predators cause the low returns of salmon in 1997?*

4. *Did disease or parasites cause the low returns of salmon in 1997?*

5. *Did other factors such as changes in age composition, delayed maturation, impacts of aquaculture on wild stocks, etc. cause the low returns of salmon in 1997?*

The definitions of the various salmon life stages used in this paper are from Allan and Ritter (1977). Thus, a postsmolt salmon refers to a salmon that has entered the ocean but has not yet completed a full winter at sea; one-sea-winter (1SW) salmon refers to a salmon that has completed its 1st winter at sea; and two-sea-winter (2SW) salmon refers to a salmon that has completed its 2nd winter at sea. A grilse is a mature 1SW salmon. Because of a lack of comprehensive age information from scale reading, catch data are frequently divided into small (< 63 cm) and large (≥ 63 cm) salmon.

Statistics were calculated using SAS procedures including CORR, GENERAL LINEAR MODELS, and REG (SAS Institute Inc. 1988). The non-parametric Spearman Rank Correlation test was used to avoid problems related to the assumption of normally distributed data. Of course, correlations do not indicate a cause and effect relationship but show only that the two data sets are varying in the same way. It may be that the significant correlations are due solely to chance alone and are thus spurious. Alternately, it may be that there is a third unidentified variable that is causally related.

1. Activities of man through fishing

Did fisheries, either aboriginal food, commercial, recreational and/or illegal fisheries increase sufficiently to reduce returns of adult salmon in 1997?

In this section, we look at the activities of man through fishing to determine if mortalities due to fishing were the cause of lower than expected returns in 1997. We will try to discern what may have been different about fishing activities in 1996 versus 1997. Fisheries, both legal and illegal, reduce the number of salmon from the overall population and when this happens prior to fish returning counting facilities, could be directly responsible for the lower returns in 1997. Since fisheries exist every year in one form or other, landings would have to have increased substantially over that of recent years and in particular, over that of 1996 when salmon returns were generally good. Legal fisheries for salmon in Newfoundland and Labrador include aboriginal, commercial, and recreational. Bycatches also occur in some non-salmon fisheries. There are only four commercial fisheries harvesting North American Atlantic salmon, viz. West Greenland, Labrador, Quebec and St. Pierre et Miquelon. Also, there are many fisheries that potentially could harvest salmon as a bycatch at either the postsmolt and/or adult stages including fisheries for capelin and other pelagic species, cod and other groundfish, and shrimp. Illegal fisheries including marine poaching etc. must also be considered even though data is difficult to acquire.

Sources of data include DFO catch statistics for the Newfoundland and Labrador angling and commercial fisheries (O'Connell et al. 1997a), Greenland Home Rule for the West Greenland salmon fishery (Anon. 1997), enumeration of net-marked salmon at six counting facilities in Newfoundland and Labrador, observer data for NAFO Divisions, data on catches by Fisheries Officers boarding domestic and foreign vessels at sea, (B. Whelan, Department of Fisheries and Ocean, Fisheries Management Branch, St. John's, Newfoundland, pers. comm). Catch and effort data from the angling fishery in Newfoundland and Labrador were collected by DFO enforcement staff in conjunction with angling reports submitted by fishing camp operators and processed by DFO Science Branch personnel. Commercial catch data for the Newfoundland and Labrador salmon fishery were collected by DFO enforcement staff from fish plant landing slips and processed by DFO Statistics and Informatics Branch personnel. Procedures for the collection and compilation of commercial and angling fishery data are described by Ash and O'Connell (1987). Anon. (1997) provide estimates of the total numbers of 1SW and 2SW North American salmon as well as numbers of salmon caught in the Labrador and Greenland commercial Atlantic salmon fisheries, 1970-96. These statistics are used to examine trends in commercial catches compared to total population sizes of North American salmon.

Bycatches of salmon in non-salmon fisheries both foreign and domestic were examined by reviewing records of vessel inspections by DFO Fisheries Officers, observer data and research vessels. Illegal fisheries were examined through violations and charges recorded annually in the Newfoundland Region. The CFIN (Canadian Fisheries Information Network) database consists of information obtained during inspections at sea of foreign and domestic vessels. The Newfoundland Region Area (NRA) of responsibility is the Northwest Atlantic including NAFO Subareas 0, 2 and 3. This database includes surveillance sightings and DFO Fisheries Officers inspection reports from 1987 to the present. The inspection reports are recorded at each boarding of a vessel from the ships logbook and direct observations of fishing activities.

Aboriginal Fisheries

A First People's food fishery has occurred sporadically at Conne River, SFA 11, since 1986, under a quota of 1200 small salmon. In view of the record high smolt production from Conne River in 1996, a licence was issued for the Conne River Band to resume a fishery in 1997. A cautious approach was taken in that only half of the previous quota was authorized pending an in-season review of the status of the Conne River salmon stock. Of the initial 600 fish allocation, 514 small salmon were caught plus a single large salmon as a trap mortality. Given the localized nature and limited catch in 1997, removals from this fishery could in no way have contributed to the widespread reduction in Atlantic salmon returns in 1997.

Commercial Fisheries

Labrador

Salmon have been exploited in Labrador by Europeans extensively since the late 18th century and by aboriginal people before the appearance of Europeans. The commercial salmon fishery in coastal Labrador is a mixed-stock fishery harvesting salmon from a variety of rivers in North America. Tagging studies and analysis of age composition of catch samples (Reddin and Dempson 1986) show that the majority of salmon harvested originate in Labrador rivers (Pippy 1980). Labrador origin salmon were harvested in the commercial fishery in Newfoundland until the moratorium in 1992 and are still harvested at West Greenland. Catch statistics indicate landings in Labrador ranged from a high in 1980 of 853 t to a low in 1997 of 46.4 t (Table 1.1). The 1997 salmon landings in small and large categories and numbers of salmon are preliminary but the total number suggests little overall change from 1996. The weight declined by 3% and the number of fish increased by 7% over those of 1996.

For smolt classes 1970-93, the Labrador salmon fishery harvested on average from 7% to 13% of the total number of North American 1SW and 2SW salmon (Fig. 1.1). The percent of the total number of North American salmon that the Labrador fishery harvests has declined for every smolt class since 1990. For the 1994 smolt class, which is the last year with complete data, the total number of North American salmon harvested ranged from 2 to 5%. The landings in Labrador are controlled by a quota which was reduced from 55 t in 1996 to 50 t in 1997 due to the closure of SFA 14B.

Thus, while the percentage that catches in Labrador represent of the total number of North American salmon may change due to lower overall population size it should not change because of harvests in Labrador. This is because catches in Labrador have been declining in recent years. Preliminary landings indicate that 16,000 salmon were caught in Labrador in 1997, an increase of about 1,000 salmon over landings in 1996 (Table 1.1). Owing to the lack of a dramatic change in the catch in Labrador in 1997 compared to 1996, and the low overall catch/quota in recent years as well as the continued decline in the number of North American salmon harvested in Labrador, it is concluded that the Labrador fishery was not responsible for the general widespread substantive decline in returns of Atlantic salmon in 1997.

Newfoundland

The commercial salmon fishery in insular Newfoundland has been under a moratorium since 1992 which continued in 1997, and thus could not have caused the lower 1997 returns.

West Greenland

Salmon at west Greenland were first commercially exploited in substantive numbers during the early 1960s, by vessels from Scandinavia and Greenland. Landings peaked in 1971 at 2,689 t followed by several years of catches of around 2,000 t (Table 1.2). The fishery at west Greenland harvests salmon exclusively originating in rivers of either Europe or North America. In 1972, the International Commission for the Northwest Atlantic Fisheries (ICNAF) reached an agreement to establish a quota of 1,190 t per annum for Greenlandic vessels. This was introduced together with a phasing out of all fishing by non-Greenlandic vessels. The phase-out was completed in 1975. Since then quotas and landings have continued to decline. In 1993 and 1994, quotas were purchased by the NASF (North Atlantic Salmon Fund) and only subsistence fishing was allowed. The fishery operated in 1995-97.

In recent years, the fishery has been conducted mainly near shore by vessels less than 42 feet in length. The gear used is 140 mm stretched mesh gillnets with no limit on length. Landings are controlled by a quota distributed at the community level and assessed through daily licensee reports. Fishing for private consumption is restricted to residents of Greenland. Here, the gear used consists of 140 mm stretched mesh gill nets that are 30 fathoms in length.

In 1997, the West Greenland Commission of NASCO (North Atlantic Salmon Conservation Organization) agreed to a quota of 57 t which was caught after about 5 weeks of fishing. The quota was divided into 50 t for the commercial fishery and 7 t for local consumption. The fishery started on August 18 and closed September 22. Commercial landings for the 5 week fishery in 1997 were about 53 t. In 1996, during the first 5 weeks of fishing there were 54 t of salmon landed. This suggests that abundance of salmon in 1996 and 1997 could have been similar if effort remained approximately the same over both years. There is no effort information available for the Greenland fishery.

For smolt classes 1970-91 (fishery years at Greenland of 1971-92), the Greenland fishery harvested on average from 26% to 37% of the total number of North American 2SW salmon (Fig. 1.2). For the smolt class of 1994, the last year for which data is available, this fishery was estimated to have harvested from 11% to 21% of the total number of North American 2SW salmon. The landings in 1995 and 1996 (smolt class year, 1994 and 1995 that returned to homewaters in 1996 and 1997) were 83 t and 92 t, respectively. At this time, the data is unavailable to derive the total number of North American salmon and hence the percentage harvested at Greenland from the 1995 smolt class. However, the number of 1SW North American salmon harvested at Greenland in 1996 was 12,357, a decline of about 40% from the previous year when it was 20,828 implying that the effect on the total stock will at least not increase and may have declined from those of previous years when the numbers captured were higher (Table 1.3). It is concluded from this information that the Greenland fishery did not cause the decline in 2SW returns to North America in 1997.

St. Pierre et Miquelon

The very small marine commercial and recreational net fisheries at St. Pierre et Miquelon recorded preliminary landings of 1.5 t for 1997 (Maritime Affairs, St. Pierre) the same as reported for 1996. The average is 1 t for 1991-95 (Anon. 1997). It is unlikely with such small landings that this fishery is the cause of lower salmon returns in 1997.

Angling Fisheries

Recreational fisheries occur annually in Newfoundland and Labrador rivers and typically take place above counting facilities on those rivers where returns are enumerated. Thus, the angling fisheries during 1997 could not have influenced the low level of returns in 1997 to those rivers where returns are measured. This can probably be extended to other rivers as well since it is evident that reductions in total stock size had apparently already occurred sometime prior to river entry. We note that recreational fisheries now account for about 70% of total harvest of Atlantic salmon (Anon. 1997).

Another possible effect of angling fisheries on stock sizes in 1997 could have occurred from a reduction in spawners in 1991-92, the spawning classes generating the 1997 returns. Angling fisheries could have reduced the number of spawners that produced the adult returns in 1997 if harvests were underestimated in those years. An under-estimate of angling harvests in 1991-92 could have eliminated any apparent increase in spawners and subsequently reduce expectations for 1997 returns. This aspect of measurement error in angling fisheries catch data and its effect on the spawners is examined in a separate section (see Section 5).

A method to examine the potential of the existing mixed-stock commercial fisheries to remove salmon from the population versus that of the terminal in-river recreational harvests would be to show their relative historical harvests. Anon. (1997) shows fishing mortalities of 2SW equivalents by North American fisheries, 1972-96. The percentage of the cohort destined to be 2SW salmon which were taken in terminal fisheries during 1972-96 in Canada and the USA has ranged from as low as 18% in 1973, 1975 and 1987 to the highest value yet of 75% in the 1996 fisheries. The percentage increased substantially with the reduction and closures of the Labrador and Newfoundland commercial fisheries, particularly since 1992. Also, quota reductions for the Greenland salmon fishery have contributed to the overall decline in the percentage of all salmon stocks taken in mixed-stock fisheries. The smaller and declining percentages is the result of moratoria and reductions in effort on commercial fishing at sea. This also suggests that the cause of lower returns in 1997 lies somewhere other than with commercial fisheries.

Other removals at sea

Salmon are removed from the population of salmon at sea in other than legal commercial fisheries. Some salmon are caught as bycatch in non-salmon gear. In Newfoundland and Labrador, salmon caught as a bycatch must be returned to the sea even if dead. There are also illegal (poaching) fisheries that take place at sea as evidenced by the list of convictions for illegal netting. Because these activities are illegal it is not possible to quantify them nor the extent to which they impact on salmon population size; however, the illegal fisheries could still be a contributing factor that resulted in low returns in 1997. At present, there are only two methods that can be used to provide an index of removals at sea, viz. recorded violations and records of net-marked salmon. Thus, if either record showed an increase it would be deemed an indication that removals at sea have increased.

<u>Net-marked salmon</u>

Net-marked salmon observed passing through fish counting facilities are an indirect measure of removals of salmon at sea. This is based on the fact that not all salmon that encounter a net will be retained, but some having been meshed will be marked by the net and subsequently escape. The salmon that escape will be visible by the mark left by the net and provide an index of fishing activity. Not all net-marked salmon will have encountered illegal nets as there are legal fisheries at sea, i.e. bait fisheries for lobster pots (O'Connell et al. 1997a). Thus, the incidence of net-marked salmon at a time when there is no legal commercial salmon fishery is indicative of, or consistent with, either a directed illegal fishery for salmon or the release of salmon caught as bycatch in other fisheries or a combination of both. In Newfoundland, all bycatches of salmon must legally be released to the sea whether alive or dead.

The incidence of net-marked salmon were recorded at counting facilities on Highlands, Humber, Harrys, Gander, Conne and Campbellton rivers. A video camera and VCR used to record and count salmon at Campbellton River was also be used to quantify the incidence of net-marked salmon. For Harrys, Gander, Conne and Highlands rivers, observations of net-marked salmon were made visually from salmon retained in enumeration traps. For Humber River, all of the salmon that were tagged and released in a mark-recapture study were examined for net marks.

The results for small and large salmon combined for 1997 are compared to those for 1994-96:

River	1994	1995	1996	1997
Highlands	0	0.7	0.9	0.5
Humber		1.4	2.6	7.6
Harrys			0.6	9.3
Conne	18.6	7.1	6.2	7.2
Campbellton	6.2	5.0	4.3	4.3
Gander	15.9	8.9	12.2	15.9

The incidence of net-marked salmon in 1997 at the Humber River mark-recapture release trap was 7.6%, an increase of almost 200% from the previous value of 2.6%. The incidence of net-marked salmon at Harrys River was 9.3% in 1997, a dramatic increase over the value of 0.6% in 1996. The Harrys River counting trap is on Pinchgut Brook, a long distance upstream whereas the counting facilities on other systems are near the river mouths. Some of the net-marked salmon seen at Pinchgut may have been from encounters with nets in freshwater. The incidence of net-marked salmon in 1997 in the Highlands River trap was 0.5%, a decrease from previous surveys. The incidence of net-marked salmon in 1997 in Conne River was 7.2%, similar to the past two seasons. The incidence of net-marked salmon in 1997 in Campbellton River was 4.3%, consistent with the previous year but lower than in 1994 and 1995. Overall, it would appear that the incidence of net-marked salmon has increased substantially at some rivers during 1997 while either decreasing or remaining stable in other cases.

Records of violations

Illegal fishing is a possible cause of low returns to freshwater in 1997. Especially important in this regard would be illegal fishing in marine waters prior to freshwater entry by salmon. Because it is illegal there are no quantifiable records of the numbers of salmon removed by poaching. However, the number of violations against the Fisheries Act recorded by Fisheries Officers provides an index of removals of salmon by illegal activities if it is assumed that effort, both in terms of the poaching effort and the effort directed towards protecting the resource, was similar in recent years. If the number of violations were to have risen in 1997, this would be consistent with an increase in illegal removals of salmon and would indicate that poaching may have been at least partially responsible in contributing to low returns of salmon to rivers in

Newfoundland during 1997. Data were only available for 1995-97. Violations have been separated from those occurring in the sea and in freshwater. In the sea, there were 152 violations in 1995, 144 in 1996, and 150 in 1997. In freshwater, there were 259 violations logged in 1995, 466 in 1996, and 193 in 1997. At sea, there was clearly no increase in poaching violations during 1997 over levels recorded in 1995 and 1996. This was consistent with the number of public complaints at DFO offices which were lower overall in 1997 suggesting that poaching in 1997 did not increase and may have even declined. In freshwater, there was a clear decline in poaching violations in 1997 over levels recorded in 1995-96. Despite these statistics, it is still rather disturbing that the resource continues to be abused. However, given the lack of an increase in the recorded number of recorded violations, it is concluded that illegal activities in 1997 were not the sole cause for the low returns of salmon to rivers in Newfoundland.

Bycatches in Offshore Fisheries

Offshore fishing for salmon is often publicly cited as a reason for declining salmon stocks. Within the Canadian Zone, all foreign vessels must carry observers and most of the Canadian registered vessels must now also do so. Fisheries Officers maintain an inspection rate of once per vessel every two weeks. Fisheries Officers inspect logbooks, catches and fishing gear for evidence of illegal activity. Since the moratorium on cod fishing was declared in 1992 for NAFO 2J3KL and extended to other areas in 1993, there have been few vessels fishing offshore and almost no foreign vessels within the Canadian zone. Also, much of the offshore area of the Labrador Sea where salmon are known to inhabit have no fisheries at all. The CFIN (Canadian Fisheries Information Network) database for the NRA (NAFO Regulatory Area) including NAFO Subareas 0, 2 and 3 showed no occurrences of salmon being caught from 1987-up to the present. In total, there were about 106,000 records examined.

The most common fishing gear used presently in offshore areas is trawl gear used for groundfish and mid-water trawls used for shrimp, redfish and other pelagic species. Thus, records from research vessels which have been used in Newfoundland to collect biological samples since the mid-60s can be used as an independent method of determining bycatches. All species regardless of number are recorded on the set details. The database stored at the Northwest Atlantic Fisheries Centre, St. John's, Newfoundland, was searched for records of salmon. In the database, an individual record consists of information collected during an individual 'set' or each time the trawl is fished. In total, there is information from about 600,000 sets, from 1965 to present and during those sets only 27 salmon were reported captured. The low catch compared to the number of sets indicates that salmon bycatches in otter and mid-water trawl gear are low. Bycatches in any fishery using similar gear would also be expected to be low, more so since commercial vessels typically use larger mesh due to regulations.

Fisheries observers from the Newfoundland Region have been deployed to vessels fishing the offshore north of the Laurentian Channel inside the Canadian zone since 1980. A primary duty of the observers is to quantify the catches on a set-by-set basis for all species including salmon. Methods for sampling fish and estimating catches at sea are given in Kulka and Firth (1987). An inspection of the records of catch from 1980 to 1997 shows that only 22 salmon were recorded from a total of 424,490 sets observed (Table 1.4). For individual years, there were from 0 (the most frequent number) up to four salmon per year recorded. The location of capture of these salmon was mainly south of 48°N, primarily along the southwest part of the Grand Bank (Fig. 1.3).

Bycatches have long been an issue of contention for shrimp fisheries where bycatches as large as that of the target species have often been recorded (D. Parsons, Department of Fisheries and Oceans, Science Branch, St. John's, Newfoundland, pers.comm.). For example, the Flemish Cap shrimp fishery in 1993 recorded 50% bycatch which by 1995 had been reduced to less than 3% following the introduction of the sorting grates. These sorting grates are mandatory within the Canadian zone and have similarly reduced bycatches there. The sorting grates allow the non-target species to escape while retaining the target species, i.e. shrimp in the trawl. The bycatch information from the Flemish Cap indicates that there were no salmon recorded as part of the bycatch.

Given the apparent low bycatch of salmon in trawl fisheries, we conclude that fisheries using trawl gear did not contribute to the widespread decline in returns of salmon in 1997.

Bycatches in Inshore Fisheries

A sentinel cod fishery was initiated in 1995 to obtain detailed information on cod abundance in inshore Newfoundland and Labrador waters. Authorized fishers used either cod traps, gill nets, or long lines. Concern over the potential for large numbers of salmon being taken as bycatch in the sentinel fishery prompted a review of sentinel fishery records for incidences of salmon. Owing to time constraints, we assumed that any bycatch of salmon would most likely occur in cod traps and limited our initial search to these records. We also assumed that any salmon that were caught would have been accurately reported. The first assumption was later addressed by examining the 1996 sentinel gillnet fishery data. Only one salmon was reported as bycatch in gillnets.

In general, the sentinel cod trap fishery occurred during periods of time Atlantic salmon would have been present in inshore waters with fisheries generally taking place from late June until mid-September (Table 1.5). Limited fisheries continued into early October in SFA 3 in 1996 and 1997. Cod traps were fished in SFAs 2 through 10 with the number of fishers ranging from 1 to 8. The total number of cod trap days-fished also varied among SFAs and years (Table 1.5). No bycatch of salmon was reported in SFAs 8 and 9, while the highest bycatch occurred in SFAs 4 and 5 (Table 1.5). Catch rates of salmon, defined as the number of salmon caught per trap-day, were low, with highest value of only 0.80 salmon caught per trap-day. The highest overall catch of salmon was 345 fish in 1996 (Table 1.5) with only 274 salmon reported caught in 1997.

Given the apparent low bycatch of salmon in the sentinel cod fishery, we conclude that this fishery did not contribute to the low returns of salmon experienced in 1997.

There was a limited cod fishery along the south and west coast of Newfoundland in 1997 for the first time since the moratorium in 1992. On the west coast, only hook and line gear was allowed and thus a bycatch of salmon is unlikely. On the south coast, fishing time was very limited due to the small quota which would limit the magnitude of the bycatch. As well the implementation of such things as salmon deflectors on cod traps or sinking the leaders and imposing conditions on herring bait licenses requiring the nets to be set one fathom under the water has considerably reduced the opportunity for salmon by-catch. The capelin fishery did not materialize in 3L in 1997 except for a limited purse seine fishery. Only a few traps (3 or 4 per bay) were set to sample capelin.

A questionnaire was sent to Fisheries Officers requesting information on possible bycatch of postsmolts. Several Fisheries Officers also included comments on the bycatch of salmon greater than 1.5 kg that were obviously not postsmolts. For the east and northeast coast of Newfoundland, the bycatch was generally lower in 1997 than in 1996. The bycatch in 1996 was particularly high in some bays. In the area of Francois to Pass Island (SFA 11) there was a report of higher bycatch of salmon 1.5 - 4 kg in size during 1996. There were also reports on significant bycatches of salmon in sea trout and food fishing nets in recent years in Labrador, although 1996 returns should have been equally affected as those in 1997. The commercial trout fishery in southern Labrador was closed in 1997. The resident food fishery for trout does not operate during the commercial salmon season of June 20 - July 31.

Summary

The available evidence indicates that the activities of man through fishing were not the cause of the low returns in 1997. All possibilities were considered including commercial fisheries at Greenland, Labrador, and St. Pierre et Miquelon, angling fisheries, native food fisheries, bycatches and poaching. The available evidence indicates that none of these sources increased (and some decreased over 1996 values) sufficient to explain the low returns in 1997. A number of activities of man outside of fishing such as the impact of hydro dams, forestry and agricultural practices were not considered. It should be recognized that while these cannot have impacted on returns for an individual year over time they are undoubtedly significant.

2. Environmental factors

Did environmental factors, e.g. water temperature, etc. either in freshwater or in the sea cause the low returns of salmon in 1997?

2A - BIOTIC FACTORS

Ecosystem change, often referred to as regime shifts, have been documented at basin scale levels in the Pacific Ocean (Beamish and Bouillon 1993; Beamish et al. 1997; Steele 1996). For a regime shift to occur there must be large scale variations in biological and physical environments in which the salmon live. Climate effects on salmon abundance are difficult to understand and harder yet to prove. An alternate method of detecting change in climate would be to look at biological characteristics of the fish. In this sub-section, we look at salmon and several other species that live in the northwest Atlantic ocean.

Biological characteristics of salmon in Newfoundland in 1997

There is no direct information available that will provide insight as to whether or not food availability in the marine environment played a role in the low returns of virgin grilse to Newfoundland rivers in 1997. An indirect approach is to examine biological characteristics of adult salmon, such as length, weight, smolt-age composition, and condition, to determine if these parameters changed in 1997 compared to previous years. It is also necessary to examine the same characteristics in smolts in 1996 in comparison to previous years, to get an indication of the extent to which the freshwater environment might be involved. Thus, it is hypothesized that: 1) reduced size and/or condition of smolts could result in increased mortality at sea from factors such as predation; and 2) decreased food availability at sea could be manifested in reduced size and/or condition of surviving adults. Also, an examination of the relative proportions of virgin grilse and repeat spawning grilse in the small salmon size category (salmon < 63 cm in fork length) in 1997 compared to previous years could provide some idea of the time in the marine phase that mortality might have occurred. Repeat spawning grilse are mainly successive spawners and they are present in the sea at around the same time as virgin grilse are returning to home rivers. An increase, or at least no change, in the proportion of repeat spawners could indicate that higher than usual mortality of virgin grilse did not occur in the vicinity of homewaters in 1997. This hypothesis assumes that mortality of repeat spawners in 1997 was similar to previous years.

Sources of data on biological characteristics of smolts were obtained by sampling throughout the run at counting fences located in Campbellton River and Gander River in SFA 4, Northeast Brook (Trepassey) and Rocky River in SFA 9, and Conne River (SFA 11). Adult salmon were also sampled at counting fences in these rivers and in the recreational fishery; in the case of Conne River, additional information was obtained by sampling broodstock used in an enhancement project and by sampling in the Native food fishery. Adults for Northeast Brook (Trepassey) were sampled as kelts in the year following their return and hence were not available for the present analysis. Adult samples were obtained from the recreational fishery in Middle Brook and Terra Nova River in SFA 5 and Northeast River (Placentia) in SFA 10. For Terra Nova River, additional information was obtained by sampling broodstock used for enhancement purposes.

Condition was examined using Fulton's condition factor (K) as follows:

$$K = W \times C / L^3$$

where,

W = whole weight (gm for smolts; kg for adults)
C = 100 (for smolts); 100,000 (for adults)
F = fork length (cm)

Mean fork length, mean weight, and mean smolt age determined from virgin grilse in 1997 were compared to means for the period 1992-96 treated as a group, using the NPAR1WAY procedure of SAS (SAS Institute 1985). The 1992-96 period was chosen because it corresponds to years of the commercial salmon fishery moratorium (O'Connell et al. 1997a). For smolts, means for 1996 were compared to means for all previous years treated as a group. Smolt-age composition for smolts and virgin grilse was also examined using the likelihood ratio (G) test as outlined in the FREQ procedure of SAS (SAS Institute, 1985). In order to eliminate the problem associated with expected cell frequencies of less than 5 (Sokal and Rohlf 1981), extreme age groups (2, 5, and 6, depending on the river) were eliminated. These age groups were consistently present in very low frequencies since for insular Newfoundland rivers, smolt ages of 3 and 4 years are most common.

Length, weight, and condition

SMOLTS: Mean fork length, mean weight, and mean K for smolts from Campbellton River, Gander River, Northeast Brook (Trepassey), Rocky River, and Conne River are shown in Figs. 2.1-2.5, respectively. There was no significant difference ($P > 0.05$) in mean fork length between 1996 and the period 1989-95 for Gander River nor between 1996 and the period 1993-95 for Campbellton River. For Northeast Brook (Trepassey), there was a significant increase in fork length in 1996 over 1986-95 ($Z = 4.76$; $P = 0.0001$) and the same was true for Conne River for 1996 versus 1987-95 ($Z = 2.53$; $P = 0.0114$). There was a significant decline in fork length for Rocky River in 1996 compared to 1990-95 ($Z = -4.17$; $P = 0.0001$).

Mean weight in 1996 increased significantly over the previous grouping of years for Northeast Brook (Trepassey) ($Z = 5.84$; $P = 0.0001$) and Conne River ($Z = 2.77$; P

= 0.0056) but decreased for Campbellton River (Z = - 1.97; P = 0.0490) and Rocky River (Z = 2.01; P = 0449).

Mean K in 1996 increased significantly over previous grouping of years for Northeast Brook (Trepassey) (Z = 3.53; P = 0.0004) and Rocky River (Z = 7.19; P = 0.0001) but decreased for Campbellton River (Z = - 5.21; P = 0.0001). There was no significant difference (P > 0.05) between 1996 and previous years for Gander River and Conne River.

<u>ADULTS:</u> Mean fork length, mean weight, and mean K for virgin grilse for the period 1992-97 for Campbellton River, Gander River, Middle Brook, Terra Nova River, Northeast River (Placentia), Rocky River, Conne River, and the Conne River Native food fishery (data are available only for 1992 and 1993 prior to 1997) are shown in Figs. 2.6 - 2.13, respectively. Mean fork length in 1997 increased significantly over that of the period 1992-96 for Rocky River (Z = 4.67; P = 0.0001), Conne River (Z = 12.91; P = 0.0001), and the Conne River food fishery (Z = -12.39; P = 0.0001) but decreased for Gander River (Z = -3.14; P = 0.0017). There was no significant difference for Campbellton River, Middle Brook, Terra Nova River, and Northeast River (Placentia) (P > 0.05).

There was no significant difference in mean weight of virgin grilse between 1997 and the period 1992-96 for Campbellton River, Gander River, Middle Brook, Terra Nova River, and Conne River. Significant increases were noted for Rocky River (Z = 3.48; P = 0.0005), Northeast River (Placentia) (Z = 3.14; P = 0.0017), and the Conne River food fishery (Z = -20.62; P = 0.0001).

Mean K in 1997 increased significantly over 1992-96 for Northeast River (Placentia) (Z = 4.74; P = 0.0001) and the Conne River food fishery (Z = -19.55; P = 0.0001) but deceased for Gander River (Z = -2.79; P = 0.0052) and Middle Brook (Z = - 2.29; P = 0.0223). There was no significant difference for Campbellton River, Terra Nova River, Rocky River, and Conne River (P > 0.05).

<u>Smolt-age composition</u>

<u>SMOLTS:</u> Mean smolt age for Campbellton River, Gander River, Northeast Brook (Trepassey), Rocky River, and Conne River is shown in Figs. 2.1-2.5. Smolt-age composition for these rivers is shown in Figs. 2.14-2.18. Gander River (Z = 2.52; P = 0.0117), Rocky River (Z = -2.50), and Conne River (Z = -4.07; P = 0.0001) showed a decrease in mean smolt age in 1996 compared to the previous grouping of years (see above) corresponding to each river. G-test results for these rivers were also significant (Gander River: G = 11.86, P = 0.003; Rocky River: G = 22.50, P = 0.001; Conne River: G = 17.19, P = 0.001); for all three rivers there was an increase in the proportion of 3+ smolts in 1996. There was no significant difference in mean smolt age for Campbellton River and Northeast Brook (Trepassey) (P > 0.05) and G-test analyses were also not significant.

<u>ADULTS:</u> Mean smolt age for virgin grilse for the period 1992-97 for Campbellton River, Gander River, Middle Brook, Terra Nova River, Northeast River (Placentia), Rocky River, Conne River, and the Conne River food fishery is shown in Figs. 2.6-2.13, respectively. Corresponding smolt-age composition for these rivers is shown in Figs. 2.19-2.26. **It should be pointed out here that virgin grilse in 1997 (year i) were smolts in 1996 (year i - 1) and the same applies to the other virgin grilse years.** This will be reflected in the presentation to follow and should be kept in mind when examining the figures.

Mean smolt age in 1996 increased significantly ($Z = 2.10$; $P = 0.0358$) over 1991-95 for Campbellton River while G was not significant ($P > 0.05$).

There was no significant change in mean smolt age for Gander River virgin grilse ($P > 0.05$) but there was a significant difference in age composition in 1996 compared to 1991-1995 ($G = 12.95$; $P = 0.0002$). The proportion of 3+ smolts in 1996 was similar to 1991-95 but there was a decrease in the proportion of 4+ smolts and an increase in 5+ smolts.

There was a significant increase in mean smolt age in 1996 compared to 1991-95 for Middle Brook ($Z = 2.48$; $P = 0.0131$) and a significant change ($G = 6.14$; $P = 0.013$) in age composition (the proportion of 4+ smolts increased).

While mean age increased significantly in 1996 for Terra Nova River ($Z = 2.63$; $P = 0.0086$), there was no change in age composition ($P > 0.05$).

There was no significant change in mean smolt age for Rocky River ($P > 0.05$) but there was for age composition ($G = 7.46$; $P = 0.006$), as reflected in an increase in the proportion of 3+ smolts in 1996.

There was no change in either mean age or age composition for Northeast River (Placentia).

Mean age in 1996 increased significantly over 1991-95 for Conne River ($Z = -4.55$; $P = 0.0001$). Age composition changed significantly ($G = 20.53$; $P = 0.001$) with an increase in the proportion of 4+ smolts in 1996.

Similar to the result obtained for sampling in Conne River, there was a significant increase in mean age in the Conne River food fishery in 1996 ($Z = -4.65$; $P = 0.0001$) and a significant change ($G = 21.01$; $P = 0.001$) in smolt age composition (the proportion of 4+ smolts increased.

<u>Egg-to-smolt survival</u>

Since 1986 for Northeast Brook (Trepassey) and 1987 for Conne River, egg deposition has shown an overall decline (Table 2.1, Fig. 2.27). Egg-to-smolt survivals corresponding to these egg depositions in Conne River have increased consistently since 1987, culminating with the highest value in the series being recorded for the 1992 year-class. This would suggest that environmental conditions conducive to good survival prevailed and indeed were trending upward. Alternatively, it could also be suggestive of density-dependent effects in that egg-to-smolt survivals at Conne River increased coincident with the decline in the number of eggs deposited per unit of fluvial habitat (Table 2.1, Fig. 2.27). The situation was different for Northeast Brook Trepassey however, in that survival was more or less stable between 1984 and 1991 and only the 1992 year-class showed any sign of an increase. When observations on condition of smolts are coupled with these results, there is an implication that events in the freshwater environment did not contribute to the decreased adult returns in 1997 for these two rivers.

Percentage of virgin grilse versus repeat spawning grilse

The percentages of virgin grilse and repeat spawning grilse for Campbellton River, Gander River, Middle Brook, and Terra Nova River for 1992-97 are shown in Fig. 2.28 and for Northeast River (Placentia), Rocky River, and Conne River in Fig. 2.29. Percentages of repeat spawning grilse for Gander River, Terra Nova River, and Conne River in 1997 were the highest since 1992, with the increase for Gander River being the most pronounced and that of Conne River the least. The percentage for Rocky River in 1997 was the second highest recorded (the highest occurred in 1994). There were no increases in 1997 for the remaining rivers; the percentage for Northeast River (Placentia) was the lowest of the past four years. In the Conne River food fishery, only 3 repeat spawners (in 1997) were encountered during the three years of sampling.

Discussion

While in the statistical sense there were significant changes for 1997 compared with previous years for the parameters examined, some in the direction anticipated, in the biological sense the magnitude of change was minimal. For example, 4 of the 8 rivers showed no change in K for virgin grilse, Gander River and Middle Brook recorded significant decreases, but Northeast River (Placentia) had a significant increase. The K values for Gander River and Middle Brook in 1997 were 1.01 and 1.08 or approximately unity, indicative of isometric growth (Ricker 1975; Bagenal and Tesch 1978). Size and K for smolts in 1996 likewise were not unusual when compared to previous years. There were no anomalies in smolt age composition in 1996 of a magnitude to produce an uncoupling of the usual year-class structures as determined either from smolts or virgin adults. The increase in the 3+ smolt age component for Gander River as evidenced by both smolts and adults is consistent with the greatly increased number of spawners in 1992 (O'Connell et al. 1997b). Middle Brook also had increased spawners in 1992 (O'Connell and Reddin 1997) but the proportion of 3+ smolts declined in 1996. Modal smolt age was more or less the same for all years for all rivers.

The present analysis suggests that size and condition of smolts leaving rivers in 1996 were not unusual. There is no evidence, at least based on the biological parameters studied, that virgin grilse encountered a lack of food resources in the sea. It could be argued that only the best-conditioned fish survived to return and hence it might not be possible to detect a change. It is doubtful that all poorly conditioned fish would die and conceivable that enough would survive to decrease condition on average. Evidence as to when in the marine cycle that mortality occurred as determined from the relative proportions of virgin grilse versus repeat spawning grilse, suggests that mortality occurred prior to spring and summer in 1997, or did not occur in the vicinity of home waters. At face value, the present results suggest that mortality might have been due to physical factors as opposed to biological factors. In the absence of evidence of reduced growth, it is doubtful that there will be an increase in returns of two-sea-winter salmon, emanating from the 1996 smolt class. Reduced marine growth has been associated with a delay in age at maturity (Scarnecchia et al. 1989, 1991).

Possible changes in postsmolt salmon distribution

There was an indication from a Fisheries Officer in Twillingate (SFA 4) that there was an unusual increase in the bycatch of postsmolts in the Notre Dame Bay, SFA 4 during the months of July, August and September in 1996. The implications of this bycatch, if widespread in occurrence, could be two fold: 1) there was an increased bycatch mortality on postsmolts, and 2) there was a migration or distribution change and postsmolts did not leave the coastal areas as in previous years. If the later occurred then the postsmolts could have been subjected to increased predation by cod, seals, birds etc.

A questionnaire was sent to 40 offices of the Conservation and Protection Branch of DFO in Newfoundland and Labrador requesting information on the relative level of bycatch of postsmolts in 1996 and 1997 compared to previous years. There were only 13 respondents, four from Labrador, six from the east and northeast coast, two from south coast and one from the west coast of Newfoundland.

The only Fisheries Officer who reported any significant bycatch of postsmolts was from Notre Dame Bay, he reported significant bycatches in 1995 and 1996, but not in 1997. The bycatch in 1996 was lower than in 1995. A fishermen in Badgers Quay west side of SFA 5 who caught significant quantities of postsmolts in the fall of 1995, fewer in 1996, and none in 1997. Fisheries Officers in the other parts of Newfoundland did not report any by-catch of postsmolts, except for a catch of 3 postsmolts in the Makkovik area in September, 1997.

The results of this survey are not conclusive since there may not have been fishing gear with suitable size mesh, in the water to capture postsmolts. However, for the Notre Dame Bay - Bonavista Bay area it does appear that a large number of postsmolts remained near shore during the summers of 1995 and, to a lesser extent in 1996. It is possible that those postsmolts that remained inshore were subjected to higher than usual predation. Fishermen report seeing, during the past few years, large numbers of cod in water depths of 6 m to 8 m from May until late fall, a phenomenon that they had not observed before. There are no data to substantiate the level of predation near shore. We do know that in the last 2 to 3 years, cod have been angled near the mouths of some rivers at about the same time as the smolt run. In previous years, there were very few if any postsmolts caught. During the summer of 1984-85, a sampling team visited several fish plants from St. Mary's Bay to Notre Dame Bay examining capelin catches for postsmolts. None were found; although it was reported by Inspection Officers that occasional postsmolts are observed mixed together with capelin.

The question remains, that if postsmolts remained near shore in 1995 and 1996, why was the sea survival so much lower in 1996/97 than in 1995/96?

Distribution & spawning time variability in capelin

During the 1990's, capelin in the stock complex on the east and northeast coast of Newfoundland (Div. 2J3KL) have exhibited significant changes in distribution, size, and behaviour. In addition, the indices of abundance that have been routinely collected by DFO personnel, namely, offshore acoustic estimates, inshore aerial survey index, and catch rates in the inshore fishery have exhibited divergent trends. These changes have occurred during a period of below normal sea temperatures and many of the biological changes observed in capelin have been attributed to the lower water temperatures. In the following discussion, we briefly summarize these changes. All of the descriptions have been documented and the reader is advised to consult the references for more detail.

Divergence in abundance indices

Two offshore acoustic surveys, one in Div. 3L during the spring (April-May) beginning in 1982 and one in Div. 2J3K during the fall beginning in 1981, were designed to estimate recruitment. These surveys were combined into one fall survey over the entire stock complex beginning in 1993.

Beginning in the early 1990's, the results from capelin acoustic surveys experienced two dramatic changes. The biomass estimates showed significant and abrupt declines in both spring and fall surveys and the main area of distribution (albeit at much lower abundance) in the fall surveys shifted further south (discussed in the next section).

In 1990, the highest estimated biomass at almost 7 million tonnes, was recorded during the spring survey. In 1991, the biomass estimates dropped to about 100,000 tonnes, an unexpected result since some of the same year classes contributed to both estimates. The survey was repeated about one month later with similar low results. Between the two surveys, the Russians completed an acoustic survey over roughly the same area and this estimate was also low (Bakanev 1992). The 1992 Canadian survey estimate was also low. Capelin in both the 1991 and 1992 surveys were widely scattered, although there was no obvious shift in distribution of the low biomass measured. One other spring survey in Div. 3L in 1996 also produced a low biomass estimate.

During the 1990's, the biomass estimates from the fall surveys were variable and did not appear to be showing promise as reliable indicators of year class abundance. The survey was expanded eastward in 1989 to compensate for possible incomplete coverage and was further enlarged to include Div. 3L in 1993 and 1994. However, since the fall of 1990, biomass estimates have remained very low [less than 100,000 tonnes].

Since the acoustic survey was measuring recruiting fish and was used primarily for projections, the expectation was that dramatic declines in the inshore indices for mature fish would be seen. However, neither the aerial survey index nor the catch rate index declined to the extent that the acoustic survey did. Other indicators such as egg density on beaches, bycatches in groundfish surveys offshore and results from O-group surveys also did not decline. It was concluded that for some reason the acoustic surveys have not been indicative of stock status during the 1990's. Carscadden and Nakashima (1997) provide a more extensive review of this situation.

Changes in offshore distribution

As noted briefly in the previous section, concentrations of capelin that contributed to the maturing biomass had shifted from Div. 2J to the southern part of Div. 3K and no concentrations of capelin were observed in Div. 2J and northern 3K during acoustic surveys in the 1990's. This shift in distribution was unusual based on the general patterns gleaned from previous acoustic surveys, historical offshore commercial fishing patterns, bycatch in groundfish surveys conducted in November and December, and capelin in cod stomachs (Lilly and Davis 1993). Normally, capelin would be off the coast of Labrador in Div. 2J in late summer and early autumn but by late autumn, most would have migrated south into Div. 3K. Some capelin would, however, remain off Labrador even in November. Exceptions occurred in 1986 and 1987 when few capelin were found off Labrador in November. During 1990-94 (Lilly and Davis 1993; Lilly 1994, 1995) capelin bycatch and cod predation indicated that by November few capelin occurred in Div. 2J but the major concentrations were even further south and east in Div. 3K than previously recorded, consistent with observations from the acoustic surveys. In addition, bycatch of overwintering capelin in shrimp fisheries in southern Div. 2J and northern Div. 3K during January-March also declined, consistent with the results from the fall acoustic and groundfish surveys (Carscadden 1996).

During approximately the same period when capelin were occurring further to the south within their normal range, capelin also increased in abundance in areas where they were not usually common, namely eastern Scotian Shelf (Div. 4VW) and Flemish Cap (Div. 3M) (Frank et al. 1996). On the Scotian Shelf, capelin catch rates began to increase during the late 1980's, coincident with a decrease in water temperatures. Capelin catch rates in these surveys have remained relatively high up to and including 1997 (Frank et al. 1996, K. Frank, Department of Fisheries and Oceans, Nova Scotia, pers. comm.). In this area, it is not known whether the increase in capelin abundance resulted from a movement of capelin into the area or from a resurgence of a small local population under favourable conditions.

On the Flemish Cap, capelin had not appeared as bycatch in groundfish surveys between 1949 and 1985 or in predator stomachs examined between 1978 and 1990. Prior to their appearance in the 1990's, the only record was a bycatch in a commercial fishery in 1973. Records at DFO, St. John's indicate capelin on the Flemish Cap at least until 1994 (Frank et al. 1996, DFO records, St. John's) but data after 1994 are sketchy because of lack of a Canadian fishery and survey. Both the 1973 record and the appearances in the 1990's coincided with below average water temperatures. Since capelin had not occurred as bycatch in most years, it is likely that the occurrences during cold years were the result of migration to the area when temperature conditions were favourable.

It has not been possible to determine whether the appearance of capelin in these areas could account for the decline in the acoustic estimates, however, bycatch increases have been significant. Catch rates increased by a factor of 100 on Scotian Shelf and capelin occurred in 72% of the 1103 observed shrimp fishing sets on Flemish Cap (total capelin bycatch weight = 4811 kilograms) in 1993.

Spawning times and mean lengths

Peak spawning time of capelin along the northeast coast of Newfoundland has been several weeks later since 1991 and this shift has been statistically linked with colder water temperatures during the maturation period just prior to spawning (Carscadden et al. 1997).

During the 1990's, the population mean lengths of mature capelin were smaller than mature capelin during the 1980's. The population mean length was smaller because of smaller fish of age 3 and older and an increased contribution of age 2 fish to the spawning stock. Carscadden et al. (1997) have shown that the time of peak spawning is also related to mean size of fish in the population, with later spawning occurring when fish are smaller. When combined with pre-spawning water temperatures, mean length explained 80% of the variation in peak spawning.

Summary

It is clear that there were significant variations in the biology and behaviour of capelin during the 1990's, as evidenced by the distribution anomalies over wide geographic areas, decrease in sizes of mature individuals and delays in peak spawning times by up to one month. These changes coincided with below average water temperatures which persisted over a large part of the Northwest Atlantic. In addition, abundance indices for capelin exhibited divergent trends.

The dichotomy in patterns of abundance indices, offshore and inshore, has never been fully reconciled. However, based on available evidence to date, it now appears that the acoustic surveys were underestimating the true population abundance of capelin offshore. The occurrence of capelin in areas where they do not usually occur, especially Flemish Cap, the continued occurrence of capelin as bycatch in groundfish surveys, the widespread distribution of young capelin in 0-group and juvenile surveys throughout the area, and the continued spawning of capelin on beaches inshore suggest that capelin abundance did not decline to the extent predicted by the acoustic surveys. It seems likely that the severe environmental conditions during the early 1990's were the major cause of the changes in biology and behaviour of capelin and these changes had their greatest impact on the acoustic estimates (Carscadden and Nakashima 1997).

Recruitment variability - cod

Recruitment of pelagic juvenile cod may serve as an indicator of environmental conditions that salmon are in at least from cod spawning to settlement. Anderson et al. (1998) note a significant decline in the abundance of juvenile pelagic cod in 1996 and 1997 compared to 1994 and 1995. Abundance was greater in 1997 than 1996 by a factor of 2.1, the 1997 year class was 50% and 33% of the estimates for 1995 and 1994, respectively. Of note was the presence of pelagic juvenile cod offshore (Northeastern Newfoundland Shelf) in 1997 which was similar to 1995 even though abundance was lower than 1994. The overall implication of the latter was that there was some degree of successful spawning in 1995 and 1997 as compared to 1996. The authors note no apparent substantial differences in biological parameters of spawning times, growth rates or condition (weight at length) of pelagic juvenile cod during the 1994 - 1997 period. Year class abundance was ranked as 1994 > 1995 > 1997 > 1996. Anderson et al. (1998) state, "*The 1996 year-class ranks the lowest in all categories: low abundance, both inshore and offshore; later spawning; low growth rates; smallest size prior to settlement.*"

Methven et al. (1998) note the 1996 catch of 0-group cod to be the lowest in the 12-year history of their survey with the 1997 catch of 0-group cod representing the highest catch of this group since the 1992 cod moratorium.

Lilly (1997) notes that mean weight at age for offshore cod has declined through the 1980's and early 1990's with the largest decline in NAFO Division 2J followed by 3K with little or no decline in 3L as well as the apparent reversal of this trend in the early 1990's. Similarly, the decline in condition levels has improved since 1992.

Summary

The overall significance of poor juvenile cod recruitment in 1996 on salmon postsmolt survival is unknown. However, for a period of time both cod and salmon are in the same pelagic environment. It may be that the factors influencing poor cod recruitment may also have influenced salmon survival.

2B - ABIOTIC FACTORS

A second method for determining the effect of environment on fish abundance is to look at environmental variables and test for their relationship with the fish. In this subsection, we take that more traditional approach but include in it a brief examination of the chemical environment as well. Also included here is an examination of available SST data for changes in ocean climate.

Ocean climate

Atlantic salmon are known for their ability to migrate over long distances and are found widely distributed over the north Atlantic. The evidence for this comes from tagging studies that have shown salmon from rivers in the southern part of their distribution can be found in the summer off west Greenland (Meister 1984; Ritter 1989). Longer distances are occasionally traveled as Canadian salmon have been caught at Faroes (Ritter 1989). Also, European salmon have been found off the coasts of Newfoundland and Labrador (Reddin et al. 1984). Salmon are not only found widespread over vast areas but coherence within single stocks for various areas is not a common feature of their migration. Indeed, salmon from a single stock and year class can be found simultaneously along the northeast coast of Newfoundland and at west Greenland. Thus, analyses to determine relationships between salmon abundance and ocean climate must consider the widespread migration and distribution of salmon over much of the northwest Atlantic. There are many studies (e.g. Ritter 1989; Scarnecchia 1984a; 1984b; Friedland and Reddin 1993; Reddin and Friedland 1993) that have related conditions in the marine environment to survival and abundance. Most have used ocean climate variables derived from single sources. More recent studies have shown that production of North American 2SW salmon is related to an index of marine habitat in the northwest Atlantic termed thermal habitat (Reddin et al. 1993). This relationship has been used to predict the number of potential 2SW termed prefishery abundance prior to the fishery at west Greenland (Anon. 1997) (Fig. 2.30).

Ocean climate as a possible cause of the lower returns of salmon in 1997 requires that we look for large-scale variations in the biological and physical environments in which salmon live. Although salmon spread out over the north Atlantic, they seem to spend most of their time near, or in surface waters. While dives to deeper depths have been observed in some tracking studies, salmon are thought to spend much of their time in the upper part of the water column where they can be caught in fisheries using surface set gillnets (Reddin and Shearer 1987). Thus, any examination of ocean climate should concentrate on relationships with upper surface water conditions. However, information on conditions at other depths should not be ignored as in oceanic areas salmon feed heavily on species that are meso- to bathy-pelagic (Hislop and Shelton 1993). The salmon's habit of living near to the surface make the ability of earth observation satellites to collect information over widespread areas of the sea especially suitable for studies of salmon and ocean climate. Satellite SST (Sea Surface Temperature) data while not without its own special set of problems can provide data not available from ships of opportunity or research vessels.

Indeed satellite SSTs have been used by Reddin and Friedland (1993), Friedland et al. (1993) and Dempson and Reddin (1995) to test various hypotheses related to overwintering habitat influencing the survival and then productivity of salmon stocks. Because temperature can affect fish production directly and indirectly, we wanted to compare salmon production trends with sea surface temperature trends in the north Atlantic from as many sources as possible.

Sources of data on SSTs

In order to test hypotheses related to the marine environment, indices of ocean climate and salmon survival are both required. A measure of ocean climate termed thermal habitat developed to provide catch advice for the West Greenland fishery has been previously described in Anon. (1995), Reddin and Friedland (1993) and Anon. (1997). Thermal habitat is a relative index of the area suitable for salmon in the northwest Atlantic. It was derived from sea surface temperature (SST) data obtained from the National Meteorological Center of the National Ocean & Atmospheric Administration and previously published catch rates for salmon from research vessels fishing in the northwest Atlantic (Reddin et al. 1993, Anon. 1995). SSTs were determined by optimal interpolation (OI) of SSTs from ships of opportunity, earth observation satellites from the Advanced Very High Resolution Radiometers (AVHRR), and sea ice cover and ships of opportunity data prior to the availability of satellite data in 1981 (Reynolds 1988; Reynolds and Smith 1994). The salmon catch rates from experimental fishing by research vessels are weighted by the area in each 2° square from which the SST data came from. The area used to determine available salmon habitat encompasses the northwest Atlantic north of 41°N latitude and west of 29°W longitude and includes the Davis Strait, Labrador Sea, Irminger Sea, and the Grand Bank of Newfoundland (Fig. 2.31). The total thermal habitat area is $4.25 * 10^6$ km^2. Thermal habitat is available for the years 1970-97. Reynolds and Smith (1994) discuss the accuracy of their data by comparing to SSTs from buoy data at specific locations. Overall, bias measured as buoy SST - satellite OI shows a bias of -0.18°C; that is the OI data gives a slightly higher SST than that measured by buoys. Residual mean square errors were 0.35. Thus, SSTs derived from satellite imagery are highly accurate.

Other satellite-derived SST data products also exist, i.e. the MCSST (Multi-Channel Sea Surface Temperature) and RSST (Reconstructed Sea Surface Temperature) data. The MCSST data are derived from measurements made by AVHRRs aboard the NOAA series of polar orbiting satellites over the period of 1981-1997. The Jet Propulsion Laboratory (JPL) maintains a MCSST archive and provides data on a 0.18° longitude by 0.18° latitude equal angle grid on a weekly basis (JPL.PODAAC Product 016). The AVHRR is a five channel instrument: two channels are located in the visible and near infrared bands of the electromagnetic spectrum and three channels are in the thermal infrared measuring energy radiated from the sea surface as well that contributed by the intervening atmosphere. Clouds are opaque to infrared radiation and no ocean surface temperature data can be retrieved through clouds. Temporal and spatial variability in atmospheric conditions as well as undetected cloud in the atmospheric column are the primary sources of error in SST estimates. An 8 day average is then computed to form the final MCSST product used here. In fact, two global sets are collected daily, one during the local afternoon and one at night. Because clouds are detected so much more easily during daylight than night, we use only the daylight MCSST data set in this analysis. The MCSST cloud detection scheme is very conservative and relatively few valid retrievals remain in the winter, especially at higher latitudes. However, the remaining SST data is still superior in coverage to that collected by ships of opportunity and research vessels.

Another source of SSTs is from the RSST data series developed using empirical orthogonal functions (EOFs) to produce in situ analyses of SSTs from 1950-81. The first step was to produce the spatial EOFs from the OI analyses previously described by Reynolds and Smith (1994). The dominant EOF modes were used as basis functions and were fitted to the *in situ* data for the period 1950-95 to determine the time dependence of each mode. A global field of SSTs was then reconstructed from these spatial and temporal modes. The details of the EOF reconstruction method are explained by Smith et al. (1996). The area used to examine ocean climate using the RSST data encompasses the northwest Atlantic north of 30°N latitude to 70°N and west of 30°W longitude to 70°W (Fig. 2.32). RSSTs are available for the years 1950-97. For purposes of relating the RSST data to salmon the northwest Atlantic was divided into 6 areas or blocks: Atlantic Nova Scotia, Newfoundland South, Gulf of St. Lawrence, Labrador Sea North, Labrador Sea South, and Grand Bank and East (Fig. 2.32).

Sources of data on salmon

Management plans based on conservation are designed to reduce mortality and increase the number of spawners. Thus, they can have a considerable impact on the proportion of salmon caught from one year to the next rendering raw catches or counts useless as an absolute or even relative index of annual salmon abundance when trying to link it with climate. Of themselves, the count data are an invaluable tool as they measure by counting the number of salmon returning to a given river. Such is the case for salmon in Newfoundland where a commercial fishing moratorium has been in place since 1992. Analyses attempting to relate climate to abundance must, therefore, use count or catch data corrected for the effects of reductions in fishing effort.

Survival data: Counts of smolts and 1SW adult salmon returning to Western Arm Brook, Northeast Trepassey Brook and Conne River, Newfoundland were used to estimate marine survival by dividing the returning adults in a given year by the outgoing smolts from the previous year (O'Connell et al. 1997a; Dempson and Furey 1997; Mullins 1997a). Further adjustments were made to these data to attempt to remove the effects of commercial exploitation in the sea so that the data are more reflective of salmon survival from natural causes. This was done as follows:

$$(R/(1-E)),$$ where

R is the uncorrected return rate and E is the exploitation rate in the commercial fishery. Exploitation rates used were 0.6 (range 0.5-0.7) for 1SW salmon for the Western Arm Brook and Northeast Brook (Trepassey) stocks and 0.3 for Conne River stock (Reddin 1981; Chadwick et al. 1985; Anon. 1990; Dempson et al. 1997a). The uncorrected survival data is in Dempson and Furey (1997) and Mullins (1997a). Data for the 1996 smolt class returning in 1997 as grilse has been added to the time series (Table 2.2).

Adult return data: Two sets of adult return and spawner data were used. The first set included estimates of total small salmon recruits produced by several individual stocks in Newfoundland as well as estimates of the spawners obtained from parental cohorts. The individual stocks used in this analysis were from the following rivers: Exploits (Bourgeois et al. 1997), Gander (O'Connell et al. 1997b), Middle Brook (O'Connell and Reddin 1997), Biscay Bay (O'Connell and Reddin 1997), Conne (Dempson and Furey 1997), Humber (Mullins 1997b), Lomond, Torrent, and Western Arm Brook (Mullins 1997a). Estimates of the total number of small salmon produced by these stocks were obtained from counts at counting facilities expanded to the total numbers of salmon produced using a range of estimates of commercial exploitation rates (Table 2.3a). Estimated numbers of spawners were obtained from parental cohorts of small salmon tracing them backwards, beginning with the estimate of spawners for the current year (Table 2.3b). The number of spawners to produce the returns were unavailable for Lomond, Torrent, and Western Arm Brook. Spawners were estimated using the same technique as described above with further details to be found in Anon. (1994) and O'Connell et al. (1997b). River and sea age information used to assign adults to the appropriate cohort were obtained from the above referenced material.

The second set of abundance information consisted of estimates of the total number of 1SW and 2SW salmon produced in North American, Newfoundland, and Labrador rivers (Anon. 1997). The total number of 1SW and 2SW North American salmon produced, also known as North American prefishery abundance, is variously estimated depending on the stock aggregates based on fish counting facilities, exploitation rates in angling fisheries and angling catch data, commercial catch data and commercial fishing exploitation rates and the ratio of small : large salmon from the fishway rivers (Table 2.4). A description of the data is in Anon. (1997). The total number of recruits produced in rivers in Newfoundland and Labrador also described in Anon. (1997).

Inter-relationships between ocean temperature and salmon

Thermal habitat varies considerably from month to month and year to year (Table 2.5, Fig. 2.33). Trends can also be noted in thermal habitat as higher annual values were observed in the 1970s, dropped in the early 80s, increased in mid-80s and remained below average in the 90s (Table 2.5, Fig. 2.33). It increased in December of 1996 and winter of 1997 then started to drop in spring and has remained below average up to present. Thermal habitat is lowest during the winter increasing from spring to autumn when the highest annual values are usually seen. Thermal habitat in winter has experienced the most interannual variability over the period of 1970-97. Spring monthly values tend to show the greatest differences among months. During the spring of 1996, thermal habitat rose by 9% over previous year values almost matching the annual spring mean value of 1858. During the autumn of 1996, thermal habitat rose by 4% over the value of the previous year. During the winter of 1997, thermal habitat increased over that of 1996 by about 10%. The trend to increasing thermal habitat continued into the spring of 1997 when values increased by 4%. Thermal habitat for grilse with the exclusion of 1986 has been generally lower in the 80s and 90s than in the 70s (Fig. 2.34). Although not as high as values in the 1970s, thermal habitat for grilse returning in 1997 increased over values of the previous 10 years. Thermal habitat for MSW salmon was lower in the 80s and 90s then in the 70s; although it increased for salmon returning in 1997 over 1996 (Fig. 2.34).

Profiles of correlation coefficients (Spearman) for thermal habitat and salmon over the time a salmon is at sea could indicate the likelihood of a climatic event influencing the lower returns in 1997 and at what life stage the event may have occurred. Correlation profiles for 2SW North American salmon (prefishery abundance of non-maturing 1SW salmon), 2SW salmon recruits for Labrador, and 2SW recruits for Newfoundland show similarities among the same groups. Ocean climate seems to be influencing the three groups in the same way as significant correlations occur at months 1-3, 5, 9-15, 17-18, and 21-26 for the 3 groups (Fig. 2.35). Correlation profiles for North American grilse (prefishery abundance of maturing 1SW North American salmon), 1SW recruits of Labrador origin, and 1SW recruits of Newfoundland origin also show similarities in the pattern among the three groups. Significant correlations for all three stock complexes occurred at 5-6 and at 15 months (Fig. 2.36). Significant correlations also were present at 1-3 months for North American and Labrador grilse. The correlation profiles for Western Arm Brook grilse compare data for 1971-96 and 1971-95. The similarity of the correlation coefficients suggests that the inclusion of the low survival values for the 1996 smolt class did not alter correlation coefficients very much possibly because of the long time series available for Western Arm Brook (Fig. 2.37). Significant correlations for Western Arm Brook grilse and thermal habitat occur at 1-3 months at sea and 9-15 months. Negative correlations at 5-7 months were not significant. The correlation profiles for Northeast Brook (Trepassey) small salmon show significant results at months 5-6 and 11-13 for 1986-95 data (Fig. 2.38). None were significant once data from the 1996 smolt class were added. Correlation profiles for Conne River grilse show significant results at months 5-6 and 11-13 for the 1987-95 data series but none for 1987-96 (Fig. 2.39). When the individual profiles for the series including the 1996 smolt class are plotted together the patterns are similar showing a dropping off of the coefficients after a couple of months of sea then several negative coefficients and then return to more positive ones (Fig. 2.40). This evidence taken collectively suggests a relationship between salmon abundance and survival and ocean climate.

The correlation profiles for small salmon recruits of northeast coast rivers and thermal habitat adjusted so that monthly habitat from the immediate postsmolt stage onward is being correlated with salmon abundance, showed significant relationships at months 1-3, 5, 11-12 and 14 for Middle Brook. For Gander River, the relationships at months 1-2, 5, 9, and 11-15 were significant. For Exploits River, none were significant. Profiles for Middle Brook and Gander River showed some similarity but were quite distinct from that of Exploits (Fig. 2.41). Correlation profiles for small salmon recruits of two south coast rivers showed significant relationships at months 4-5 for Biscay Bay River and 1-2 and 9-11 for Conne River (Fig. 2.42). Correlation profiles for small salmon recruits of four west coast rivers were significant for Humber River at months 1-3, 5, 9, 11-12 and 15. There were no significant correlations for small salmon recruits from Lomond and Torrent rivers. For Western Arm Brook, small recruits showed significant relationships at months 1-3, 10-11, and 13-15 (Fig. 2.43).

In all, there were 318 relationships of which 122 were significant at less than the 5% level (Table 2.6). The possibility of Type 2 statistical error can be tested by comparing the number of significant relationships to that expected by chance assuming that 5%, or 16 of the correlations, would have been by chance significant. The number of significant correlations to those expected by chance were tested by the binomial theorem. The z-score was 30.2 with a $p<0.0001$. This suggests that at least for some stocks there is some evidence for relationships between ocean climate and abundance.

There were a number of very interesting correlations of thermal habitat and salmon survival at months 1-3. In order to examine the potential of relationships with inshore SSTs near salmon rivers and salmon survival, the MCSST data, because of its potentially greater detail, was examined. An interpolation scheme was implemented to produce weekly time series of SSTs at several selected sites in inshore Newfoundland (Fig. 2.44). Weeks 14-27 from early April to the first of July were chosen to approximate the earliest time when smolts are moving to sea and the prime time for returning adult salmon in Newfoundland. Briefly an area of up to six pixels was chosen adjacent to river mouths in each area, and the average weekly SST and the number of data contributing to each average was computed over the 15 year series. A weighted spline was fit to the observed data to form a weekly time series of interpolated values that were then compared to salmon returns. The weights were chosen as inversely proportional to the number of estimates.

Similar variability is observed in inshore SSTs around the coast of Newfoundland among sites and years (Fig. 2.44). Low temperatures were recorded at the Western Arm Brook in 1985-86 and all sites experienced declines in SST in 1990 from the previous year. High temperatures were recorded at Humber Arm in 1995 (Fig. 2.44). Sites closest to each other were sometimes correlated, i.e. Site 1 SSTs were not correlated with those of other sites, Site 2 was correlated with 3, and Site 4 with 5 and 6 (Table 2.7). The inshore SSTs showed some annual variability with coefficients of variation ranging from 17% for Site 1 to 56% for Site 6. Overall, there were no significant trends over time. Thus, SSTs around the coast of Newfoundland are sufficiently different from each other to warrant separate measurements based on geography.

The location of the RSST blocks is shown in Fig. 2.32. For the six blocks of data, seasonal temperatures follow a specific pattern within a block that is consistent from block to block. Summer has the highest RSST followed by fall, spring and then winter with the coldest. The coldest winter RSSTs occurred in the Gulf of St. Lawrence which were consistently around 0 °C. The warmest summer RSSTs occurred in the Atlantic Nova Scotia block where RSSTs above 20 °C were typically recorded. Examination of RSST profiles indicates that average RSSTs occurred in the four seasons of 1996-97 in Atlantic Nova Scotia (Fig. 2.45). For the Newfoundland South block RSSTs were high during the winter of 1996 but not exceptionally so. Spring RSSTs were about average in 1996 and near to their lowest values in 1997. Summer and fall RRSTs in 1996 were about average. For the Gulf of St. Lawrence, RSSTs were high during the winter of 1996 but not exceptionally so. Spring RSSTs were about average in 1996 and low in 1997. Summer and fall RRSTs in 1996 were about average. For the Labrador Sea North, RSSTs were average during the winter of 1996. Spring RSSTs were high but not exceptional. Summer and fall RRSTs in 1996 were high compared to those of recent years but higher have occurred in 1950s and 1960s. For the Labrador Sea South block, RSSTs were high during the winter of 1996 compared to recent values but average for values in 1950s to early 1970s. Spring RSSTs in 1996 and 1997 were also high for recent values about average compared to long term. Summer and fall RRSTs in 1996 were about average. For the Grand Bank of Newfoundland and East RSSTs were high for the recent past but average for values in the 1950s to early 1970. Spring RSSTs were about average in 1996 and 1997. Summer and fall RRSTs in 1996 were about average.

Summary

Thermal habitat data, RSST and MCSST values were examined for conditions in the spring of 1996, summer of 1996, fall of 1996, winter of 1997, and spring of 1997. The high number of significant correlations, and the similarity in correlation profiles among rivers, suggests that for at least some periods in the life history of salmon ocean climate is important in controlling survival and abundance, and hence, future returns. The fact that all of the ocean climate variables examined to date suggest that the spring, summer and fall of 1996 and winter and spring of 1997 were average means that ocean climate is unlikely to have caused the low returns in 1997. A major obstacle to determination of the cause of the low returns in 1997 is a lack of information on the sea life of Atlantic salmon.

Chemical oceanography

Pollution

At a public meeting (Dec. 1997), it was suggested by an attendee that acid rain and heavy metal pollution in freshwater and the marine environments, respectively, were the causes of low salmon abundance in 1997 in Newfoundland Region.

Acid Rain: Because of the chemical makeup of the marine environment it possesses almost unlimited acid rain neutralizing potential and can be eliminated as a possible cause (Faust and Aly 1981). Acid rain has long been known to affect freshwater production of Atlantic salmon (Daye and Garside 1977). Clarke et. al (unpublished manuscript) provide a synopsis of research and monitoring conducted in Newfoundland and Labrador from 1980-96. For acid rain to have impacted the return of adult salmon to Newfoundland rivers in 1997, it would have had to have resulted in lower smolt production in 1996. In fact, quite the opposite occurred. Smolt production from five fish counting facilities in Newfoundland were either the highest recorded to date (Campbellton, Rocky, and Conne rivers) or above average (Northeast Brook (Trepassey and Western Arm Brook). At Highlands River, the smolt count in 1996 was below the 1980-82 average, but higher than smolt counts in 1993-95. With the exception of Highlands River, smolt counts in 1997 are higher yet than those of 1996. This does not suggest that acid rain is not impacting salmon production in Newfoundland, but does illustrate that acid rain in and by itself was not the cause of low abundance observed in 1997 unless its impact was in the marine environment which is unlikely given the immense buffering capacity of the ocean.

Heavy Metal Pollution: It was suggested during the December, 1997, public meeting in St. John's, that airborne heavy metal pollution depositions in the Arctic were being transported down the Labrador Current and that these depositions were in fact causing a barrier to migrating Atlantic salmon thereby keeping them offshore.

The basis for this theory lies within the climatology of the earth. Simplified, there are two huge belts of moving air, the North and South Hadley Cells, surrounding the earth at the equator. In the Northern hemisphere, heated air rises near the equator and drifts northward. This air is deflected east and west at the latitude of Florida. This easterly deflection, Coriolis effect (Jet Stream), takes this air northward across the eastern United States and Canada to an area west of Greenland where the northern edge of the Hadley Cell merges with the Polar Cell. This easterly deflection air would deposit pollutants in the Gulf Stream. The Polar Cell, which sits atop the earth like a cap, would eventually loose its pollutants to the area below from the eastern United States, Canada and Europe. Some of these pollutants would be brought down in the Labrador Current creating a migrational barrier if of sufficient strength. The problem with this proposed theory is that if a migrational barrier existed due to heavy metal pollutants within the Labrador Current, then it should act as a barrier to easterly as well as westerly migration. If this were the case, then North American salmon would be unable to pass through it and there would be none present at West Greenland. Also, this theory does little to explain the rather good returns of salmon that occurred in many Newfoundland rivers in 1996. Owing to the lack of information, the possibility that pollution in the Labrador Current is impacting salmon in other ways cannot be determined at present.

Phytotoxins: Events such as the occurrence of phytotoxins, algae, dinoflagellates and diatom blooms, have all been known to result in fish kills. In an effort to ascertain the occurrence of such events during the 1997, individuals working in the Environmental Sciences Division and Marine Environment and Habitat Management Division of DFO were contacted as well as staff of the Canadian Food Inspection Agency (CFIA) and Memorial University of Newfoundland (Marine Sciences Research Laboratory). There were no large-scale problems with phytotoxins reported for the Newfoundland area in 1997. Additionally, a literature search revealed no further evidence of any such occurrence that would be considered widespread enough to impact salmon production within the Newfoundland Region. While there were no documented events, it must be realized that no individuals were actively seeking the occurrence of such events. The greatest effort devoted to events of this nature is by staff of the CFIA who inspect shellfish products for organisms that are harmful to human health prior to marketing.

3. Predation

Did predators cause the low returns of salmon in 1997?

In Newfoundland, Atlantic salmon smolts range in average fork length from 131 mm (e.g. Highlands River) to about 175 mm (Northeast Brook Trepassey) (O'Connell and Ash 1993). Smaller smolts more often occur in stocks characterized by multi-sea-winter (MSW) salmon, as O'Connell and Ash (1993) have shown a correspondence between smolt size and sea age at maturity. In addition to variation in size of smolts, the timing of smolt migration also varies among rivers, and it can also vary among years within a river by as much as three weeks (Fig. 7). The duration of the run is also variable among years in all rivers (Fig. 7). Thus salmon at the smolt life-stage are potentially available as prey to a variety of marine feeding organisms during the spring and early summer.

Cod predation

Atlantic salmon are known to be prey for a number of organisms including cod (e.g. Hvidsten and Mokklegjerd 1987; Hvidsten and Lund 1988; Hislop and Shelton 1993). A number of comments were made during public meetings in Newfoundland (December 1997) that suggested 'abundant' cod resources in inshore waters were feeding heavily on Atlantic salmon. Given salmon returning to Newfoundland waters in 1997 were lower than expected, one possible explanation for the low returns was an unusually high rate of consumption of salmon smolts by Atlantic cod in 1996. However, the occurrence of cod among inshore bays and around headlands is not new. Lilly (1996) has summarized information on the distribution of cod in inshore waters prior to the 1990s. Among other areas, traditional fisheries for cod commonly occurred in Trinity and Bonavista Bays during the early spring. So, what would have made the 1996 season different from past years to have contributed to the low returns of Atlantic salmon?

To determine if there is any evidence of excessive predation, records of cod stomach examinations conducted by DFO in 1996 and other years was searched for the occurrence for salmon.

Is there evidence that cod preyed on salmon smolts in 1996?

Collections of stomachs were obtained from cod caught in the Sentinel Surveys on the east and south coasts of Newfoundland in 1996 (Tables 3.1 and 3.2). A total of 1575 stomachs were examined, of which 74% of the samples were obtained either in the January to March, or August to December period. No salmon, however, were identified in the stomachs.

Have Atlantic cod ever been found to prey on salmon?

Collections of stomachs were also obtained from cod caught in the Sentinel Surveys on the east and south coasts of Newfoundland in 1995 (Tables 3.1 and 3.2) and from the shallow-water commercial fishery in several years between 1959 and the present (Table 3.3). In addition, many thousands of cod have been sampled offshore. A total of 2783 stomachs were examined from the 1995 Sentinel program of which 55% were obtained in the January-March or August-December period. No salmon were identified in any of the stomachs. Similarly, of over 5100 stomachs examined from the shallow-water surveys, of which 54% were obtained in the June-July period, no salmon were identified in the stomachs.

Would the cod stomach sampling be expected to reveal predation on salmon if this were going on?

The cod stomach samples were collected for the most part from times and places where commercial cod fishing was in progress or might be occurring if a cod moratorium were not in effect. Relatively few samples were taken from those months which are considered to be most crucial for migrating smolts (May and June), and very few, if any, samples were taken near the mouths of salmon rivers.

Little Codroy River, Newfoundland, and other investigations

In addition to the above sampling information, about 1700 cod stomachs were examined for evidence of smolt predation from two sites, situated on either side of the mouth of Little Codroy River, in 1957. Samples were reportedly obtained twice weekly from mid-June until early August. No salmon were identified in the stomachs (Fisheries Research Board of Canada 1958).

Hislop and Shelton (1993) reported results from a study by Daan (1989) where thousands of stomachs of cod, whiting (*Merlangius merlangus*), and pollock (*Pollachius virens*) were examined during the North Sea Stomach Sampling Program by ICES in 1981. Again, no salmon were reported. We note, however, that in Newfoundland, Dempson (1988) reported a tagged Conne River salmon smolt being predated upon by pollock (*P. virens*) that was captured approximately 80 km from Conne River.

Recommendation

To determine whether cod prey on salmon smolts a cod stomach sampling program should be initiated in nearshore waters close to the mouths of one or more salmon rivers. Sampling should start 2-3 weeks prior to when smolts would be expected to enter the sea and continue at periodic intervals until late July. Ideally, this program should continue over several years to determine annual variability in results.

Seal predation

Six species of seals are present in Newfoundland waters, harp (*Phoca groenlandica*), hooded (*Cystophora cristata*), grey (*Halichoerus grypus*), harbour (*Phoca vitulina*), ringed (*Phoca hispida*), and bearded (*Erignathus barbatus*). Each species differs in its distribution, abundance and diet. We have a large amount of information on all or some of these aspects for some species (e.g. harp seals) while little is known about others (e.g. bearded seals).

<u>Distribution and Abundance</u>

HARP SEALS

Harp seals give birth ("whelp") on the ice in the White Sea, near Jan Mayen Island and in the northwest Atlantic ocean. The northwest Atlantic breeding stock, historically the largest, summers in the Canadian Arctic and Greenland. In the fall most of these seals migrate southward to the Gulf of St. Lawrence (Gulf), or to the area off southern Labrador and northern Newfoundland (Front) where they give birth in late February or March. After weaning, the adults disperse, presumably to feed. Seals one year of age and older form large moulting concentrations on the sea ice off northeastern Newfoundland and in the northern Gulf of St. Lawrence in April and May. After moulting, seals disperse and eventually migrate northward. Small numbers of harp seals may remain in southern waters throughout the summer.

Beginning in the late 1980s, fishermen reported that seals were arriving in Newfoundland earlier in the fall and leaving later in the spring. Also, there were a number of reports of seals in offshore areas of the southern Labrador Shelf. A study of the movements of harp seals using satellite telemetry carried out in 1995 and 1996 (Stenson and Sjare 1997) indicated that offshore areas of the northern Grand Banks and southern Labrador Shelf were important wintering areas for harp seals. Seals moved northward later, and returned to southern areas earlier, in 1995 than in 1996, but the differences were not significant. If the timing of movements are related to environmental conditions (possibly affecting prey availability), the differences observed between the two years may be related to the warmer water temperatures and reduced ice coverage seen in 1996.

The most recent estimate of harp seal pup production in the Gulf of St. Lawrence and at the Front was obtained from surveys conducted in March 1994 (Stenson et al. 1996). The total number of pups born was estimated to be 703,000 $\pm$ 127,000 and the total population was estimated to be approximately 4.8 million (95% C.I. 4.1 - 5.0 million; Shelton et al. 1996). This estimate could be as low as 4.5 million if pup mortality is assumed to be higher than that of older seals.

HOODED SEALS

Like harp seals, hoods are migratory and give birth on pack ice. In the northwest Atlantic, whelping occurs off the coast of southern Labrador or northeastern Newfoundland ('Front'), in Davis Strait, and in the Gulf of St. Lawrence ('Gulf'). Hooded seals spend most of the year in offshore waters. They summer off south and west Greenland or in the Canadian Arctic, and migrate to the whelping areas during the late fall or early winter. A single pup, called a blueback, is born during late March. After the pup is weaned, the female mates and then disperses to feed. Recent data obtained using satellite transmitters show that hooded seals that whelp at the Front move off the Continental Shelf towards either the Flemish Cap or Rekjanes Ridge, southwest of Iceland. Eventually they migrate to the Denmark Strait near southeast Greenland to moult in late June or July. Seals that whelp in the Gulf move to the north slope of the Laurentian Channel where they feed before migrating out of the Cabot Strait and along the shelf-edge of the Grand Banks enroute to Denmark Strait.

In the past two years, increased numbers of hooded seals have been reported hauling out on beaches both in Newfoundland and in the St. Lawrence estuary. Although most of the reports have referred to young hoods, adults have also been reported. The reason for this apparent increase in hooded seals near shore is unknown.

In the northwest Atlantic, most pups are born at the Front. Aerial surveys carried out in 1990 resulted in an estimate of 83,000 (SE=12,600) pups (Stenson et al. 1997). Comparing this result to those of a survey carried out in 1984 using similar methods suggest that pup production has increased slowly at slightly less than 5% per annum during the late 1980s. However, because of the wide confidence intervals the two estimates are not significantly different.

The only available estimate of pup production in the Davis Strait, 18,600 (95% C.I. 14,000-23,000), was based on aerial surveys conducted in 1984 (Bowen et al. 1987). Low numbers of hooded seals are born in the Gulf of St. Lawrence. Using visual survey techniques, Hammill et al. (1992) estimated that pup production in the Gulf during 1990 and 1991 was 1,638 (SE=466) and 2,006 (SE=190) respectively.

The total pup production for the northwest Atlantic stock of hooded seals is unknown because the three whelping areas have not been surveyed in the same year and estimates obtained in different years cannot be combined without information on the degree of mixing.

Applying a Leslie-type matrix model to the Front and Gulf pup production estimates and assuming both populations are growing at 4.8%, Hammill and Stenson (1998) estimated that the total population of hooded seals in 1990 was approximately 450,000. Under these same assumptions, the population would have increased to 597,000 by 1996.

RINGED SEALS

Ringed seals are primarily Arctic species whose southern range extends down the coast of Labrador to northern Newfoundland. They likely undergo some seasonal movements and are found along the northern peninsula and southern Labrador more in the winter. However, the exact nature of their movements is unknown.

Ringed seals are considered to be the most common pinniped in Labrador and are considered to be `numerous' through most of their range. However, very little is known about their actual numbers. Studies carried out under the Offshore Labrador Biological Studies Program (OLABS) in the late 1970s (Boles et al. 1980) indicated that ringed seals were more common on shorefast ice than pack ice, and that the density of seals was higher in northern Labrador (north of Okak Islands) than in central (Cape Harrison to Okak). However, this latter finding may have been affected by the early break-up of shorefast ice in the central area. Boat surveys of various bays indicated that ringed seals were found in higher densities in the Saglek, Nachvak and Hebron fiord areas than in Voisey's Bay or around Okak Island. Unfortunately, no estimates of total abundance could be made from the surveys carried out under the OLABS project. However, Boles et al. (1980) reported an estimate of 5000 ringed seals in Lake Melville during the late 1970s.

In the Nain and Hopedale area, ringed seals are reported in the bays throughout the year.

BEARDED SEALS

Like the ringed seals, bearded seals are an Arctic species that are found along the coast of Labrador and northern Newfoundland. Their distribution appears to be similar to that of ringed seals. Bearded seals are solitary and are considered rare. No population estimates are available for this species.

GREY SEALS

In Atlantic Canada, the grey seal population is divided into two components based upon the location of major whelping areas. The first ('Sable') gives birth in January or early February on Sable Island while the second ('Gulf') gives birth mainly in Northumberland Strait, St. George's Bay and along the west coast of Cape Breton. Small groups of pups are born on Ile du Mort in the Magdalen Islands, Hay Island (near Sydney, Nova Scotia) and on some of the small islands along the eastern shore of Nova Scotia. Although grey seals appear to undergo seasonal migrations, the majority of seals remain in the Gulf or on the Scotian Shelf. Seals from both the Sable Island and Gulf breeding stocks are seasonal migrants to Newfoundland. They have been reported from all areas of Newfoundland and Labrador as far north as Nain. Bounty returns indicate that grey seals are most common during July and August but low numbers are present in all months of the year. No confirmed whelping concentrations have been found in Newfoundland and the numbers migrating into the area are unknown.

Although the Sable and Gulf components of the population form a single stock, population trends for the two groups are usually considered separately. A series of pup production estimates obtained between 1977 and 1990 indicate that the Sable Island component was increasing at 12.6% (Zwanenburg and Bowen 1990). In 1990 the population was estimated to be 68,400. Less is known about the Gulf component, but based on a series of estimates from the mid and late 1980s, this group appeared to have been increasing at 6.8% during this period with total population of 40,300 in 1990 (Hammill et al. 1998). Assuming these rates of increase continued, population size in 1996 was estimated to be 139,500 and 59,700 for the Sable and Gulf groups, respectively (Hammill and Stenson 1998)

HARBOUR SEALS

Harbour seals are also distributed across Atlantic Canada, including most areas of Newfoundland and Labrador. Although locally common in many areas, particularly, St. Mary's Bay, the Bay of Islands area and southern Labrador around Cartwright, the distribution and population size is not known.

There are no recent estimates of abundance of harbour seals in Atlantic Canada. Boulva and McLaren (1979) estimated an eastern Canadian population of 12,700 in 1973. Using this as a starting point and making a series of assumptions concerning reproductive rates and survival, Hammill and Stenson (1998) estimated that the total population of harbour seals in Atlantic Canada may be in the order of 30,000 in 1996. However, it should be noted that this estimate is dependent upon a variety of assumptions and should be considered an indication of the relative abundance only.

Diet

A sampling program to study the diets of seals in Newfoundland and Labrador was begun in 1978. Initially designed to collect harp and hooded seals along the northeast coast of Newfoundland, it was expanded to other areas of the province, and other species, in the mid-1980s. In total, over 10,000 seals have been examined with over 7,000 having food in their stomachs. Summaries of the seasonal and geographic distribution of these samples are given in Table 3.4 - 3.9. Efforts have been made to obtain samples from most months and areas where the seals are found. The gaps that exist reflect the seasonal distribution of the seals and the absence of hunting effort.

Most of the research has been carried out on the diet of harp and hooded seals. In addition to studies of diet, total prey consumption has been estimated (Hammill and Stenson 1998). Consumption of salmon by harps is very limited; only one of the 5,797 seals examined (Table 3.4) contained salmon remains in its stomach. The one exception was captured near Brighton in May 1993. Salmon have been found in the stomachs of harp seals from the Gulf although they account for a very small part of the diet (0.37%, Hammill and Stenson 1998). Harp seals appear to feed mainly upon small (10-20 cm) pelagic fish such as Arctic cod in nearshore waters of Newfoundland and capelin in offshore waters and in the Gulf (see Hammill and Stenson 1998 for a summary).

Salmon have not been found in the stomachs of any of the hooded seals examined (Table 3.5). This species appears to prey mainly upon deepwater fish such as Greenland halibut, redfish, various flatfish and Atlantic cod (Ross 1993; Lawson and Stenson unpublished data).

Although ringed seals have been reported to take salmon in other areas, a study of their diet on the Labrador coast in 1980-81 (deGraaf et al. 1981) found no evidence of salmon. Salmon were not found in any of the 663 food containing stomachs we examined (Table 3.6). Most of the Labrador samples were from sealers hunting in coastal waters around Cartwright, Hopedale, Postville and Nain. The Newfoundland samples are primarily winter samples from the northern peninsula.

Bearded seals feed primarily upon bottom dwelling invertebrates. No salmon have been found in the stomachs of seals from Newfoundland and Labrador we examined (Table 3.7). The vast majority of bearded seals were captured near St. Anthony.

Although none of the 84 grey seal stomachs we examined (Table 3.8) contained salmon, grey seals are known to take salmon in the northern Gulf and Bay of Fundy (see Hammill and Stenson 1998 for a summary of the diet and estimates of consumption in various areas). Most of our samples were from west and south coasts of Newfoundland during the summer months although a few were from Labrador.

Harbour and grey seals have been reported stealing salmon from nets along the Labrador coast (e.g. Sandwich Bay) and populations of harbour seals are found up rivers apparently feeding on salmon and trout. However, none of the 84 stomachs we examined contained evidence of predation on salmon even though almost half were from Labrador (Table 3.9). These samples were mainly from July and August. Most of the remaining harbour seals were collected throughout the year along the south coast of Newfoundland.

Summary

The most common species of seals (harp, hooded and ringed) appear to take no or very few salmon in Newfoundland and Labrador. Harbour and grey seals likely take some salmon but are found in low numbers in this area. Harbour seals are the most commonly reported to take salmon and if they are having an impact on salmon, it is likely be localized in particular areas.

4. Disease & parasites

Did disease or parasites cause the low returns of salmon in 1997?

There were no outbreaks of disease or parasites reported to the DFO Fish Health Officer of sufficient magnitude to have caused the low returns of salmon in 1997. However, our examination of information related to low returns in 1997 suggests that the cause lies sometime during the marine stage of salmon life history. Disease and parasite infestations of a magnitude to cause significant levels of mortality might go undetected if occurring at sea where there few fish are likely to be seen. An example of what could happen is seen in the recent collapse of sea trout stocks in Ireland that have been related to lice infestations from sea farms (K. Whelan, Salmon Research Trust, County Mayo, Ireland, pers. comm.). The wide ranging migratory habits of salmon might make infestation by sea lice from fish farms an unlikely reason for salmon declines. Naturally occurring lice infestations also cause problems when water levels in rivers are low and water temperatures high resulting in salmon remaining off river mouths where sea lice infestations can increase. The lesions caused by the presence of the lice lead to scale loss and subsequent fungal diseases. *There is little available evidence to draw any conclusions on the likelihood of disease or parasites causing the low returns of salmon in 1997. This aspect should be a subject for further research.*

5. Other factors

Did other factors such as changes in age composition, delayed maturation, impacts of aquaculture on wild stocks, etc cause the low returns of salmon in 1997?

Atlantic salmon undergo changes associated with the parr-smolt transformation (Hoar 1976) that allow the fish to migrate and survive from one medium to another. Among other features, salmon physiology related to hypo-osmoregulatory ability and salinity tolerance are altered. Salmon migrate to sea during a particular 'window' that should provide the most optimal period of suitable marine conditions (Power et al. 1987; Hansen and Jonsson 1989)

There was one common feature among most Newfoundland rivers where smolts were monitored in 1996. This was that most rivers had either the earliest smolt run ever (Conne, Northeast Brook Trepassey, Rocky, and Campbellton rivers), or in the case of Western Arm Brook, the earliest smolt run in seven years (Fig. 7). This leads one to ask whether it is possible that the 1996 smolt migration was too early?

Smolt physiology

Since 1995, Atlantic salmon smolts from Conne River have been sampled to examine changes in Na+,K+-ATPase (sodium-potassium) activity throughout the run. Increased ATPase activity is associated with increased sea water tolerance during migration (McCormick et al. 1987). The 1995 - 1997 period at Conne River incorporates both the earliest (1996) and latest (1997) smolt run timing events to date (Fig. 7).

In all years, gill Na+,K+-ATPase started at low levels and increased throughout the run to relatively high levels in all years. Although peak levels among years varied (1995 = 5.0; 1996 = 7.9; 1997 = 9.2), they were in the normal range for smolts and well above levels seen in parr (normally 1-3). The highest initial levels at the beginning of the migratory period were seen in 1996 and may be associated with the higher temperatures in that year. Both laboratory and field studies in other rivers indicate that higher temperature will advance increases in gill Na+,K+-ATPase seen during smolting. Abnormal smolting would be indicated if there was an absence of increase in gill ATPase, or if decreases at the end of the migratory period were observed. Such was not the case in any of the years of sampling at Conne River and we conclude that, at least for Conne River, there is no evidence of a physiological problem affecting smolts that could have contributed to the low returns in 1997.

Plankton and nekton surveys of the Northeast Newfoundland Shelf and Grand Banks

One commonality among five of six populations where smolts were monitored in 1996 was the early timing of their migrations (Fig. 7). Indeed, as stated earlier, four populations from the south and northeast coasts recorded the earliest runs on record. Could smolts have gone to sea too early in 1996 and been out of phase with the onset of the oceanic production cycle? What information can be examined to characterize the pelagic marine environment?

A multi-species, multi-disciplinary survey has been carried out in late summer, 1994 - 1997, to measure the plankton and nekton of the Northeast Newfoundland Shelf and Grand Banks. This survey extends from southern Labrador to the southern Grand Bank, and includes all inshore areas (NAFO Divisions 2J3KLNO). The survey has several objectives: 1) to estimate pre-recruit abundance of cod (2J3KL, 3NO); 2) to estimate pre-recruit abundance of capelin ages 0 and 1 year (2J3KLNO); 3) to measure the nekton biomass and community structure; and 4) to measure the physical and biological oceanography of the pelagic zone.

Below we note the following key results, extracted from Dalley and Anderson (1997), related to information through the 1996 season. Specific details regarding sampling protocol and respective gears used can be found in Dalley and Anderson (1997).

Mean surface temperatures in 1996 were intermediate between those of 1994 and 1995 during this time of year while temperatures at the 50 m depth were similar to those in 1995. With respect to zooplankton biomass, nothing unusual was reported in 1996 for either total biomass or for the largest fraction (> 2 mm). However, the mid-size (1-2 mm) and smallest size fraction (< 1 mm) were the highest in 1996. Mean wet nekton biomass, including jellyfish, was significantly less in 1996 with capelin and Arctic cod being the two most important species contributing to the nekton biomass. Interestingly, Dalley and Anderson (1997) reported that abundance of age 0+ Atlantic cod was significantly lower in 1996 in comparison with 1994 and 1995 and similarly, Arctic cod were also more abundant in 1994 in comparison with the other two years. In addition, there were significantly more sculpins and seasnails and significantly fewer squid in 1996 than in the other years. Overall, variation in variables analysed was generally greater among areas than among the three years that were sampled.

Based on the brief summary of results, there does not appear to have been any consistent anomalies associated with either temperature or zooplankton results for 1996. In contrast, nekton biomass was the lowest among the three years surveyed. The significance of this result as it applies to the 1996 smolt year class of Atlantic salmon is unknown.

Escaped aquaculture fish

Salmon aquaculture is an important industry in a number of countries, for example, Norway and Scotland. It is also an industry associated with much controversy as inferences have been made that associate the decline in wild salmon production either directly or indirectly to the rise in farmed salmon production (e.g. Gausen and Moen 1991; Heggberget et al. 1993; Carr et al. 1997; Hansen et al. 1997).

The most classic cases of impacts on wild stocks from farmed salmon come from Norway where many salmon populations have been destroyed by the parasite *Gyrodactylus salaris* (Heggberget et al. 1993; McVicar 1997) and over 70 rivers affected with furunculosis (Johnsen and Jensen 1994) both, apparently, associated with escapees from fish farms. Other studies have concluded that even a small percentage of escaped farmed salmon have the potential to impact resident populations in an area either through demographic or genetic changes in stock characteristics (Hutchings 1991). In Norway, it is reported that the number of salmon that escape from sea cages is greater than the total number of wild fish (Gausen and Moen 1991) (see Hutchinson 1997, for recent information on interactions between salmon culture and wild stocks of Atlantic salmon).

Is it conceivable that high seas transmission of disease or parasites is affecting the survival of free-swimming wild salmon? Or, could marine aquaculture operations be having other unknown impacts on wild stocks? Answers to these questions cannot be provided, but, if there are literally many times more escaped farmed salmon than wild salmon can these questions be so easily dismissed?

In Newfoundland, Bay d'Espoir (SFA 11) is the only area where salmonids (Atlantic salmon and rainbow trout) are being raised in sea cages. Escaped rainbow trout were first reported in Conne River in 1990 while the first confirmed occurrence of a farmed Atlantic salmon in Conne River was in 1994 (Dempson and Reddin 1995). Total returns of small Atlantic salmon to Conne River experienced the greatest single year decline from 1990 to 1991 (Dempson and Furey 1997), a period during which aquaculture production was still relatively low. To date, there have been no detectable impacts associated with escapees of either species; numbers that do occur in Conne River are low. Thus, there is no evidence to associate the widespread decline in salmon returns to Newfoundland rivers in 1997 with the localized production at Bay d'Espoir.

Changes in age composition

Biological characteristics are fully analysed and discussed in Section 2 under Biotic factors. There were no deviations from the normal smolt age structure of a magnitude that could alter the year classes proportionately contributing to the 1997 returns.

Delayed maturation

The total production of 1SW maturing and 1SW non-maturing North American salmon for the period 1971 to 1995 can be used to show changes in the age at maturity within a cohort. There has been a steadily increasing trend in the proportion of the cohort of North American salmon that matures at 1-sea-winter in age (Fig. 5.1). This proportion has risen from about 45% at the beginning of the 1970s to around 70% in the last three years. Environmental variation could have resulted in earlier maturation of the salmon or the historically higher exploitation rates on the non-maturing component could have reduced the recruitment of this component. Over the 25 year time series, there are only two cohorts that matured later as 2SW salmon rather than grilse, i.e. 1978 and 1990 (Fig. 5.1). Thus, there is about a one chance in ten that the low returns in 1997 were solely due to a change in maturation schedule and next year (1998) will see the remainder of the cohort return to rivers as 2SW salmon. This speculation should be tempered by some knowledge of whether the fish are still at sea or not.

Discussion

Clearly, the low unexpected returns to Newfoundland rivers in 1997 and an apparent lack of a causal explanation demonstrate the need for a better understanding of what is happening to Atlantic salmon in the sea. Much information has been published about the freshwater life of salmon but little is known about life of salmon in the sea and most comes from studies related to commercial fisheries (Parrish and Horsted 1980; Reddin and Dempson 1986; Reddin 1987). What is known about the sea life of salmon in the northwest Atlantic ocean, including migration patterns, food resources, ocean distribution, and abundance of postsmolts, grilse, and multi-sea winter salmon, has been summarized by (May 1973; Lear 1976; Møller Jensen and Lear 1980; Dutil and Coutu 1988; Reddin 1985; Reddin and Shearer 1987; Reddin 1988a, b; Mills 1989; Reddin and Short 1991; Reddin and Friedland 1993; Friedland and Reddin 1993; Friedland et al. 1993). There are also several references to relationships between the environment and salmon abundance/distribution (Scarnechia 1984a, b; Reddin and Shearer 1987; Ritter 1989) including changes in sea age (Saunders et al. 1983; Martin and Mitchell 1985) although this information has not been incorporated as a variable in salmon assessments or used to predict salmon returns.

The management of Atlantic salmon stocks and fisheries has the goal of achieving a suitable level of spawning escapement based on available freshwater parr-rearing habitat (Anon. 1991; Anon. 1997). In order for this approach to be successful, fisheries managers require forecasts of salmon abundance in advance of their return to freshwater. Accurate forecasts depend on knowledge of the mechanisms of salmon mortality at all stages in its life history but at sea mortality seems particularly important. Current forecasts of salmon for all North American salmon stocks producing two-sea winter (2SW) salmon, are based on a relationship between the distribution in winter of sea surface water temperature in the northwest Atlantic termed thermal habitat and the number of 2SW salmon (Reddin et al. 1993, Anon. 1997). While the relationship between thermal habitat and salmon abundance has proven to be statistically robust, the underlying biological cause(s) of salmon mortalities and overall declining salmon abundance remains unknown (Friedland et al. 1993; Anon. 1997). These downturns in abundance have a number of possible causes including both biotic factors such as a reduction in the availability or abundance of food and an increase in the number of predators, and abiotic ones such as climate. Climate change or climate variability could lead directly or indirectly to mortalities by reducing fitness or suitability to survive in a known environment (Youngson 1995; Reddin and Friedland 1996). Another possibility is that there has been a change in the proportion of the overall stock maturing as grilse versus those maturing later as 2SW salmon (Anon. 1997). Saunders et al. (1983) and Scarnecchia (1983) have shown that sea age at maturity can also be altered by environment.

Variability in salmon recruitment prior to exploitation in commercial fisheries for both Atlantic and Pacific salmonids is well known (see Introduction). The ability to forecast numbers of returning adult salmon is compromised by the high variability in sea survival. Low and high returns in some years should be expected and have occurred in the past (Porter and Ritter 1984; Reddin and Shearer 1986; Ritter 1989). Examination of the time series of abundance estimates for North American 1-sea winter (1SW) and 2SW salmon used to provide catch advice for fisheries in Greenland and North America shows a very serious decline in 2SW salmon and more recently in 1SW salmon as well. (Anon. 1997). While in a single year the effects of recruitment overfishing may be nullified by high recruitment in subsequent years we have to maintain our vigilance to ensure conservation requirements are not compromised in the long-term.

In the Pacific, shifts in ocean climate have been detected on basin scale level (Beamish et al. 1997). In particular, it has been shown that trends in abundance of Pacific salmon were closely associated with changes in the climate-ocean environment and that these changes occurred throughout the distribution of Pacific salmon (Beamish and Bouillon 1993). For most stocks of most of the Pacific salmonids, marine survival improved after the climate event in 1976-77 resulting in increased productivity and catches. Associated with these natural fluctuations is the concept of regimes and regime shifts, either towards higher productivity from low or the reverse (Hare and Francis 1995; Steele 1996; Beamish et al. 1997). Beamish et al. (1997) noted that change can occur quickly and it can be large. For the northwest Atlantic, there is evidence that a basin-scale shift in productivity may have also occurred for Atlantic salmon. Our correlation results for salmon in inshore areas of Newfoundland suggest that the shift in productivity is occurring in the offshore waters consistent with the decline in thermal habitat observed by Anon. (1997). Basin-scale events may also be linked to downturns in salmon abundance in the North Atlantic similar to the Pacific through links to the North Atlantic Oscillation Index (Dickson 1997).

While we have concluded that the cause of the mortality lies in the ocean life of salmon, the actual cause of the mortality remains unknown. Variation in temperature conditions may prompt changes in ecosystem productivity that can affect feeding opportunities for post-smolts. Recent studies with Pacific salmonids have highlighted the importance of variation in diet in the recruitment process (Healey 1991; Brodeur et al. 1992; Perry et al. 1996). Prey availability is often related to oceanographic processes and structural features in the water column (Levings 1994). Juvenile salmonids have been shown to modify their diet in response to restrictions imposed by thermal structure (Reddin 1985; Pearcy et al. 1988) or opportunities created by the concentration of food along oceanographic fronts (Brodeur 1989; St. John et al. 1992). Variation in ocean productivity has also been hypothesized to act on postsmolts by altering predation pressure from other species (Fisher and Pearcy 1988). Alternately, shifts in migration pathways can alter fitness to survive in a given environment and cause additional mortality due to predation or the inability to find food in the new location (Youngson 1995). As indicated above, long term declines have been referred to as regime shifts (Steele 1996) and have been used to explain large scale changes in salmon production in the Pacific (Beamish and Bouillon 1993). Any changes in the extent or the quality of the habitat available to migratory species (at any life stage) will affect their fitness and abundance. In the Pacific, Welch et al. (1995) have shown sharp declines in salmon abundance occurs with temperature and suggest that thermal barriers can limit the distribution of salmon to a relatively small area. Since Reddin et al. (1993) and Anon. (1997) have documented reductions in thermal habitat available for salmon in the northwest Atlantic and shown that salmon abundance is related directly to that habitat, it seems reasonable to conclude that this could be a contributing factor for the downturn in salmon abundance.

A possible mechanism for salmon mortalities at sea has been proposed by Youngson (1995). He drew on information from bird migration studies which showed that climate variations shifted bird migration pathways away from those normally traveled (Berthold 1993). Bird migrations are highly structured and once out of their recognized migration areas, mortalities from predation and the inability to locate new food sources increased over what would have normally occurred. It is well known that both Atlantic and Pacific salmon also change migration pathways due to shifts in climate that create thermal barriers, e.g., sea temperature and ice in particular (Welch et al. 1995; Narayanan et al. 1995). Also, salmon have many known predators at all stages of sea life which could take advantage of any shifts in distribution (Hislop and Shelton 1993). If this is similar to what has been reported for birds, then salmon could have difficulties adapting to new food sources when migration pathways and distributions change, and thus potentially suffer increased mortality. Additional mortality at any stage in the migration route will reduce the total number of fish returning later to the spawning grounds (and to fisheries).

Summary

Atlantic salmon populations are characterized by annual fluctuations in abundance. At times these fluctuations can be quite severe and occur commonly over wide geographic areas. A review of the status of insular Newfoundland stocks clearly indicted an overall decline in abundance in 1997. The population size in some rivers was the lowest, or among the lowest recorded since 1984. For some areas, this was unexpected. Substantive increases in spawning escapements in northeast coast rivers, high or record high smolt production in 1996 from six geographically distributed rivers where smolts were monitored, improved sea survival in recent years, and indications of suitable ocean climate conditions, were all suggestive that returns in 1997 would have been higher than in 1996. We note that declines in salmon returns from one year to the next of a magnitude similar to that experienced in 1997 have occurred in the past on a number of occasions. We also note that regardless of the events associated with reduced returns to insular Newfoundland rivers in 1997, returns to some monitored south coast stocks have not increased in a consistent manner following the closure of the commercial fisheries in 1992. Exceptions to the decline in abundance in 1997 occurred in most rivers in Bay St. George. Information on the abundance of salmon in Labrador in 1997 is unknown due to a lack of assessment facilities.

Following a brief period of increasing sea survival, from smolt to 1SW returns, there was a substantive decline in survival of the 1996 smolt class on five of the six monitored rivers. This low marine survival is responsible for the decline in returns in 1997. Sea survival increased for the monitored river in Bay St. George.

In this paper, a number of factors that potentially could have contributed to the low returns in 1997 were examined. This included legal and illegal fisheries, environmental conditions, predation, disease, parasites, and others such as delayed maturation. No single factor, nor combinations of factors were identified that were clearly indicative of having been the direct cause of the lower than expected returns in 1997. The only outstanding feature in the freshwater life history of the cohort returning in 1997 was their exceptionally early entry to the sea as smolts in the spring of 1996. The consequences this may have had for survival of salmon are unknown.

There is some indication that the ecosystem of the northwest Atlantic has changed in recent years as evidenced by biological studies for a number of species. Could this have been a factor? In recent years Atlantic cod have been reported to be concentrated in inshore areas and close to rivers from spring to late fall. Although there are dietary records for thousands of cod, which indicated that salmon are not commonly a part of the diet, the samples were not generally collected in river estuaries at the time of smolt migration when cod are most likely to prey on salmon. Is this important? Seal populations have been increasing over the past 10 years and there are reports that seals have been migrating south earlier and staying longer. There is considerable information on seal stomach contents indicating that salmon are only a minor part of the diet. But, samples were generally not taken near rivers. While the few salmon in the samples may seem to discount seals as a player in the global picture, they still may be of considerable importance to some individual stocks. For example, in Labrador, harbour seals have been observed far upstream where salmonids are the only possible prey. Other evidence of ecological changes in the ocean are the changes in the biology, distribution and behaviour of capelin during the 1990's, the significant decline in abundance of larval cod in 1996 in contrast with 1994 and 1995, and the occurrence of postsmolts in some inshore areas during late summer and fall of 1995 and 1996. Unfortunately, there are presently no studies directed at the marine life stage of Atlantic salmon or factors which could assist in understanding changes in the ecosystem which could affect salmon survival.

Finally, there could be a suite of other factors not even considered or recognized owing either to insufficient information, or lack of understanding of their links with salmon abundance that may have been responsible for changes in survival.

Recommendations

1. Additional studies of all aspects of salmon life history at the smolt, postsmolt, and adult stages are essential in order to answer questions adequately regarding events that affect salmon at sea.

2. The diet of seals and cod in areas and times when salmon are available should be investigated to clarify fully the potential impacts associated with these predators.

3. The effect of parasites and diseases should be investigated along with directed studies associated with the impact escaped farmed salmonids have on wild stocks.

4. Fish counting fences are unquestionably the best means by which salmon abundance and status of stocks can be determined. As a minimum all counting facilities operating in 1997 should continue in 1998 and beyond, counts at Biscay Bay should be reinstated, and one and preferably two in each SFA in Labrador should established. In addition, two to three more facilities where smolts are monitored should be added as they are the only means to obtain information on marine survival of salmon.

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References

Allan, I.R.H. and J.A. Ritter. 1977. Salmonid terminology. Journal du Conseil, Conseil International pour l'Exploration de la Mer 37:293-299.

Anderson, J.T., E. L. Dalley and D. Davis. 1998. Year-class strength of Northern cod (2J3KL) estimated from pelagic juvenile fish surveys in the Newfoundland Region, 1994 - 1997. DFO Can. Stock Ass. Sec. Res. Doc. 98/11. 20 p.

Anon. 1990. Report of the Study Group on the North American Salmon Fisheries. ICES C.M. 1990/M:3, 111 p.

Anon. 1991. Definition of conservation for Atlantic salmon. Canadian Atlantic Fisheries Science Advisory Committee, Advisory Document 91/15, 4 p.

Anon. 1994. Report of meeting of the Working Group on North Atlantic salmon (Copenhagen). Cons. Int. Explor. Mer., C.M. 1994/Assess: 16, 182 p.

Anon. 1995. Report of the Working Group on North Atlantic Salmon. Cons. Int. Explor. Mer C.M.1995/Assess:14. 181 p.

Anon. 1997. Report of the North Atlantic Salmon Working Group. ICES C.M. 1997/Assess:10, 242 p.

Ash, E.G.M., and M.F. O'Connell. 1987. Atlantic salmon fishery in Newfoundland and Labrador, commercial and recreational, 1985. Can. Data Rep. Fish. Aquat. Sci. 672: v + 284 p.

Bagenal, T.B., and F.W. Tesch. 1978. Age and growth, 101-136. *In* T. Bagenal [ed.] IBP handbook no. 3. Oxford: Blackwell Scientific Publications.

Bakanev, V.S. 1992. Results from acoustic capelin surveys in Div. 3LNO and 2J + 3KL in 1991. NAFO SCR Doc. 92/1, Ser. No. N2034, 12 p.

Beamish, R., and D. Bouillon. 1993. Pacific salmon production trends in relation to climate. Canadian Journal of Fisheries and Aquatic Sciences 50: 1002-1016.

Beamish, R., C. Mahnken, and C.M. Neville. 1997. Hatchery and wild production of Pacific salmon in relation to large scale, natural shifts in the productivity of the marine environment. ICES Journal of Marine Science 54: 1200-1215.

Berthold, P. 1993. Bird Migration, Oxford Univesity Press, Oxford.

Boles, B., G.J. Chaput, and F.R. Phillips. 1980. Offshore Labrador Biological Studies 1979: Seals. Unpublished report prepared by Atlantic Biological Services for Total Eastcan Exploration Ltd. 109 p.

Boulva, J. and I.A. McLaren. 1979. Biology of the harbor seal, *Phoca vitulina*, in eastern Canada. Bul. Fish. Res. Bd. Can. 200: 23 p.

Bourgeois, C.E., J. Murray, and V. Mercer. 1997. Status of the Exploits River stock of Atlantic salmon (*Salmo salar* L.) in 1996. DFO Can. Stock Ass. Sec. Res. Doc. 97/32. 40 p.

Bowen, W.D., R.A. Myers, and K. Hay. 1987. Abundance estimation of a dispersed, dynamic population: hooded seal (*Cystophora cristata*) in the Northwest Atlantic. Can. J. Fish. Aqua. Sci. 44: 282-295.

Brodeur, R.D. 1989. Neustonic feeding by juvenile salmonids in coastal waters of the Northeast Pacific. Can. J. Zool. 67: 1995-2007.

Brodeur, R.D., R.C. Francis, and W.G. Pearcy. 1992. Food consumption of juvenile coho (*Oncorhynchus kisutch*) and chinook salmon (*O. tshawytscha*) on the continental shelf off Washington and Oregon. Can. J. Fish. Aquat. Sci. 49: 1670-1685.

Carr, J.W., J.M.Anderson, F.G. Whoriskey, and T. Dilworth. 1997. The occurrence and spawning of cultured Atlantic salmon (*Salmo salar*) in a Canadian river. ICES J. Marine Science 54: 1064-1073.

Carscadden, J.E. 1996. Bycatch of capelin in shrimp fisheries in NAFO Div. 2J3K and Div. 3M. In: Anon. Capelin in SA2 + Div. 3KL. DFO Atl. Fish. Res. Doc. 96/90. 269 p.

Carscadden, J., and B.S. Nakashima. 1997. Abundance and changes in distribution, biology, and behaviour of capelin in response to cooler waters of the 1990's. p. 457-468. In: Forages Fishes in Marine Ecosystems. Proceedings of the International Symposium on the Role of Forage Fishes in Marine Ecosystems. Alaska Sea Grant College Program Report No. 97-01. University of Alaska Fairbanks, 1997.

Carscadden, J., B.S. Nakashima, and K.T. Frank. 1997. The effects of fish length and temperature on the timing of peak spawning in capelin (*Mallotus villosus*). Can. J. Fish. Aquat. Sci. 54: 781-787.

Chadwick, M., R. Porter, and D. Reddin. 1978. Atlantic salmon management program, Newfoundland and Labrador, 1978. The Atlantic Salmon Journal. 1: 9-15.

Chadwick, E.M.P., D.G. Reddin, and R.F. Burfitt. 1985. Fishing and natural mortality rates for 1SW Atlantic salmon (*Salmo salar* L.). ICES C.M. 1985/M:18, 10 p.

Chadwick, E.M.P. 1993. Measuring marine exploitation of Atlantic salmon in Canada, p. 184-202. *In*. D. Mills [ed.] Salmon in the sea and new enhancement strategies. Fishing News Books, London.

Clarke, K.D., P.M. Ryan, and D.A. Scruton. [in prep.]. Long range transport of atmospheric pollutants (LRTAP) in Newfoundland and Labrador. A Synopsis of Research and Monitoring Conducted from 1980 to 1996. Can. Tech. Rept. Fish. Aquat . Sci.

Daan, N. [ed.]. 1989. Data base report of the stomach sampling project 1981. ICES Coop. Res. Rep. 89.

Dalley, E.L., and J.T. Anderson. 1997. Plankton and nekton of the Northeast Newfoundland Shelf and Grand Banks in 1996 compared to 1994 and 1995. DFO Can. Stock Ass. Sec. Res. Doc 97/120. 27 p.

Daye, P.G., and E.T. Garside. 1977. Lower lethal levels of pH for embryos and alevins of Atlantic salmon, *Salmo salar* L. Can. J. Zoology 55: 1504-1508.

DeGraaf, D.A., M.G. Foy, and R.A. Buchanan. 1981. Ringed seal feeding along the Labrador coast 1980-1981. Unpublished report by LGL Limited for Petro-Canada Explorations. 33 p.

Dempson, J.B. 1988. Status of the Atlantic salmon, *Salmo salar*, population of Conne River, Newfoundland, 1988. Can. Atl. Fish. Sci. Adv. Comm. Res. Doc. 88/70. 18 p.

Dempson, J.B., and D.G. Reddin. 1995. Factors affecting the returns of adult Atlantic salmon , *Salmo salar,* with emphasis on Conne River. DFO Atlantic Fisheries Res. Doc. 95/78, 27 p.

Dempson, J.B., and G. Furey. 1997. Stock status of Atlantic salmon from Conne River, SFA 11, Newfoundland, 1996. DFO Can. Stock Ass. Sec. Res. Doc. 97/34. 44 p.

Dempson, J.B., D.G. Reddin, M.F. O'Connell, C.C. Mullins, and C.E. Bourgeois. 1997a. Trends in Atlantic salmon abundance illustrated using a scaled index of returns, and estimates of marine exploitation prior to the closure of the Newfoundland commercial fishery. DFO Can. Stock Ass. Sec. Res. Doc. 97/117. 20 p.

Dempson, J.B., V.A. Pepper, G. Furey, M. Bloom, T. Nicholls, and G. Hoskins. 1997b. Evaluation of an alternate strategy to enhance salmon populations: cage rearing wild Atlantic salmon smolts from Conne River, Newfoundland. ICES CM 1997/P:03. 38 p.

DFO. 1997. Atlantic salmon - Newfoundland and Labrador, Salmon Fishing areas 1-14B. DFO Science Stock Status Report D2-01. Fisheries and Oceans.

DFO. 1998. Atlantic salmon abundance - Overview for 1997. DFO Science Stock Status Report D0-02. Fisheries and Oceans.

Dickson, R. 1997. From the Labrador Sea to global change. Nature, 386: 649 –679.

Dutil, J.-D., and J.-M. Coutu. 1988. Early marine life of Atlantic salmon, *Salmo salar*, postsmolts in the Gulf of St. Lawrence. Fish. Bull. 86: 197-212.

Faust, S.D., and O.M. Aly. 1981. Chemistry of Natural Waters. Ann. Arbour Science Publishers. 400 p.

Fisher, J.P. and W.G. Pearcy. 1988. Growth of juvenile coho salmon (*Oncorhynchus kisutch*) off Oregon and Washington, USA, in years of differing coastal upwelling. Can. J. Fish. Aquat. Sci. 45: 1036-1044.

Fisheries Research Board of Canada. 1958. Annual Report 1957 - 1958. 43 p.

Frank, K.T., J.E. Carscadden, and J.E. Simon. 1996. Recent excursions of capelin (*Mallotus villosus*) to the Scotian Shelf and Flemish Cap during anomalous hydrographic conditions. Can. J. Fish. Aquat. Sci. 53: 1473-1486.

Friedland, K.D., D.G. Reddin and J.F. Kocik. 1993. Marine survival of North American and European salmon: effects of growth and environment. Conseil International pour l'Exploration de la Mer, Journal of Marine Science 50: 481-492.

Friedland, K.F., and D.G. Reddin. 1993. Marine survival in Atlantic salmon from indices of postsmolt growth and sea temperature, Chapt. 6, p. 119-138, *In* D. Mills [ed.] Salmon in the sea and new enhancement strategies. Fourth International Atlantic Salmon Symposium, St. Andrews. Fishing News Books.

Gausen, D., and V. Moen. 1991. Large-scale escapes of farmed Atlantic salmon (*Salmo salar*) into Norwegian rivers threaten natural populations. Can. J. Fish. Aquat. Sci. 48: 426-428.

Hammill, M.O., G.B. Stenson, and R.A. Myers. 1992. Hooded seals (*Cystophora cristata*) pup production in the Gulf of St. Lawrence. Can. J. Fish. Aquat. Sci. 49: 2546-2550.

Hammill, M.O., and G.B. Stenson. 1998. Estimated prey consumption by harp seals (*Phoca groenlandica*), grey seals (*Halichoerus grypus*), harbour seals (*Phoca vitulina*) and hooded seals (*Cystophora cristata*) in the Northwest Atlantic. NAFO Sci. Council Res. Doc. 97/40. 37 p.

Hammill, M.O., G.B. Stenson, R.A. Myers, and W. T. Stobo. 1998. Pup production and population trends of the grey seal (*Halichoerus grypus*) in the Gulf of St. Lawrence. Can. J. Fish. Aquat. Sci. 55: 423-430.

Hansen, L.P., and B. Jonsson. 1989. Salmon ranching experiments in the River Imsa: effect of timing of Atlantic salmon (*Salmo salar*) smolt migration on survival to adults. Aquaculture 82: 367-373.

Hansen, L.P., M.L. Windson, and A.F. Youngson. 1997. Interactions between salmon culture and wild stocks of Atlantic salmon: The scientific and management issues. Introduction. ICES J. Marine Science 54: 963-964.

Hare, S.R., and R.C. Francis. 1995. Climate change and salmon production in the northeast Pacific Ocean, p. 357-372. *In* R. J. Beamish [ed.] Climate change and northern fish populations. Canadian Special Publication of Fisheries and Aquatic Sciences 121.

Healey, M.C. 1991. Diets and feeding rates of juvenile pink, chum, and sockeye salmon in Hecate Strait, British Columbia. Trans. Am. Fish. Soc. 120:303-318.

Heggberget, T.G., B.O. Johnsen, K. Hindar, B. Jonsson, L.P. Hansen, N.A. Hvidsten, and A.J. Jensen. 1993. Interactions between wild and cultured Atlantic salmon: a review of the Norwegian experience. Fisheries Research 18: 123-146.

Hislop, J.R.G., and R.G.J. Shelton. 1993. Marine predators and prey of Atlantic salmon, (*Salmo salar* L.), p. 104-118. *In*, D. K. Mills [ed.] Salmon in the sea and new enhancement strategies. Fishing News Books, London.

Hoar, W.S. 1976. Smolt transformation: evolution, behaviour, and physiology. J. Fish. Res. Board Can. 33: 1234-1252.

Huntsman, A.G. 1931. The Maritime salmon of Canada. Bull. Biol. Board Can. XXI. 99 p.

Huntsman, A.G. 1937. The cause of periodic scarcity in Atlantic salmon. Trans. Royal Soc. Can. Section V: 17-27.

Huntsman, A.G. 1944. Why did Ontario salmon disappear? Trans. Royal Soc. Can. Section V: 83-102.

Hutchings, J.A. 1991. The threat of extinction to native populations experiencing spawning intrusions by cultured Atlantic salmon. Aquaculture 98: 119-132.

Hutchinson, P. [Guest Editor]. 1997. Interactions between salmon culture and wild stocks of Atlantic salmon: The scientific and management issues. Proceedings of an ICES/NASCO Symposium held in Bath, England, 18-22 April, 1997. ICES J. Marine Science 54(6).

Hvidsten, N.A., and P.I. Mokkelgjerd. 1987. Predation on salmon smolts, *Salmo salar* L., in the estuary of River Surna, Norway. J. Fish Biol. 30: 273-280.

Hvidsten, N.A., and R.A. Lund. 1988. Predation on hatchery-reared and wild smolts of Atlantic salmon, *Salmo salar* L., in the estuary of River Orkla, Norway. J. Fish Biol. 33: 121-126.

Johnsen, B.O., and A.J. Jensen. 1994. The spread of furunculosis in salmonids in Norwegian rivers. J. Fish Biol. 45: 47-55.

Kulka, D.W. and J.R. Firth. 1987. Observer Program Training Manual - Newfoundland Region. A manual for the observer training sourse, St. John's, NF, 1996. Dept. of Fisheries and Oceans, St. John's, Newfoundland.

Lear, W.H. 1976. Migrating Atlantic salmon (*Salmo salar*) caught by otter trawl on the Newfoundland continental shelf. J. Fish. Res. Board Can. 33: 1202-1205.

Levings, C.D. 1994. Feeding behavior of juvenile salmon and significance of habitat during estuary and early sea phase. Nord. J. Freshwater Res. 69: 7-16.

Lilly, G.R. 1997. Size & condition of cod in Divisions 2J+3KL during 1978-1996. NAFO SCR Doc. 97/62, Ser. No. N2896, 21 p.

Lilly, G.R., and D.J. Davis. 1993. Changes in the distribution of capelin in Divisions 2J, 3K and 3L in the autumns of recent years, as inferred from bottom-trawl by-catches and cod stomach examinations. NAFO SCR Doc. 93/54, Ser. No. N2237, 14 p.

Lilly, G.R. 1994. By-catches of capelin in bottom-trawl surveys. p. 99-108. In: J. Carscadden (compiler) Capelin in SA2 + Div. 3KL. DFO Atl. Fish. Res. Doc. 94/18, 164 p.

Lilly, G.R. 1995. By-catches of capelin during autumn bottom trawl surveys in Divisions 2J3KLNO, with emphasis in 1994. p. 93-109. In: Anon. Capelin in SA2 + Div. 3KL. DFO Atl. Fish. Res. Doc. 95/70, 338 p.

Lilly, G.R. 1996. Observations on cod in the inshore environment of Eastern Newfoundland. NAFO SCR Doc. 96/59. 10 p.

Martin, J.H.A., and K.A. Mitchell. 1985. Influence of sea temperature upon the numbers of grilse and multi-sea-winter Atlantic salmon (*Salmo salar*) caught in the vicinity of the River Dee (Aberdeenshire). Can. J. Fish. Aquat. Sci. 42: 1513-1521.

May, A.W. 1973. Distributions and migration of salmon in the Northwest Atlantic. Int. Atl. Salmon Found. Spec. Publ. Ser. 4: 373-382.

May, A.W. 1993. A review of management and allocation of the Atlantic salmon resource in Atlantic Canada, p. 220-232. *In* D. Mills [ed.] Salmon in the sea and new enhancement strategies. Fishing News Books, London.

McCormick, S.D., R.L. Saunders, E.B. Henderson, and P.R. Harmon. 1987. Photoperiod control of parr-smolt transformation in Atlantic salmon (*Salmo salar*): changes in salinity tolerance, gill $Na+,K+$-ATPase activity, and plasma thyroid hormones. Can. J. Fish. Aquat. Sci. 44: 1462-1468.

McKinney, M.L. 1997. Extinction vulnerability and selectivity: combining ecological and paleontological views. Ann. Rev. Ecology and Systematics 28: 495-516.

McVicar, A.H. 1997. Disease and parasite implications of the coexistence of wild and cultured Atlantic salmon populations. ICES J. Marine Science 54: 1093-1103.

Meister, A.L. 1984. The marine migrations of tagged Atlantic salmon (*Salmo salar* L.) of USA origin. ICES C.M. Doc. M:27. 37 p.

Methven, D.A., D.C. Schneider and D.W. Ings. 1998. Results of the 1997 Fleming survey of demersal juvenile cod in the coastal zone of eastern Newfoundland. DFO Joint Research Agreement No. F6074-7-0004. 25 p.

Mills, D.H. 1989. Ecology and management of Atlantic salmon. Chapman and Hall Ltd. 351 p.

Møller Jensen J. and W.H. Lear. 1980. Atlantic salmon caught in the Irminger Sea and at East Greenland. J. Northw. Atl. Fish. Sci. 1: 55-64.

Mullins, C.C. 1997a. The status of Atlantic salmon (*Salmo salar* L.) stock of three selected rivers in SFA 14A, Newfoundland, 1996. DFO Can. Stock Ass. Sec. Res. Doc. 97/38.

Mullins, C.C. 1997b. The status of Atlantic salmon (*Salmo salar* L.) stock of the Humber River, Newfoundland, 1996. DFO Can. Stock Ass. Sec. Res. Doc. 97/37.

Narayanan, S., J. Carscadden, J.B. Dempson, M.F. O'Connell, S. Prinsenberg, D.G. Reddin, and N. Shackell. 1995. Marine climate off Newfoundland and its influence on salmon (*Salmo salar*) and capelin (*Mallotus villosus*), p. 461-474. *In* R.J. Beamish [ed.] Climate change and northern fish populations. Can. Spec. Publ. Fish. Aquat. Sci. 121.

Noakes, D.J., D.W. Welch, M. Henderson, and E. Mansfield. 1990. A comparison of pre-season forecasting methods for returns of two British Columbia sockeye salmon stocks. North Am. J. Fish. Management 10: 46-57.

O'Connell, M.F., and E.G.M. Ash. 1993. Smolt size in relation to age at first maturity of Atlantic salmon (*Salmo salar*): the role of lacustrine habitat. J. Fish. Biol. 42: 551-569.

O'Connell, M.F., J.B. Dempson, C.C. Mullins, D.G. Reddin, N.M. Cochrane, and D. Caines. 1997a. Status of Atlantic salmon (*Salmo salar* L.) stocks of the Newfoundland Region, 1996. DFO Atlantic Fisheries Res. Doc. 97/42. 104 p.

O'Connell, M.F., J.B. Dempson, T.R. Porter, D.G. Reddin, E.G.M. Ash, and N.M. Cochrane. 1992b. Status of Atlantic salmon (*Salmo salar* L.) stocks of the Newfoundland Region, 1991. Can. Atlan. Fish. Sci. Adv. Comm. Res. Doc. 92/22. 56 p.

O'Connell, M. F., J.B. Dempson, and D.G. Reddin. 1992a. Evaluation of the impacts of major management changes in the Atlantic salmon (Salmo salar L.) fisheries of Newfoundland and Labrador, Canada, 1984-88. Cons. Int. Explor. Mer J. mar. Sci. 49: 69-87.

O'Connell, M.F., J.B. Dempson, D.G. Reddin, E.G.M. Ash, and N.M. Cochrane. 1993. Status of Atlantic salmon (*Salmo salar* L.) stocks of the Newfoundland Region, 1992. DFO Atlantic Fisheries Res. Doc. 93/37. 51 p.

O'Connell, M.F., and D.G. Reddin. 1997. Status of Atlantic salmon (*Salmo salar* L.) in Middle Brook and Terra Nova River (SFA 5), Biscay Bay River (SFA 9), and Northeast River, Placentia (SFA 10), Newfoundland, in 1996. DFO Can. Stock Ass. Sec. Res. Doc. 97/40. 51 p.

O'Connell, M.F., D.G. Reddin, and E.G.M. Ash. 1997b. Status of Atlantic salmon (*Salmo salar* L.) in Gander River, Notre Dame Bay (SFA 4), Newfoundland, 1996. DFO Can. Stock Ass. Sec. Res. Doc. 97/41. 30 p.

Parrish, B.B., and Sv.Aa. Horsted (eds). 1980. ICES/ICNAF Joint investigation on north Atlantic salmon. Rapp. P.-v. Reun. Cons. int. Explor. Mer 176: 1-146.

Pearcy, W.G., R.D. Brodeur, J.M. Shenker, W.W. Smoker, and Y. Endo 1988. Food habits of Pacific salmon and steelhead trout, midwater trawl catches and oceanographic conditions in the Gulf of Alaska, 1980-1985. Bull. of the Ocean Res. Inst. Tokyo. Biology of the subarctic Pacific (Pt. 2) 26: 29-78.

Perry, R.I., N.B. Hargreaves, B.J. Waddell, and D.L. Mackas. 1996. Spatial variations in feeding and condition of juvenile pink and chum salmon off Vancouver Island, British Columbia. Fish. Oceangr. 5: 73-88.

Pippy, J. (Chairman). 1980. Report of the Working Group on the Interception of Mainland Salmon in Newfoundland. Can. MS Rep. Fish. Aquat. Sci. 1654: x + 196 p.

Porter, T.R., and J.A. Ritter. 1984. Possible causes of low abundance of Atlantic salmon in Canada - 1983. ICES C.M.1984/M:28. 27 p.

Power, G., M.V. Power, R. Dumas, and A. Gordon. 1987. Marine migrations of Atlantic salmon from rivers in Ungava Bay, Quebec. Am. Fish. Soc. Symposium 1: 364-376.

Reddin, D.G. 1981. Estimation of fishing mortality for Atlantic salmon (*Salmo salar*) in Newfoundland and Labrador commercial fisheries. ICES C.M.1981/M:24. 11 p.

Reddin D.G. 1985. Atlantic salmon (*Salmo salar* L.) on and east of the Grand Bank of Newfoundland. J. Northw. Atl. Fish. Sci., Vol. 6: 157-164.

Reddin, D.G. 1987. Contribution of North American salmon (*Salmo salar* L.) to the Faroese fishery. Le Naturaliste Can. 114:211-218.

Reddin, D.G. 1988a. Sea-surface temperature and distribution of Atlantic salmon, p.25-36. *In* R.H. Stroud [ed.] Present and future Atlantic salmon management. Symp. Proc. Marine Recreational Fisheries 12. National Coalition for Marine Conservation, Inc. Savannah, Georgia.

Reddin, D.G. 1988b. Ocean life of Atlantic salmon (*Salmo salar* L.) in the Northwest Atlantic, p. 483-511. In D.H. Mills and D. J. Piggins [eds.] Atlantic salmon: planning for the future. Proceedings of the Third International Atlantic salmon Symposium, Biarritz, France, October 21-23, 1986. Croom Helm, London.

Reddin, D.G., and J.B. Dempson. 1986. Origin of Atlantic salmon (Salmo salar L.) caught at sea near Nain, Labrador. Le Naturaliste Canadien 113: 211-218.

Reddin, D.G., and K.F. Friedland. 1993. Marine Environmental Factors Influencing the Movement and Survival of Atlantic Salmon, Chap. 4, p. 79-103, *In* D. Mills [ed.] Salmon in the Sea. Fourth International Atlantic Salmon Symposium, St. Andrews. Fishing News Books.

Reddin, D.G., and K.D. Friedland. 1996. Declines of Scottish spring salmon and thermal habitat in the northwest Atlantic. How are they related? pp. 45-66, *In* D. Mills (ed.) Enhancement of Spring Salmon. Proceedings of a One-day Conference Held in the Rooms of the Linnean Society of London. 26 January 1996. The Atlantic Salmon Trust, Pitlochry, Scotland.

Reddin, D.G., K.D. Friedland, P.J. Rago, D.A. Dunkley, L. Karlsson, and D.J. Meerburg. 1993. Forecasting the abundance of North American two-sea winter salmon stocks and the provision of catch advice for the west Greenland salmon fishery. Cons. Int. Explor. Mer C. M. 1993/M:43, 23 p.

Reddin D.G., and W.W. Shearer. 1987. Sea-surface temperature and distribution of Atlantic salmon in the Northwest Atlantic Ocean. American Fisheries Society Symposium on Common Strategies in Anadromous/Catadromous Fishes. Symposium 1: 262-275.

Reddin, D.G., W.M. Shearer, and R.F. Burfitt. 1984. Inter-continental migrations of Atlantic salmon (Salmo salar L.). ICES, C.M. 1984/M: 11. 9 p.

Reddin, D.G. and P.B. Short. 1991. Postsmolt Atlantic salmon (*Salmo salar*) in the Labrador Sea. Can. J. Fish. Aquat. Sci. 48: 2-6.

Reynolds, R.W. 1988. A real-time global sea surface temperature analysis. J. Climate 1: 75-86.

Reynolds, R.W. and T.M. Smith. 1994. Improved global sea surface temperature analyses using optimum interpolation. J. Clim. 7: 929-948.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Fish. Res. Board Can. Bull. 191. 382 p.

Ritter, J.A. 1989. Marine migration and natural mortality of North American Atlantic salmon (*Salmo salar* L.). Can. Manusc. Rep. Fish. Aquat. Sci. 2041. 136 p.

Ross, S.-A. 1993. Food and feeding of the hooded seal in Newfoundland. M. Sc. thesis. Memorial University of Newfoundland.

SAS Institute. 1985. SAS user's guide: statistics, version 5 edition. Cary, NC: SAS Institute.

SAS Institute Inc. 1988. SAS Procedures Guide, Release 6.03 Edition. Cary, North Carolina, USA. 441 pp.

Saunders, R.L., E.B. Henderson, B.D. Glebe, and E.J. Loudenslager. 1983. Evidence of a major environmental component in determination of the grilse:large salmon ratio in Atlantic salmon (*Salmo salar*). Aquaculture 33:107-118.

Scarnecchia, D.L. 1983. Age at sexual maturity in Icelandic stocks of Atlantic salmon (*Salmo salar*). Can. J. Fish. Aquat. Sci. 40: 1456-1468.

Scarnecchia, D.L. 1984a. Climatic and oceanic variations affecting yield of Icelandic stocks of Atlantic salmon (*Salmo salar*). Can. J. Fish. Aquat. Sci. 41: 917-935.

Scarnecchia, D.L. 1984b. Forecasting yields of two-sea-winter Atlantic salmon (*Salmo salar*) from Icelandic rivers. Can. J. Fish. Aquat. Sci. 41: 1234-1240.

Scarnecchia, D.L., A. Isaksson, and S.E. White. 1989. Effects of oceanic variations and the West Greenland fishery on age at maturity of Icelandic west coast stocks of Atlantic salmon (*Salmo salar*). Can J. Fish. Aquat. Sci. 46: 16-27.

Scarnecchia, D.L., A. Isaksson, and S.E. White. 1991. Effects of the Faroese long-line fishery, other oceanic fisheries and oceanic variations on age at maturity of Icelandic north-coast stocks of Atlantic salmon (*Salmo salar*). Fish. Res. 10: 207-228.

Shelton, P.A., G.B. Stenson, B. Sjare and W. . Warren. 1996. Model estimates of harp seal numbers at age for the northwest Atlantic. NAFO Sci. Coun. Stud. 26: 1-14 (NAFO SCR Doc. 95/20, Serial No. N2527).

Sokal, R.R., and F.J. Rohlf. 1981. Biometry: the principles and practice of statistics in biological research, 2nd edn. New York: W. H. Freeman.

Smith, T.M., R.W. Reynolds, R.E. Livezey, and D.C. Stokes. 1996. Reconstruction of historical sea surface temperatures using empirical orthogonal functions. J. Clim. 9: 1403-1420.

St. John, M.A., J.S. MacDonald, P.J. Harrison, R.J. Beamish, and E. Choromanski. 1992. The Fraser River plume: some preliminary observations on the distribution of juvenile salmon, herring, and their prey. Fish. Oceagr. 1: 153-162.

Steele, J.H. 1996. Regime shifts in fisheries management. Fisheries Research 25: 19-23.

Stenson, G.B., and B. Sjare. 1997. Seasonal distribution of harp seals, *Phoca groenlandica,* in the Northwest Atlantic. ICES C.M. 1997/CC:10.

Stenson, G.B., M.O. Hammill, M.C.S. Kingsley, B. Sjare, W.G. Warren and R.A. Myers. 1996. 1994 Pup production of northwest Atlantic harp seals, *Phoca groenlandica*. NAFO Sci. Coun. Stud. 26:47-62 (NAFO SCR Doc. 95/17, Serial No. N2524).

Stenson, G.B., R.A. Myers, I-H. Ni, and W.G. Warren. 1997. Pup production and population growth of hooded seals (*Cystophora cristata*) near Newfoundland, Canada. Can. J. Fish. Aquat. Sci 54 (Suppl. 1): 209-216.

Taylor, V.R. 1985. The early Atlantic salmon fishery in Newfoundland and Labrador. Can. Spec. Publ. Fish. Aquat. Sci. 76: 71 p.

Welch, D.W., A.I. Chigirinsky, and Y. Ishida. 1995. Upper thermal limits on the oceanic distribution of Pacific salmon (Oncorhynchus spp.) in the spring. Can. J. Aquat. Sci. 52: 489-503.

Youngson, A. 1995. Spring salmon. Atlantic Salmon Trust, Moulin, Pitlochry. 52 p.

Zwanenburg, K.C.T., and W.D. Bowen. 1990. Population trends of the grey seal (*Halichoerus grypus*) in eastern Canada. p. 185-197. *In* W.D. Bowen [ed.] Population biology of sealworm (*Pseudoterranova decipiens*) in relation to its intermediate and seal hosts. Can. Bull. Fish. Aquat. Sci. 222: 306 p.

Table 1. Newfoundland Region summary of the conservation egg requirement attained for various rivers during the five-year period prior to the commercial salmon fishery moratorium (1987-91) and the five years during the moratorium (1992-96) (from O'Connell et al. 1997a).

SFA	River	Year									
		1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
4	Exploits River:										
	-Lower	65	61	48	47	31	69	117	105	126	216
	-Middle	9	12	14	12	15	17	15	18	19	42
	-Upper	97	125	119	88	0.3	2	7	8	16	26
	Gander River			44	38	36	118	128	91	95	124
	Campbellton River							311	239	279	304
5	Terra Nova River	14	28	19	19	15	28	53	26	45	36
	Middle Brook	90	55	49	74	51	148	238	174	114	250
	Northwest River									40	55
9	Biscay Bay River	119	117	87	122	38	141	97	143	77	117
	Rocky River	22	30	17	40	22	28	34	25	56	34
10	Northeast River	166	247	302	269	175	555	527	434	422	736
11	Conne River*	214	159	103	112	51	51	61	40	81	112
	Little River**	51	30	61	105	47	45	82	38	22	298
13	Harry's River						12	37	46	48	48
	Pinchgut (tributary of Harry's)						36	117	145	150	130
	Highlands River							47	86	68	78
	Humber River				60	27	117	96	40	129	186
	Flat Bay River								27	45	65
	Crabbes Brook										56
	Middle Barachois Brook										79
	Robinsons River										62
14 A	Lomond River	56	70	61	62	64	121	118	143	187	143
	Torrent River	201	266	225	221	176	314	538	530	1033	1279
	Western Arm Brook	103	67	142	114	68	151	288	292	285	430

*Conne River is evaluated against a Management Target which is higher than the corresponding conservation egg requirement.

**Colonization program at Little River. Eggs removed from most adult returns, incubated, and fry subsequently stocked into the system. Conservation requirement achieved includes natural egg deposition and fry stocking egg equivalents.

Table 2. Estimates of average marine exploitation rates on small and large salmon for various rivers in Newfoundland, 1984-1991 (from Dempson et al. 1997a).

SFA	River	Small salmon Exploitation rate %	Large salmon Exploitation rate %
4	Exploits River	46.0	76.4
4	Gander River		
	Salmon Brook	29.4	82.4
	* Main River	66.0	72.1
5	Middle Brook	36.6	79.8
5	Terra Nova River	35.1	69.6
10	Northeast Placentia River	39.1	73.9
13	Humber River	47.3	59.6
14A	Lomond River	28.0	62.9
14A	Torrent River	56.0	75.1
14A	Western Arm Brook	56.8	97.6
Average exploitation for all rivers		44.0	74.9
	Minimum : Maximum values	28.0 - 66.0 %	59.6 - 97.6 %
	95% Confidence interval	35.0 - 53.1%	67.4 - 82.5%

* Main stem Gander River is for the period 1989-1991.

Table 3. Matrix of Spearman correlation coefficients of Atlantic salmon returns to Newfoundland rivers, 1984-1997. Coefficients above the diagonal line refer to small salmon while below the diagonal line represent large salmon. Statistically significant values are in bold. Blocked areas separate the respective Northeast, South, and West coast regions.

		Northeast Coast					South Coast					West Coast			
SFA	River	Exploits	Salmon Bk	Gander	Middle Bk	Terra Nova	Biscay Bay	NE Trepassey	Rocky	NE Placentia	Conne	Humber	Lomond	Torrent	Western Arm Bk
4	Exploits		**0.53**	**0.95**	**0.86**	**0.75**	0.18	-0.01	0.19	0.42	-0.32	0.46	**0.53**	**0.62**	0.67
4	Salmon Bk	**0.81**		**0.83**	0.50	**0.68**	0.34	0.23	0.05	0.23	0.01	0.41	0.28	0.18	0.31
4	Gander	**0.55**	**0.72**		**0.90**	**0.97**	0.07	0.13	0.07	**0.77**	-0.10	**0.78**	**0.77**	**0.88**	**0.90**
5	Middle Bk	**0.86**	**0.92**	**0.62**		**0.75**	0.21	0.03	0.20	**0.57**	-0.32	**0.58**	**0.67**	**0.69**	**0.65**
5	Terra Nova	**0.61**	**0.78**	**0.68**	**0.63**		0.03	-0.09	0.36	0.49	-0.22	**0.70**	**0.65**	**0.70**	**0.66**
9	Biscay Bay	0.29	0.11	0.05	0.20	0.13		0.43	0.22	-0.17	0.45	0.01	-0.01	-0.04	-0.10
9	NE Trepassey	-0.17	-0.30	-0.33	-0.21	**-0.69**	0.14		-0.43	-0.40	0.12	-0.27	-0.13	-0.18	-0.09
9	Rocky	**0.61**	**0.73**	**0.90**	**0.70**	**0.83**	0.12	**-0.62**		0.18	0.12	0.48	0.32	0.33	0.08
10	NE Placentia	**0.88**	**0.81**	0.65	**0.83**	**0.76**	0.42	-0.51	**0.78**		-0.19	**0.57**	0.29	**0.60**	**0.75**
11	Conne	-0.29	-0.28	-0.13	-0.37	-0.40	0.30	0.45	-0.49	-0.28		0.06	-0.43	-0.25	-0.27
13	Humber	**0.62**	**0.62**	**0.80**	0.46	**0.59**	-0.08	-0.41	0.46	**0.63**	0.01		0.46	**0.77**	**0.54**
14A	Lomond	**0.77**	**0.84**	**0.70**	**0.74**	**0.70**	0.13	-0.36	**0.70**	**0.81**	-0.44	**0.66**		**0.58**	0.35
14A	Torrent	**0.86**	**0.74**	0.65	**0.81**	**0.68**	0.26	-0.52	**0.83**	**0.96**	-0.49	**0.54**	**0.82**		**0.85**
14A	Western Arm Bk	**0.73**	**0.80**	**0.72**	**0.81**	**0.75**	-0.08	-0.45	**0.73**	**0.69**	-0.46	**0.61**	**0.56**	**0.64**	

Table 4. Correlation analysis for North American 1SW returns for regional stock complexes of Labrador, Newfoundland, Quebec, the Gulf of St. Lawrence, Scotia-Fundy and USA, 1971-96. Values in the table are the Spearman correlation coefficients, the probability level, and the number of observations.

	Year	Labrador	NFld	Quebec	Gulf	SF	USA
Year	1.00000	-0.06393	0.05778	0.71145	0.32103	0.00171	0.66496
	0.0	0.7564	0.7792	0.0001	0.1098	0.9934	0.0002
	26	26	26	26	26	26	26
Labrador	-0.06393	1.00000	0.38667	0.30462	0.23829	0.42085	0.23897
	0.7564	0.0	0.0510	0.1303	0.2411	0.0323	0.2397
	26	26	26	26	26	26	26
Nfld	0.05778	0.38667	1.00000	0.24650	0.24103	0.17265	0.27043
	0.7792	0.0510	0.0	0.2248	0.2356	0.3990	0.1815
	26	26	26	26	26	26	26
Quebec	0.71145	0.30462	0.24650	1.00000	0.68137	0.41265	0.79077
	0.0001	0.1303	0.2248	0.0	0.0001	0.0362	0.0001
	26	26	26	26	26	26	26
Gulf	0.32103	0.23829	0.24103	0.68137	1.00000	0.51658	0.58427
	0.1098	0.2411	0.2356	0.0001	0.0	0.0069	0.0017
	26	26	26	26	26	26	26
SF	0.00171	0.42085	0.17265	0.41265	0.51658	1.00000	0.56376
	0.9934	0.0323	0.3990	0.0362	0.0069	0.0	0.0027
	26	26	26	26	26	26	26
USA	0.66496	0.23897	0.27043	0.79077	0.58427	0.56376	1.00000
	0.0002	0.2397	0.1815	0.0001	0.0017	0.0027	0.0
	26	26	26	26	26	26	26

Table 5. Correlation analysis for North American 2SW returns for regional stock complexes of Labrador, Newfoundland, Quebec, the Gulf of St. Lawrence, Scotia-Fundy and USA, 1971-96. Values in the table are the Spearman correlation coefficients, the probability level, and the number of observations.

	Year	Labrador	Nfld	Quebec	Gulf	SF	USA
Year	1.00000	-0.17265	-0.29504	-0.31419	-0.53983	-0.59795	0.24991
	0.0	0.3990	0.1434	0.1180	0.0044	0.0013	0.2182
	26	26	26	26	26	26	26
Labrador	-0.17265	1.00000	0.52615	0.06462	0.31897	-0.00855	-0.49333
	0.3990	0.0	0.0058	0.7538	0.1122	0.9669	0.0104
	26	26	26	26	26	26	26
Nfld	-0.29504	0.52615	1.00000	-0.04137	0.43932	0.03658	-0.18974
	0.1434	0.0058	0.0	0.8410	0.0247	0.8592	0.3532
	26	26	26	26	26	26	26
Quebec	-0.31419	0.06462	-0.04137	1.00000	0.53983	0.68957	0.32513
	0.1180	0.7538	0.8410	0.0	0.0044	0.0001	0.1051
	26	26	26	26	26	26	26
Gulf	-0.53983	0.31897	0.43932	0.53983	1.00000	0.47556	-0.08034
	0.0044	0.1122	0.0247	0.0044	0.0	0.0141	0.6964
	26	26	26	26	26	26	26
SF	-0.59795	-0.00855	0.03658	0.68957	0.47556	1.00000	0.34154
	0.0013	0.9669	0.8592	0.0001	0.0141	0.0	0.0877
	26	26	26	26	26	26	26
USA	0.24991	-0.49333	-0.18974	0.32513	-0.08034	0.34154	1.00000
	0.2182	0.0104	0.3532	0.1051	0.6964	0.0877	0.0
	26	26	26	26	26	26	26

Table 6. Identification and analysis of factors potentially contributing to low returns of Atlantic salmon in 1997.

Life stage	Type	Factor	Quantitative test possible	Data availability/analysis
Spawning		**Low egg deposition contributing to 97 returns**	Yes	Various rivers with counting facilities
	Abiotic	- measurement error	Yes	Examine CIs on mark-recapture
	Biotic	- natural shift in smolt age	Yes	Sampling database
	Abiotic	- hook & release mortalities	Yes/No	Examination of literature for possible rates
	Biotic	- lower fecundity	Yes	Mike's paper from last year
	Abiotic	- poaching & disease	No	
Egg to parr	Biotic	**Poor hatching success**	Yes	Juvenile surveys - Highlands, others (Conrad)
		Low survival in freshwater for 96 smolts		Age classes of smolts in 96 compared to previous
	Abiotic	- climate variability/change	Yes	Counting fence data/DOE climate data
	Biotic	- predation	No	
	Abiotic	- mortality on bycatches in eel nets	No	
	Biotic	- density dependence	Yes	Counting fence data
Smolt		**Low survival in the sea for 96 smolts (1 month)**	**Yes**	**Aquaculture/kelt survival at same time**
	Biotic	- predation	No	
	Biotic	- cod	No	
	Biotic	- seabirds	No	
	Abiotic	- climate variability/change	Yes	Condition factor
Postsmolt		**Low survival in the sea (~10 months)**	**Yes**	**Kelt survival at same time**
	Biotic	- predation		
	Biotic	- cod	No	
	Biotic	- seabirds	Yes	Montevecchi study
	Biotic	- seals	No	
	Abiotic	- climate variability/change	Yes	Climate/SST data
Adult		**Low survival in the sea (~4 months)**	**Yes**	**Kelt survival at same time**
	Biotic	- predation	No	
	Biotic	Disease inflicted mortality		
		- furunculosis	No	
		- sea lice (check ICES report)	No	
		- other diseases or related issues	No	
	Abiotic	- climate variability/change	Yes	Climate/SST data
	Abiotic	- measurement error in counts or scale reading	No	
	Abiotic	-delayed maturation	Yes	Previous time series to discern if occurred before
	Abiotic	Fishing mortality at sea		
		- Labrador	Yes	Examine natural mortality rates from counting fences
		- West Greenland	Yes	Examine natural mortality rates from counting fences
		- illegal fishing at sea	No	Fisheries officers/observer data
		- bycatch in non-salmon fishing gear	No	Fisheries officers
	Abiotic	Pollution from heavy metals, acid rain	Yes/no	

Table 1.1. Summary of Atlantic salmon commercial catch data for Labrador (Salmon Fishing Areas 1, 2, & 14B), 1974-97. Weight in kilograms. Also shown is percentage change for 1996 in relation to 1995 and the 1984-89, 1986-91 and 1992-95 means.

LABRADOR (SFAs 1, 2 & 14B)

YEAR	SMALL WEIGHT	SMALL NUMBER	LARGE WEIGHT	LARGE NUMBER	TOTAL WEIGHT	TOTAL NUMBER	QUOTA WEIGHT
1974	112603	56321	601581	122765	714183	179086	
1975	212434	111791	492469	114521	704903	226312	
1976	164273	78209	591998	131540	756270	209749	
1977	139157	69602	573293	116980	712448	186582	
1978	63962	33656	429986	91473	493949	125129	
1979	96025	45714	229911	52238	325936	97952	
1980	227564	103479	625039	124955	852601	228434	
1981	238383	114680	576188	112334	814571	227014	
1982	158382	79449	389267	83243	547650	162692	
1983	96859	49441	272658	60212	369515	109653	
1984	52261	25590	199676	43202	251935	68792	
1985	86893	47359	152588	33995	238480	81354	
1986	140336	71396	297975	58565	438310	129961	
1987	177982	89454	384778	79170	562759	168624	
1988	159933	83109	234288	49598	394217	132707	
1989	114269	56486	216115	47743	330382	104229	
1990	66667	33027	137129	27487	203794	60514	260,000
1991	53994	26768	65403	13465	119396	40233	295,000
1992	46662	24249	157840	32341	204502	56590	273,000
1993	32325	17074	79962	17096	112285	34170	178,000
1994	18188	8640	74962	15377	93150	24017	92,000
1995	17236	7980	43748	11176	60983	19156	73,500
1996*	15141	7849	32590	7267	47731	15116	55,000
1997*	20661	9973	25709	6351	46370	16324	50,000
$\bar{X}$ 84-89	121945.7	62232	247570.0	52046	369347.2	114278	
S.D.	47042.3	23907	82277.5	15536	122648.0	36859	
95% LCL	72569.8	37139	161211.0	35739	240615.1	75590	
95% UCL	171321.6	87325	333929.0	68352	498079.3	152966	
$\bar{X}$ 86-91	118863.5	60040	222614.7	46005	341476.3	106045	
S.D.	50192.4	25983	113294.3	23132	160949.4	48180	
95% LCL	66181.2	32768	103700.3	21726	172542.8	55475	
95% UCL	171545.8	87312	341529.0	70284	510409.8	156615	
$\bar{X}$ 92-95	28602.8	14486	89128.0	18998	117730.0	33483	
S.D.	13876.4	7714	48529.6	9237	61599.3	16626	
95% LCL	6525.4	2213	11917.4	4302	19725.5	7031	
95% UCL	50680.1	26759	166338.6	33693	215734.5	59935	
%Change, 1997 vs:							
1996	36	27	-21	-14	-3	8	
$\bar{X}$ 84-89	-83	-84	-90	-88	-87	-86	
$\bar{X}$ 86-91	-83	-83	-88	-86	-86	-85	
$\bar{X}$ 92-95	-28	-31	-71	-67	-61	-51	

* Preliminary data.

Table 1.2. Nominal catches of salmon, West Greenland 1960-96 (metric tons round fresh weight).

Year	Norway	Faroes	Sweden	Denmark	Greenland[4]	Total	Quota
1960	-	-	-	-	60	60	-
1961	-	-	-	-	127	127	-
1962	-	-	-	-	244	244	-
1963	-	-	-	-	466	466	-
1964	-	-	-	-	1539	1539	-
1965	-[1]	36	-	-	825	861	-
1966	32	87	-	-	1251	1370	-
1967	78	155	-	85	1283	1601	-
1968	138	134	4	272	579	1127	-
1969	250	215	30	355	1360	2210	-
1970	270	259	8	358	1244	2146[3]	-
1971	340	255	-	645	1449	2689	-
1972	158	144	-	401	1410	2113	1100
1973	200	171	-	385	1585	2341	1100
1974	140	110	-	505	1162	1917	1191
1975	217	260	-	382	1171	2030	1191
1976	-	-	-	-	1175	1175	1191
1977	-	-	-	-	1420	1420	1191
1978	-	-	-	-	984	984	1191
1979	-	-	-	-	1395	1395	1191
1980	-	-	-	-	1194	1194	1191
1981	-	-	-	-	1264	1264	1265[5]
1982	-	-	-	-	1077	1077	1253[5]
1983	-	-	-	-	310	310	1191
1984	-	-	-	-	297	297	870
1985	-	-	-	-	864	864	852
1986	-	-	-	-	960	960	909
1987	-	-	-	-	966	966	935
1988	-	-	-	-	893	893	-[6]
1989	-	-	-	-	337	337	-[6]
1990	-	-	-	-	274	274	-[6]
1991	-	-	-	-	472	472	840
1992	-	-	-	-	237	237	-
1993	-	-	-	-	0[2]	0[2]	-
1994	-	-	-	-	0[2]	0[2]	-
1995	-	-	-	-	83	83	77
1996	-	-	-	-	92	92	-
1997	-	-	-	-	57	57	57

[1] Figures not available, but catch is known to be less than Faroese catch.
[2] The fishery was suspended.
[3] Including 7 t caught on longline by one of two Greenland vessels in the Labrador Sea early in 1970.
[4] For Greenland vessels: all catches up to 1968 were taken with set gillnets only; after 1968, the catches were taken with set gillnets and drift nets. All non Greenland catches from 1969-84 were taken with drift nets.
[5] Quota corresponding to specific opening dates of the fishery.
[6] Quota for 1988-90 was 2,520 t with an opening date of 1 August and annual catches not to exceed the annual average (840 t) by more than 10%. Quota adjusted to 900 t in 1989 and 924 t in 1990 for later opening dates.

Factor used for converting landed catch to round fresh weight in fishery by Greenland vessels = 1.11.
Factor for Norwegian, Danish, and Faroese drift net vessels = 1.10.

Table 1.3. History of commercial catches (in numbers) of North American 1SW and 2SW salmon in Labrador and Greenland as a proportion of total stock, 1970-96.

Smolt class	Non-maturing 1SW salmon (NN1)		Maturing 1SW salmon (MN1)		Total of NN1 & MN1		Labrador small & large catches converted to 1SW & 2SW										Greenland harvest of 1SW North American salmon		
Year	Min	Max	Min	Max	Min	Max	1SW (i + 1)		2SW (i + 2)		% 1SW		% 2SW		% Total		Catch	% of total NN1	
(i)	(i + 1)	(i + 1)	(i + 1)	(i + 1)			Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	(i + 1)	Min	Max
70	558772	698262	415268	705924	974041	1404186	56663	63746	59837	82951	8.03	15.35	8.57	14.85	8.30	15.06	287672	41.20	51.48
71	537924	704156	431739	690466	969663	1394622	42412	47713	78674	104742	6.14	11.05	11.17	19.47	8.68	15.72	200784	28.51	37.33
72	646237	827293	565961	838495	1212198	1665788	9280	10440	79551	109736	1.11	1.84	9.62	16.98	5.33	9.91	241493	29.19	37.37
73	602040	767372	539814	823767	1141855	1591139	45057	50689	80516	114599	5.47	9.39	10.49	19.04	7.89	14.48	220584	28.75	36.64
74	690698	874657	614940	997022	1305637	1871679	89433	100612	89036	123165	8.97	16.36	10.18	17.83	9.54	17.14	278839	31.88	40.37
75	584919	792954	607984	975395	1192903	1768349	62567	70388	78572	108928	6.41	11.58	9.91	18.62	7.98	15.03	155896	19.66	26.65
76	479650	630508	470612	782491	950262	1412999	55682	62642	60659	82319	7.12	13.31	9.62	17.16	8.23	15.25	189709	30.09	39.55
77	274681	350041	296216	506560	570897	856602	26925	30290	37129	52148	5.32	10.23	10.61	18.98	7.48	14.44	118853	33.95	43.27
78	596098	784262	443811	711629	1039908	1495892	36571	41143	86126	121465	5.14	9.27	10.98	20.38	8.20	15.64	200061	25.51	33.56
79	520049	686938	630211	1020455	1150260	1707393	82783	93131	80190	114124	8.11	14.78	11.67	21.94	9.55	18.02	187999	27.37	36.15
80	505980	656164	656009	1124364	1161989	1780527	91744	103212	58721	83314	8.16	15.73	8.95	16.47	8.45	16.05	227727	34.71	45.01
81	423668	542030	564552	936858	988220	1478888	63559	71504	42023	59009	6.78	12.67	7.75	13.93	7.14	13.21	194715	35.92	45.96
82	216351	317097	384197	626928	600547	944025	39553	44497	29141	40340	6.31	11.58	9.19	18.65	7.28	14.13	33240	10.48	15.36
83	228661	331793	377445	620092	606106	951885	20472	23031	25511	37046	3.30	6.10	7.69	16.20	4.83	9.91	38916	11.73	17.02
84	379639	521528	476295	767226	855934	1288753	37887	42623	42766	61618	4.94	8.95	8.20	16.23	6.26	12.18	139233	26.70	36.68
85	416903	558125	605171	987478	1022074	1545603	57117	64256	56484	81263	5.78	10.62	10.12	19.49	7.35	14.24	171745	30.77	41.20
86	378207	511367	629695	1029387	1007902	1540753	71563	80509	37670	55900	6.95	12.79	7.37	14.78	7.09	13.53	173687	33.97	45.92
87	297491	406641	597625	1009425	895116	1416065	66487	74798	34791	49988	6.59	12.52	8.56	16.80	7.15	13.94	116767	28.72	39.25
88	222691	330833	420310	677099	643001	1007932	45189	50837	19866	28666	6.67	12.10	6.00	12.87	6.45	12.36	60693	18.35	27.25
89	202077	284709	392319	672665	594396	957374	26422	29724	10357	15727	3.93	7.58	3.64	7.78	3.84	7.65	73109	25.68	36.18
90	234257	338756	292723	483564	526980	822320	21414	24091	22343	31236	4.43	8.23	6.60	13.33	5.32	10.50	110680	32.67	47.25
91	132563	211438	351932	638772	484495	850210	19399	21824	12006	17133	3.04	6.20	5.68	12.92	3.69	8.04	41855	19.80	31.57
92	84288	176420	301807	580253	386095	756672	13659	15367	10264	14203	2.35	5.09	5.82	16.85	3.16	7.66	0	0.00	0.00
93	84729	188746	208228	430118	292957	618864	6912	7776	7559	10592	1.61	3.73	4.00	12.50	2.34	6.27	0	0.00	0.00
94	99398	182194	199179	456912	298576	639106	6384	7182	5125	7363	1.40	3.61	2.81	7.41	1.80	4.87	20828	11.43	20.95
95			297416	636006			6279	7064			0.99	2.38					12357		
96																			

Table 1.4. List of salmon bycatch records from the observed offshore fisheries, 1980 - 1997. Directed sets refer to the total number of observed sets fished offshore.

Year	Catch	Directed Fishery	NAFO Division	Date	Depth (m)	Directed Sets
1980	1 salmon	Yellowtail	3N	16-May	49	20,401
1981	1 salmon	Haddock	4W	1-Apr	65	24,907
1982	1 salmon	Cod	3O	29-May	76	17,974
	2 salmon	Cod	3O	28-Jun	69	
	3 salmon	White hake	3O	6-Jun	110	
1983	1 salmon	Cod	3N	1-Jun	52	15,896
1984	no records					11,532
1985	no records					11,741
1986	no records					14,338
1987	no records					29,069
1988	1 salmon	Capelin	3O	19-May	75	31,568
	2 salmon	Shrimp	2H	18-Jul	355	
1989	no records					34,859
1990	2 salmon	American Plaice				44,490
1991	no records					39,029
1992	1 salmon	American Plaice				32,900
1993	1 salmon	Shrimp	3M	24-Jun	417	24,701
1994	no records					24,695
1995	no records					14,704
1996	4 salmon	Atlantic halibut	3O	18-Mar	146	21,869
1997	1 salmon	Cod	3Ps	26-Jun	26	9,817
	1 salmon	Cod	3Ps	18-Jul	18	
Total	**22 salmon**					**424,490**

Table 1.5. Summary of Atlantic salmon reported as bycatch in sentinel fishery cod traps, SFAs 2-10, 1995 - 1997.

SFA	1995 No. of fishers	1995 No. of days fished	1995 Dates fished	1995 No. of salmon caught	1995 Salmon catch per trap-day	1996 No. of fishers	1996 No. of days fished	1996 Dates fished	1996 No. of salmon caught	1996 Salmon catch per trap-day	1997 No. of fishers	1997 No. of days fished	1997 Dates fished	1997 No. of salmon caught	1997 Salmon catch per trap-day
2	3	99	Aug 9 - Sep 18	2	0.02	4*	101	Jul 29 - Sep 4	4.00	0.04	4	99	Jul 14 - Sep 5	4	0.04
3	7	232	Jul 24 - sep 21	7	0.03	7	181	Jul 8 - Oct 6	4	0.02	7	179	Jul 7 - Oct 4	1	0.01
4	8	257	Jul 11 - Sep 9	70	0.27	8	237	Jun 24 - Aug 2	127	0.54	8	242	Jun 26 - Aug 6	193	0.80
5	3	81	Jul 24 - Aug 28	16	0.20	3	71	Jul 1 - Aug 3	21	0.30	3	77	Jun 23 - Aug 1	57	0.74
6	3	95	Jul 24 - Aug 25	6	0.06	3	79	Jun 23 - Aug 9	11	0.14	3	79	Jun 22 - Aug 2	7	0.09
7	2	61	Jul 24 - Aug 25	0	0.00	3	76	Jul 1 - Aug 29	5	0.07	3	75	Jun 23 - Aug 29	10	0.13
8	7	208	Jul 19 - Sep 4	0	0.00	8	263	Jun 29 - Aug 14	0	0.00	8	237	Jul 8 - Aug 20	0	0.00
9	1	32	Jul 17 - Aug 18	0	0.00	1	25	Jul 3 - Jul 27	0	0.00	1	24	Jun 23 - Jul 18	0	0.00
10	3	80	Jul 17 - Aug 20	0	0.00	4	98	Jun 24 - Jul 26	173	1.77	3	44	Jun 23 - Jul 25	2	0.05
Total	37	1145		101	0.09	37	1131		345	0.31	40	1056		274	0.26

* One fisher had a trap set to catch cod for tagging purposes in SFA 10, 1996. This fisher reported a bycatch of 169 salmon.

Table 2.1. Estimates of egg deposition, smolt production by year class, and egg-to-smolt survival for Northeast Brook (Trepassey) and Conne River.

Year-class (eggs)	Estimated egg deposition (no.)	Smolt production (no.)	Survival (%)	Eggs/100 m^2
Northeast Brook (Trepassey)				
1984	330308	1604	0.49	594
1985	449780	1611	0.36	809
1986	529817	2442	0.46	953
1987	368281	1476	0.40	662
1988	306446	1787	0.58	551
1989	249768	1232	0.49	449
1990	224730	816	0.36	404
1991	358191	1221	0.34	644
1992	182172	(1893)[1]	1.04	328
Conne River				
1984				
1985				
1986	11340000	56873	0.50	860
1987	16730000	76655	0.46	1269
1988	12420000	65038	0.52	942
1989	8040000	55335	0.68	610
1990	8730000	68720	0.79	662
1991	3980000	57793	1.45	302
1992	3970000	(95083)[1]	2.40	301

[1]To age 4 smolts in 1997

Table 2.2. Sea survival both corrected for commercial exploitation and uncorrected for Western Arm Brook, Northeast Brook (Trepassey), and Conne River, Newfoundland.

	Western Arm Brook				Northeast Brook, Trepassey				Conne River			
Year	Smolts year i	1SW year i+1	Survival %	Survival corrected%	Smolts year i	Adults year i+1	Survival %	Survival corrected%	Smolts year i	1SW year i+1	Survival %	Survival corrected%
71	5735	389	6.8	17.0								
72	11905	794	6.7	16.7								
73	8484	506	6.0	14.9								
74	11854	639	5.4	13.5								
75	9600	552	5.8	14.4								
76	6232	373	6.0	15.0								
77	9899	308	3.1	7.8								
78	13071	1572	12.0	30.1								
79	8349	465	5.6	13.9								
80	15665	477	3.0	7.6								
81	13981	467	3.3	8.4								
82	12477	1135	9.1	22.7								
83	10552	235	2.2	5.6								
84	20653	462	2.2	5.6								
85	13417	527	3.9	9.8								
86	17719	437	2.5	6.2	1117	91	8.1	20.4				
87	17029	355	2.1	5.2	1404	97	6.9	17.3	74585	7487	10.0	14.3
88	15321	455	3.0	7.4	1692	62	3.7	9.2	65962	4764	7.2	10.3
89	11407	435	3.8	9.5	1708	71	4.2	10.4	73724	5277	7.2	10.2
90	10563	233	2.2	5.5	1902	99	5.2	13.0	56943	2302	4.0	5.8
91	13453	479	3.6	3.6	1911	49	2.6	2.6	74645	2409	3.2	3.2
92	15405	817	5.3	5.3	1674	79	4.7	4.7	68208	2581	3.8	3.8
93	13435	919	6.8	6.8	1849	99	5.4	5.4	55765	1464	2.6	2.6
94	9284	823	8.9	8.9	944	80	8.5	8.5	60762	3440	5.7	5.7
95	15144	1230	8.1	8.1	792	73	9.2	9.2	62749	3323	5.3	5.3
96	14500	509	3.5	3.5	1749	50	2.9	2.9	94088	2881	3.1	3.1
97												

Table 2.3a. Data on recruits of small salmon used in correlations with environmental correlations.

Year	Middle Br	Biscay Bay	Gander R	Exploits R	Conne R	Humber R	Lomond R	Torrent R	Western Arm Br
71									1553
72							689		998
73							959		1961
74	2438	1268	35918			26578	889		1285
75	3565	1928	47088	30550		59583	1474		1570
76	2633	3000	37563	15255		49454	1904		1357
77	7208	2573	35903	20178		20917	1673		865
78	4230	2160	52723	12708		26384	1125		754
79	3428	3323	66440	21058		32404	1047	4769	3878
80	5283	5053	42153	33335		34042	1446	1843	1130
81	7120	7573	72438	28418		40051	1502	5279	1199
82	4135	6553	34430	23263		41554	1420	5351	1130
83	3675	7393	32168	21323		30145	1683	4862	2804
84	4188	6075	32088	48893		27838	2401	4201	578
85	3208	4815	53133	44345		23554	957	3778	1145
86	3868	6720	37358	26745	8302	33499	1765	7343	1295
87	2633	3483	22848	24478	10155	29796	1588	6214	1074
88	3343	4505	42500	24108	7627	39179	2048	5558	1037
89	1565	2510	19358	19165	4968	11796	1588	3519	1118
90	2675	4175	19350	17793	5368	29602	1892	5861	791
91	1908	985	16863	14395	2411	13871	1780	3643	573
92	1563	1467	18179	13818	2523	17032	770	2526	456
93	2247	1117	26205	22777	2703	17910	792	3760	903
94	1844	1600	18273	18472	1533	7750	1002	3471	910
95	1448	1151	22264	17090	3502	27042	1323	5501	785
96	2112	1217	23668	32369	4440	29510	954	6575	1213
97	1221	.	10494	13552	3200	11217	751	3665	510

Table 2.3b. Data on small salmon spawners used in correlations with environmental correlations.

Year	Middle Br	Biscay Bay	Gander R	Exploits R	Conne R	Humber R	Lomond R	Torrent R	Western Arm Br
79					4646	8887	112		
80	13492	1111	604	8103	6166	20048	510	438	322
81	14676	1149	936	8395	6158	16674	168	716	399
82	12447	1832	923	7430	5561	7033	179	933	387
83	14191	2138	780	6039	5495	8741	132	1748	323
84	19471	1477	1039	7709	3861	10938	204	1036	805
85	19355	1668	1583	12617	6104	11216	270	1826	1054
86	17975	2334	2380	12964	6863	13400	143	2110	494
87	19665	2110	2345	10395	7870	13966	258	2029	422
88	11317	1449	2468	9162	6251	10154	252	1847	692
89	10827	1320	2221	16419	5776	9380	394	1606	695
90	13433	1005	1582	19285	6585	7970	226	2550	289
91	15933	752	1979	14136	5811	11336	344	2570	445
92	10776	812	1434	10461	7176	10083	366	2165	461
93	10146	748	1291	9976	6176	13258	461	1517	335
94	11451	545	959	9736	4138	3992	663	2101	339
95	6576	591	1198	8607	3723	10017	764	1600	392
96	6208	603	629	7250	2522	4694	693	2151	293
97	9849	813	1131	13135	1858	16167	449	3660	336

Table 2.4. North American, Labrador, and Newfoundland salmon abundance used in ocean climate analysis.

Year	2SW North American salmon abundance	Labrador 2SW salmon	Nfld 2SW salmon	2SW North American salmon abundance	Labrador 2SW salmon	Nfld 2SW salmon
69	.	106834	3742	.	85596	471055
70	.	126841	5307	.	116521	605559
71	.	124704	3976	560596	151819	487256
72	628517	145512	4157	561102	113634	470329
73	621040	143043	4991	702228	24864	623448
74	736765	154954	3280	681791	124499	366505
75	684706	152009	3970	805981	247117	484997
76	782677	196066	3879	791689	172883	497874
77	688937	141822	3133	626552	153857	474826
78	555079	122431	3341	401388	74397	420625
79	312361	70374	1839	577720	101052	462336
80	690180	142321	4079	825333	228743	521103
81	603493	142782	3862	890187	253503	677704
82	581072	124867	4958	750705	175624	605143
83	482849	89776	4186	505562	109291	473625
84	266724	46055	3788	498769	56567	557995
85	280227	37569	1603	621760	104688	522458
86	450583	75133	2654	796324	157823	539027
87	487514	106297	2231	829541	197740	541542
88	444787	75984	2589	803525	183715	570998
89	352066	73601	1174	548704	124864	258562
90	276762	36493	2235	532492	73007	427624
91	243393	20583	1762	388143	59171	276846
92	286507	39614	1512	495352	54593	174035
93	172001	26454	744	441030	63307	196383
94	130354	22955	945	319173	42708	143071
95	136738	32309	1148	328045	57026	167824
96	140796	29190	1262	466711	117888	214362

Table 2.5. Thermal habitat values for the northwest Atlantic, 1970-97.

Year	January	Febuary	March	April	May	June	July	August	September	Octobe	Novembe	December	Winter	Average values Spring	Summer	Fall	All year	Return year Grilse	MSW
70	2046	1899	1901	1870	2097	2289	2126	1599	1778	2133	2116	2055	1949	2085	1834	2101	1992		
71	2049	2011	1819	1894	2034	2103	2022	1554	1694	2060	2054	1967	1960	2010	1757	2027	1938	2007	
72	2034	1990	1914	1793	1829	2126	2244	2002	1826	1855	1898	1866	1979	1916	2024	1873	1948	1941	1967
73	2007	1708	1896	1792	2026	2210	2269	1736	1833	2215	2174	1890	1870	2009	1946	2093	1980	1949	1942
74	1926	1862	1746	1834	2055	2256	2593	1900	1924	2161	2086	1952	1845	2048	2139	2066	2025	2002	1965
75	1761	1827	1842	1764	1899	2336	2069	1577	1810	2184	2096	2080	1810	2000	1819	2120	1937	2025	2003
76	1795	1676	1953	1689	1972	2328	2568	1836	1691	2059	2079	1989	1808	1996	2032	2042	1970	1962	1984
77	1780	1915	1994	1927	2340	2095	1987	1706	2007	2185	2157	2068	1896	2121	1900	2137	2013	2041	1990
78	1892	1951	1979	1907	2058	2171	2099	1737	1944	2208	2089	1955	1941	2045	1927	2084	1999	2036	2025
79	1925	2058	1999	1938	2007	2426	2092	1503	1788	2150	2157	1932	1994	2124	1794	2080	1998	2044	2034
80	1799	1823	2088	1760	2079	2164	2058	1580	2225	2251	2336	2071	1903	2001	1954	2219	2020	1983	1998
81	1746	1912	1807	1663	2069	2532	2029	1616	1679	1941	2007	2033	1822	2088	1775	1994	1920	2035	2001
82	1800	1703	1621	1662	1796	2188	2198	1760	1833	2064	1969	1681	1708	1882	1930	1905	1856	1905	1945
83	1526	1416	1369	1424	1649	1810	1619	1776	1793	1845	1768	1577	1437	1628	1729	1730	1631	1763	1822
84	1436	1257	1209	1338	1467	1766	1935	1656	1685	2010	1805	1589	1301	1524	1759	1801	1596	1594	1674
85	1371	1410	1397	1508	1690	2097	2427	2062	2297	2557	2180	1967	1393	1765	2262	2235	1914	1670	1633
86	1832	1688	1547	1674	1880	2366	2346	1778	1674	2312	1990	1757	1689	1973	1933	2020	1904	2019	1841
87	1711	1627	1471	1658	1655	1754	1896	1519	1784	2186	1974	1848	1603	1689	1733	2003	1757	1856	1923
88	1747	1698	1622	1676	1864	2022	2098	1797	1820	2188	2271	1992	1689	1854	1905	2150	1900	1803	1839
89	1807	1642	1552	1552	1665	1985	2091	1710	1872	1860	1874	1744	1667	1734	1891	1826	1780	1875	1831
90	1526	1503	1491	1318	1543	1747	2410	2070	1999	1991	1925	1656	1507	1536	2160	1857	1765	1709	1790
91	1403	1357	1519	1529	1592	2050	2483	2329	2282	2403	2042	1706	1426	1724	2365	2050	1891	1771	1747
92	1474	1381	1378	1395	1582	1891	2291	2437	2250	2233	1852	1624	1411	1623	2326	1903	1816	1856	1813
93	1441	1252	1242	1353	1517	1923	2309	1918	1993	2162	1966	1556	1312	1598	2073	1895	1719	1778	1823
94	1487	1329	1373	1403	1711	1955	2447	2060	2126	2164	2268	1720	1396	1690	2211	2051	1837	1757	1771
95	1444	1311	1279	1378	1679	1941	2056	1728	2098	2209	1948	1749	1345	1666	1961	1969	1735	1820	1785
96	1647	1470	1419	1495	1859	2086	2268	1740	1819	2117	2065	1948	1512	1813	1942	2043	1828	1813	1817
97	1791	1594	1605	1714	1868	2071	1873	1449	1489	1932	2046	1994	1663	1884	1604	1991	1786	1896	1846

Table 2.6. Summary of significant correlations at 5% level of signficance (black box) for thermal habitat and salmon abundance.

Months at sea

Stock	Data type	Apr		Jun		Aug		Oct		Dec		Feb		Apr		Jun		Aug		Oct		Dec		Feb		Apr		Jun	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Total North America	2SW recruits	■	■	■		▒				■	■	■	■	■	■			▒	▒		■	■	■	■	■	■	■	■	
Labrador	2SW recruits	■	■	■		▒				■	■	■	■	■	■			▒	▒		■	■	■	■	■	■	■	■	
Newfoundland	2SW recruits	■	■	■		▒	▒			■	■	■	■	■	■			▒	▒	▒		■	■	■	■	■	■	■	
Total North America	1SW recruits	■	■	■		▒	▒			■	■	■	■	■	■	■													
Labrador	1SW recruits	■	■	■		▒			■			■	■	■	■	■													
Newfoundland	1SW recruits					▒	▒			■						■													
Western Arm Brook	1SW survival	■	■	■						■	■	■	■	■	■	■							NO DATA						
Northeast Trepassey	Small survival					▒	▒					■	■	■															
Conne River	1SW survival																												
Middle Brook	Small recruits	■	■	■		▒						■	■		■														
Gander River	Small recruits	■	■			▒				■		■	■	■	■	■													
Exploits River	Small recruits																												
Biscay Bay River	Small recruits				▒	▒																							
Conne River	1SW recruits	■	■			▒				■	■	■																	
Humber River	1SW recruits																												
Lomond River	Small recruits																												
Torrent River	Small recruits																												
Western Arm Brook	Small recruits	■	■	■							■	■		■	■	■													

■ +ve correlation

▒ -ve correlation

Table 2.7. Correlation analysis for inshore SSTs from six sites around Newfoundland, 1984-96. Values in the table are the Spearman correlation coefficients, the probability level, and the number of observations. Site 1 is Bay d'Espoir, 2 – Trepassey, 3 – Bonavista Bay, 4 – Humber, 5 – Bay St. George, and 6 – near Western Arm Brook.

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Site 1	1.00000 0.0 13	0.52747 0.0640 13	0.25824 0.3943 13	0.46364 0.1509 11	0.46154 0.1124 13	0.46703 0.1076 13
Site 2	0.52747 0.0640 13	1.00000 0.0 13	0.63187 0.0205 13	0.11818 0.7293 11	0.29670 0.3249 13	0.13187 0.6676 13
Site 3	0.25824 0.3943 13	0.63187 0.0205 13	1.00000 0.0 13	-0.13636 0.6893 11	0.04396 0.8866 13	0.04945 0.8725 13
Site 4	0.46364 0.1509 11	0.11818 0.7293 11	-0.13636 0.6893 11	1.00000 0.0 11	0.62727 0.0388 11	0.63636 0.0353 11
Site 5	0.46154 0.1124 13	0.29670 0.3249 13	0.04396 0.8866 13	0.62727 0.0388 11	1.00000 0.0 13	0.12637 0.6808 13
Site 6	0.46703 0.1076 13	0.13187 0.6676 13	0.04945 0.8725 13	0.63636 0.0353 11	0.12637 0.6808 13	1.00000 0.0 13

Table 3.1. Number of stomach content examinations for Atlantic cod sampled during Sentinel Surveys in southern Labrador and on the east and northeast coasts of Newfoundland (NAFO Divisions 2J, 3K, 3L) in 1995-1996.

Year	NAFO	Community	Jan-Mar	April	May	June	July	Aug-Dec	Total
1995	2J	Triangle	0	0	0	0	0	13	13
		Williams Hr.	0	0	0	0	0	4	4
	3K	Great Brehat	0	0	0	0	0	17	17
		Conche	0	0	0	0	0	12	12
		La Scie	0	0	0	0	0	34	34
		Shoe Cove	0	0	0	0	0	24	24
	3L	Lumsden	0	0	0	0	0	21	21
		Eastport	0	0	0	0	0	6	6
		Bonavista	0	0	0	0	0	12	12
		Little Catalina	0	0	0	0	0	15	15
		Foxtrap	0	0	0	0	0	35	35
		Petty Harbour	0	0	0	0	0	6	6
		Calvert	0	0	0	0	0	16	16
		Admirals Beach	0	0	0	0	0	23	23
		Total	0	0	0	0	0	238	238
1996	2J	Triangle	0	0	0	0	0	20	20
	3K	Conche	0	0	0	0	23	24	47
		LaScie	0	0	0	0	35	91	126
	3L	Eastport	0	0	0	0	60	18	78
		Little Catalina	0	0	0	19	40	63	122
		Hopeall	0	0	0	37	0	0	37
		Petty Harbour	0	0	0	0	21	36	57
		Aquafort	0	0	0	0	7	89	96
		Admirals Beach	0	0	0	0	54	96	150
		Total	0	0	0	56	240	437	733

Table 3.2. Number of stomach content examinations for Atlantic cod sampled during Sentinel Surveys on the south coast of Newfoundland (NAFO sub-Division 3Ps) in 1995-1996.

Year	NAFO	Community	Jan-Mar	April	May	June	July	Aug-Dec
1995	3Ps	Ramea	59	107	98	36	0	74
	3Ps	Francois	38	50	65	14	0	84
	3Ps	Seal Cove	50	45	52	46	0	104
	3Ps	Harbour Breton	15	37	63	87	22	171
	3Ps	Rencontre East	39	14	0	11	0	141
	3Ps	Lords Cove	0	0	0	0	0	50
	3Ps	Red Harbour	0	0	0	0	0	59
	3Ps	Monkstown	3	19	76	26	12	34
	3Ps	North Harbour	49	0	36	23	31	123
	3Ps	Arnolds Cove	1	0	12	6	0	10
	3Ps	Little Harbour	7	0	73	69	0	108
	3Ps	Fox Harbour	0	0	4	32	31	0
	3Ps	Placentia	0	0	0	0	0	75
	3Ps	St. Brides	0	0	2	26	16	10
		Total	261	272	481	376	112	1043
1996	3Ps	Ramea	0	0	0	0	0	152
	3Ps	Harbour Breton	0	0	0	0	0	74
	3Ps	Rencontre East	57	0	0	0	0	135
	3Ps	North Harbour	144	0	0	0	0	92
	3Ps	Little Harbour	0	0	0	0	74	41
	3Ps	St. Brides	0	0	0	0	34	39
		Total	201	0	0	0	108	533

Table 3.2. Number of stomach content examinations for Atlantic cod sampled during Sentinel Surveys on the south coast of Newfoundland (NAFO sub-Division 3Ps) in 1995-1996.

Year	NAFO	Community	Jan-Mar	April	May	June	July	Aug-Dec	Total
1995	3Ps	Ramea	59	107	98	36	0	74	374
	3Ps	Francois	38	50	65	14	0	84	251
	3Ps	Seal Cove	50	45	52	46	0	104	297
	3Ps	Harbour Breton	15	37	63	87	22	171	395
	3Ps	Rencontre East	39	14	0	11	0	141	205
	3Ps	Lords Cove	0	0	0	0	0	50	50
	3Ps	Red Harbour	0	0	0	0	0	59	59
	3Ps	Monkstown	3	19	76	26	12	34	170
	3Ps	North Harbour	49	0	36	23	31	123	262
	3Ps	Arnolds Cove	1	0	12	6	0	10	29
	3Ps	Little Harbour	7	0	73	69	0	108	257
	3Ps	Fox Harbour	0	0	4	32	31	0	67
	3Ps	Placentia	0	0	0	0	0	75	75
	3Ps	St. Brides	0	0	2	26	16	10	54
		Total	261	272	481	376	112	1043	2545
1996	3Ps	Ramea	0	0	0	0	0	152	152
	3Ps	Harbour Breton	0	0	0	0	0	74	74
	3Ps	Rencontre East	57	0	0	0	0	135	192
	3Ps	North Harbour	144	0	0	0	0	92	236
	3Ps	Little Harbour	0	0	0	0	74	41	115
	3Ps	St. Brides	0	0	0	0	34	39	73
		Total	201	0	0	0	108	533	842

Table 3.3. Number of stomach content examinations for Atlantic cod sampled from the shallow-water commercial fishery in southern Labrador and on the east and northeast coasts of Newfoundland from 1959 to the present. Labrador samples came from various ports.

Year	NAFO	Community	Jan-Mar	April	May	June	July	Aug-Dec	Total
1959		Labrador (var.)	0	0	0	0	117	219	336
1960		Labrador (var.)	0	0	0	0	332	59	391
1962		Labrador (var.)	0	0	0	0	207	127	334
1963		Labrador (var.)	0	0	0	0	105	296	401
1964		Labrador (var.)	0	0	0	0	61	56	117
1968		Labrador (var.)	0	0	0	0	0	194	194
	3K	LaScie	0	0	0	0	126	0	126
1971	3K	Twillingate	0	0	0	93	84	0	177
1979		Labrador (var.)	0	0	0	0	33	26	59
1982	3L	New Bonaventure	0	0	0	41	50	82	173
		Trinity	0	0	0	0	42	8	50
1983	3L	Bonavista	0	0	0	117	133	295	545
1984	3K	Twillingate	0	0	0	0	199	74	273
	3L	Bonavista	0	0	0	142	502	714	1358
		Old Perlican	0	0	0	0	73	45	118
1988	3L	St. John's	0	0	0	0	0	60	60
		Pouch Cove	0	0	0	60	60	0	120
		Petty Harbour	0	0	0	0	0	59	59
1989	3L	Pouch Cove	0	0	0	30	0	0	30
		Logy Bay	0	0	0	0	90	0	90
		Petty Harbour	0	0	0	30	30	60	120
		Total	0	0	0	513	2244	2374	5131

Table 3.4. Number of food containing stomachs of harp seals sampled in Newfoundland and Labrador from November 1978 to August 1996.

	Labrador 1980-96	**NE Coast** 1978-96	**S Coast** 1985-96	**W Coast** 1989-96	**Offshore** 1980-96	**Total**
January	14	604	1	7	43	669
February		718	19	8	121	866
March	14	653	17	41	74	799
April		533	58	67	83	741
May	15	646	116	104	74	955
June	32	135	129	44	66	406
July	10	2	36	5	14	67
August	5		1			6
September	4					4
October	19	3			3	25
November	413	34	1	1	61	510
December	450	207		1	91	749
Total	976	3535	378	278	630	5797

Table 3.5. Number of food containing stomachs of hood seals sampled in Newfoundland and Labrador prior to August 1996.

	Labrador 1989-96	**NE Coast** 1981-96	**S Coast** 1990-96	**W Coast** 1989-96	**Offshore** 1984-96	**Total**
January		44	2		10	56
February		33	9		20	62
March		51	3	1	5	60
April		116	1	2	41	160
May		12	2	1	2	17
June		3		1	1	5
July						
August						
September						
October	1					1
November	3	4			8	15
December	1	11			3	15
Total	5	274	17	5	90	391

Table 3.6. Number of food containing stomachs of ringed seals sampled in Newfoundland and Labrador prior to August 1996.

	Labrador 1986-96	NE Coast 1983-96	S Coast 1990-94	W Coast 1993	Offshore 1986-93	Total
January	54	16				70
February		23				23
March	3	32				35
April		42	3	1		46
May	6	27	2		2	37
June	13	10				23
July	42	2				44
August	42					42
September	24					24
October	37					37
November	89	3			10	102
December	161	11			8	180
Total	471	166	5	1	20	663

Table 3.7. Number of food containing stomachs of bearded seals sampled in Newfoundland and Labrador prior to August 1996.

	Labrador 1988-94	NE Coast 1979-96	S Coast	W Coast	Offshore 1992-94	Total
January		8				8
February		22				22
March		19				19
April		32			3	35
May	1	10			2	13
June	1	4				5
July	1					1
August	1					1
September						
October	2					2
November	2	1			2	5
December	5	4				9
Total	13	100	0	0	7	120

Table 3.8. Number of food containing stomachs of grey seals sampled in Newfoundland and Labrador from prior to August 1996.

	Labrador 1989-96	NE Coast 1990	S Coast 1985-96	W Coast 1991-96	Offshore 1987	Total
January						
February						
March				4		4
April			14	15		29
May			6	10		16
June			2	3		5
July	2	1	3	1		7
August	14		2			16
September	3		1			4
October						
November			1			1
December					2	2
Total	19	1	29	33	2	84

Table 3.9. Number of food containing stomachs of harbour seals sampled in Newfoundland and Labrador prior to August 1996.

	Labrador 1989-96	NE Coast 1987-95	S Coast 1985-96	W Coast 1989-96	Offshore	Total
January		2		1		3
February			2			2
March		2	1	3		6
April			5	1		6
May			5	1		6
June			4			4
July	16		3	1		20
August	10		5			15
September	4		6			10
October	2					2
November	1	1	4			6
December	1	2	1			4
Total	34	7	36	7	0	84

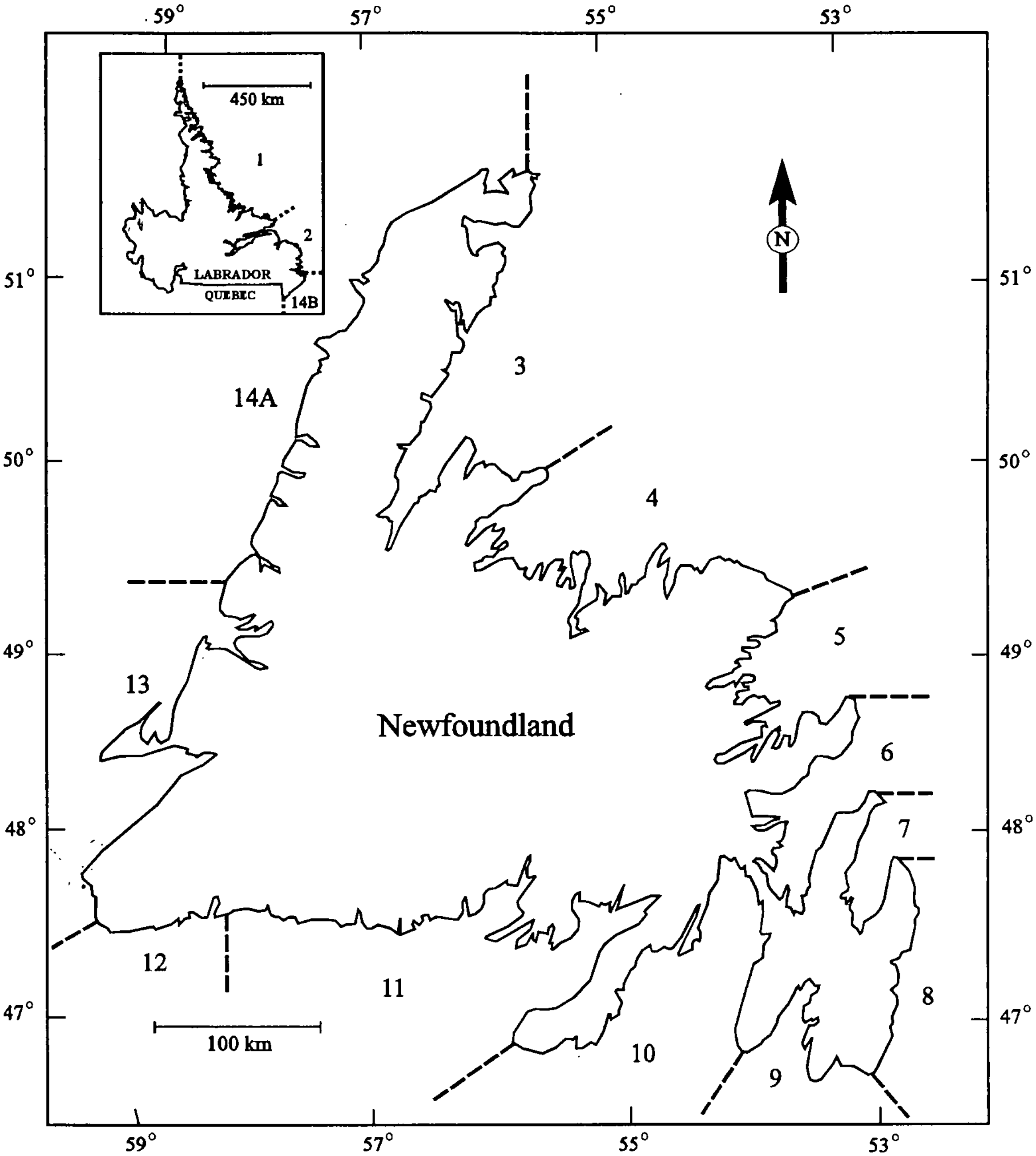


Fig. 1. Map showing the 14 Salmon Fishing Areas of the Newfoundland Region.

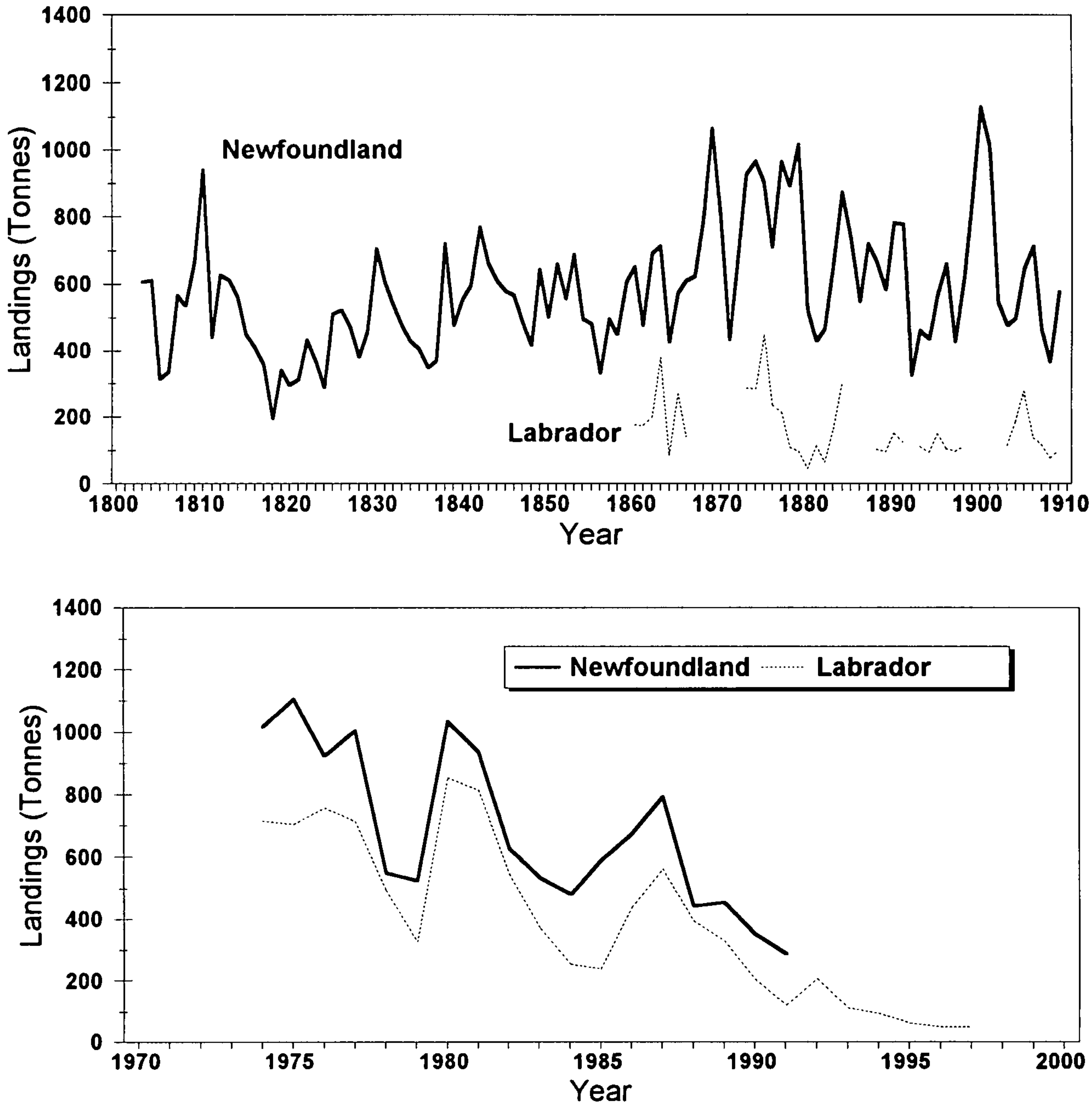


Figure 2. Historic and recent trends in Atlantic salmon abundance, Newfoundland and Labrador, derived from commercial catch statistics. Historic information obtained from Taylor (1985) and largely reflects salmon exports.

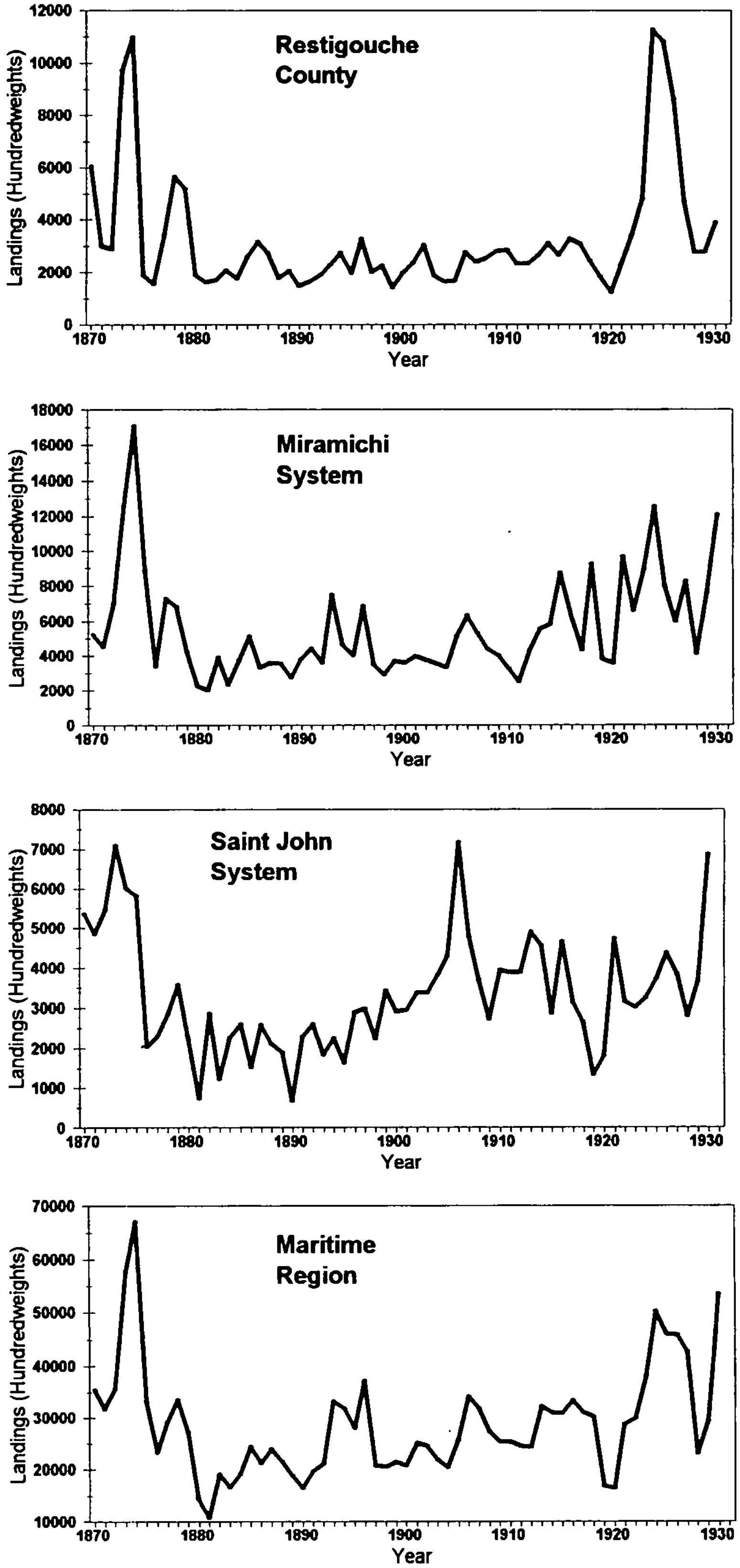


Figure 3. Trends in historic Atlantic salmon abundance, for Restigouch County, Miramichi System, Saint John System, and the Maritime Region 1870 - 1930. Data obtained from Huntsman (1931).

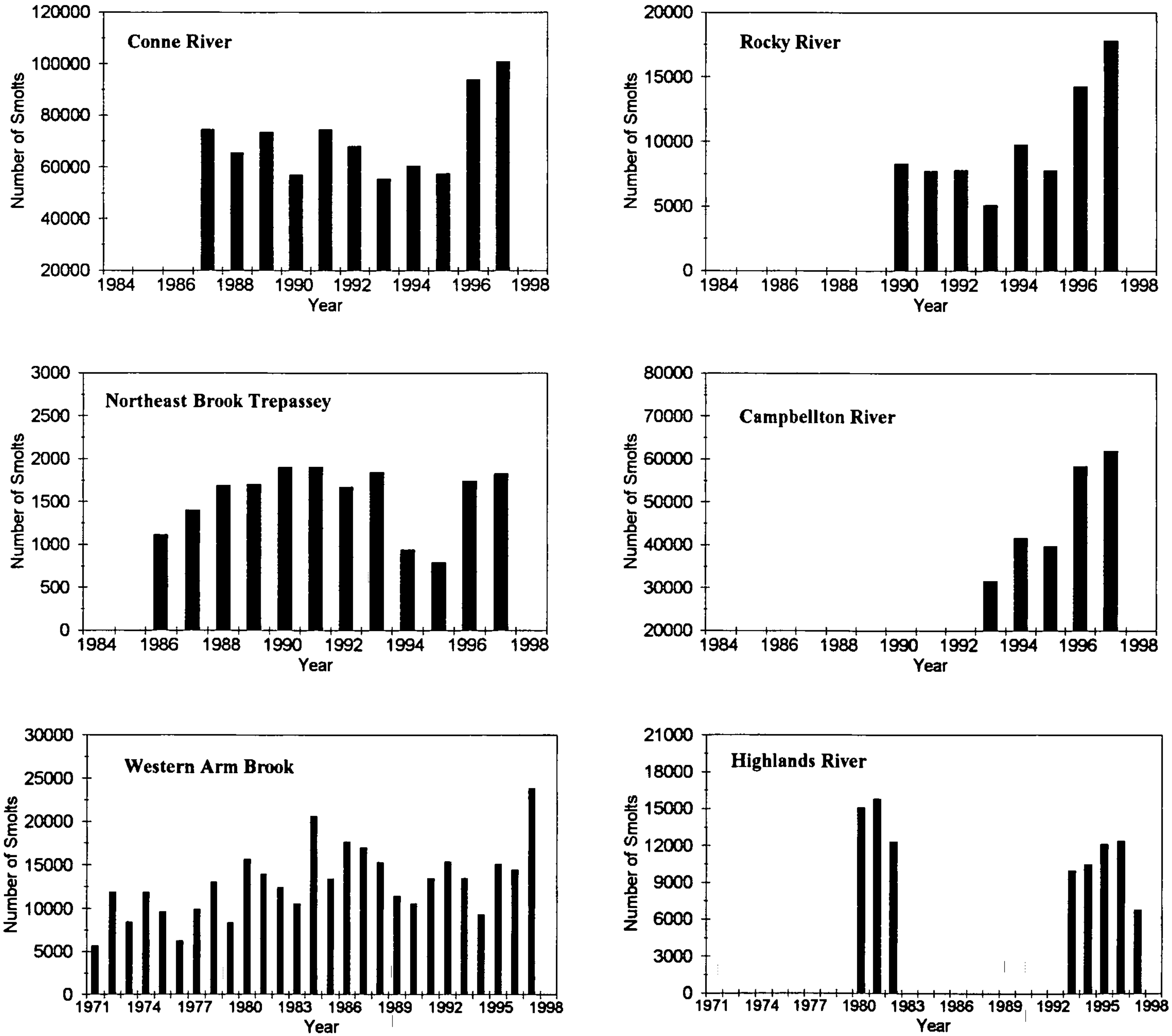


Figure 4. Atlantic salmon smolt production from various Newfoundland rivers.

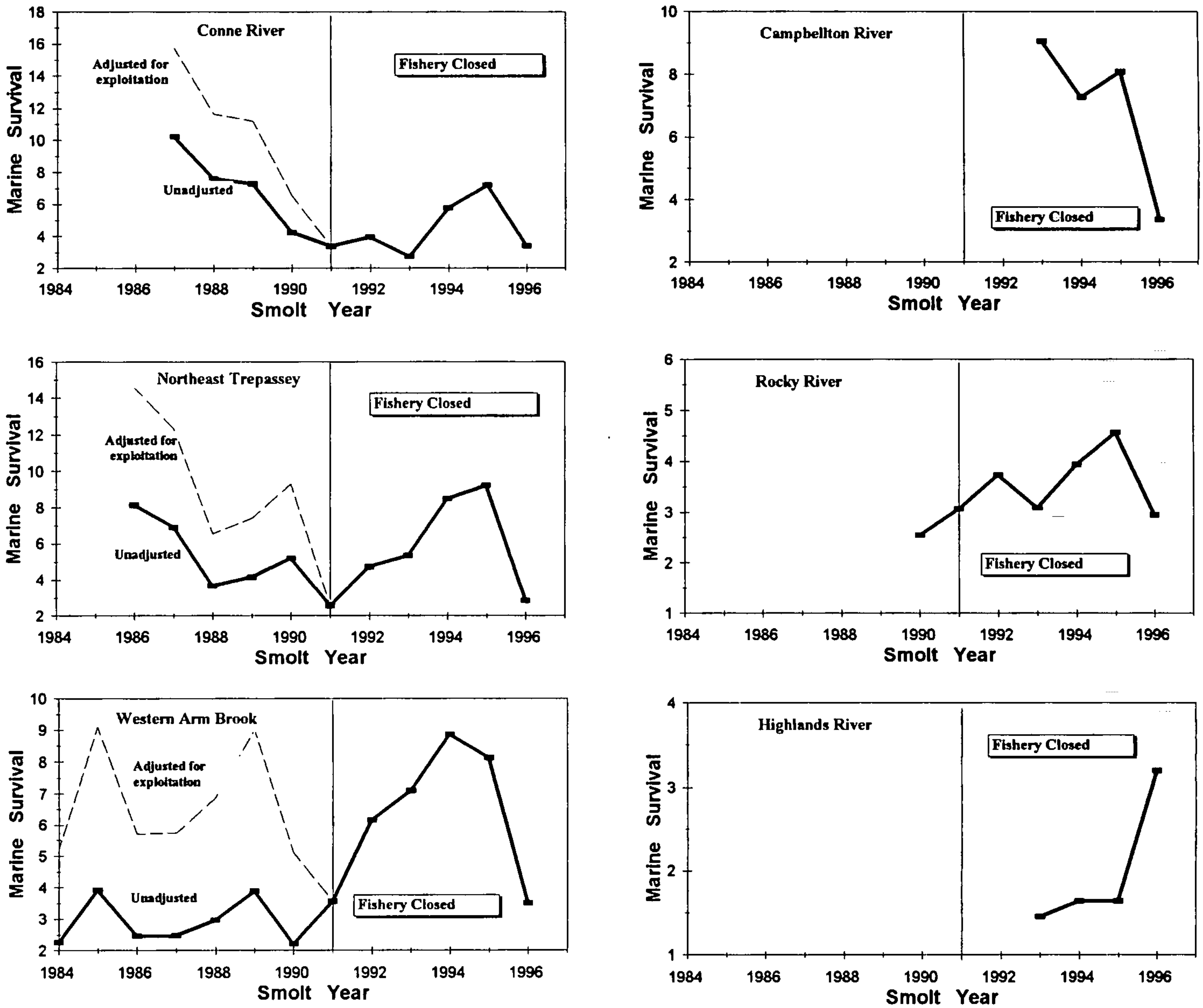


Figure 5. Estimates of marine survival from smolts in year i to adult small salmon in year i+1. Dashed line represents the marine survival adjusted for average marine exploitation rate. Exploitation rates used were 35% for Conne River (lower 95% confidence interval from data in Table 2); 44% for Northeast Brook (overall mean value from Table 2); and 56.8% for Western Arm Brook (calculated value from Table 2).

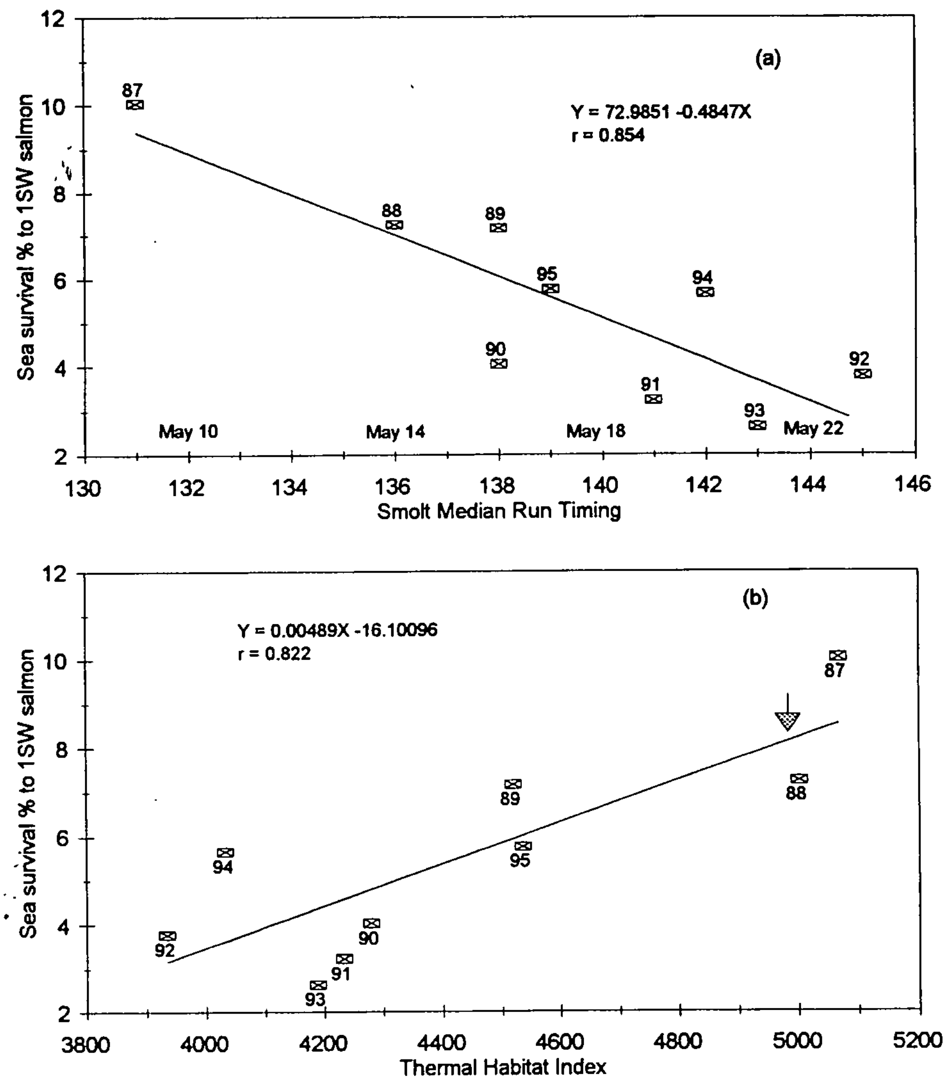


Figure 6. Relationships between (a) median timing of the Conne River smolt run in year i with surival to 1SW salmon in year i+1; and (b) index of marine thermal habitat in year i (January - March) with sea survival to 1SW salmon returning in the same year. Years shown represent the smolt year class. Arrow indicates respective value of corresponding 1997 thermal habitat. Smolt run timing in 1996 was day 124.

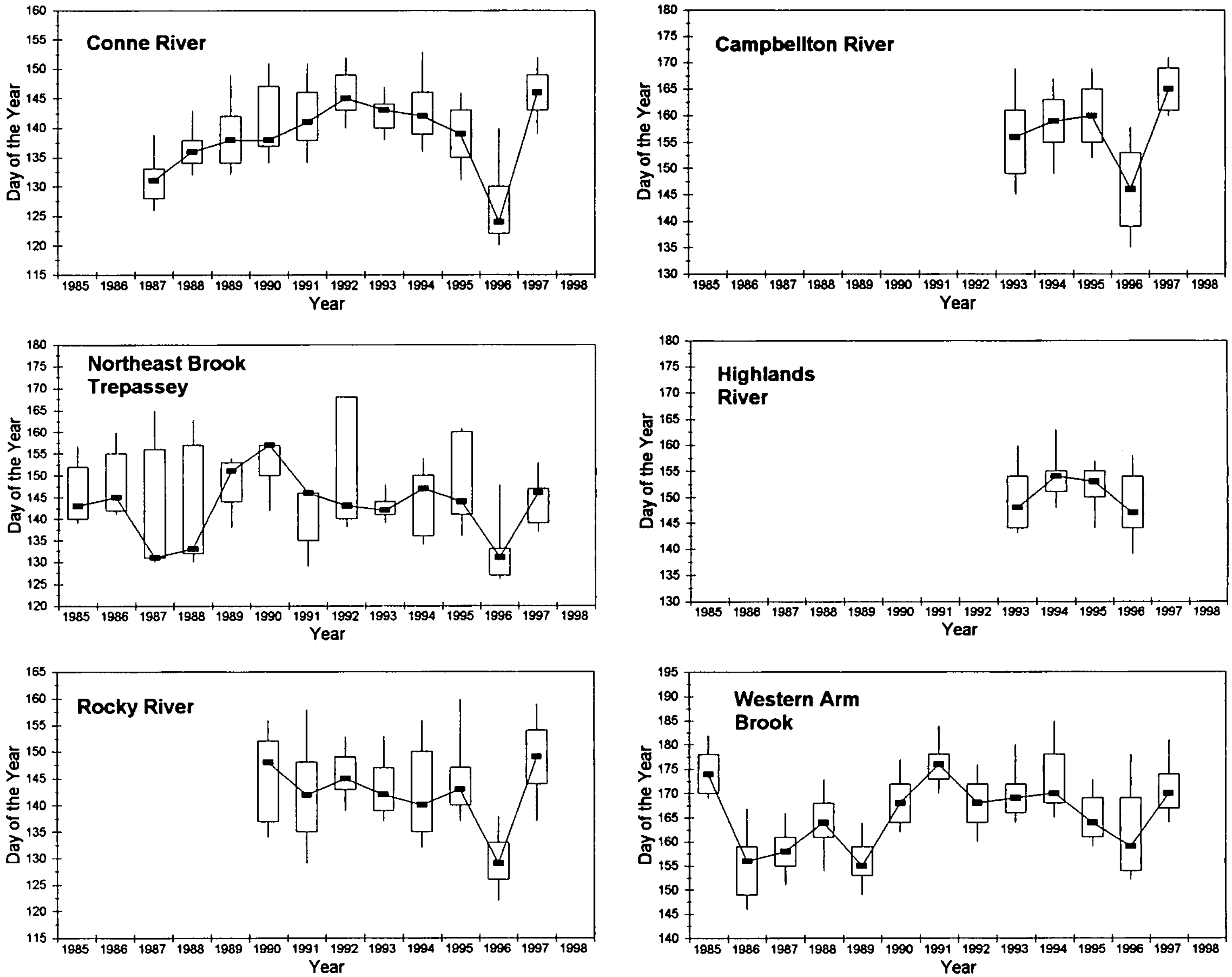


Figure 7. Annual variation in Atlantic salmon smolt run timing from various Newfoundland rivers. Vertical lines represent the 10th and 90th percentiles of the day of the year of the migration, the rectangle is the 25th and 75th percentiles, and the marker within the rectangle is the median run timing value.

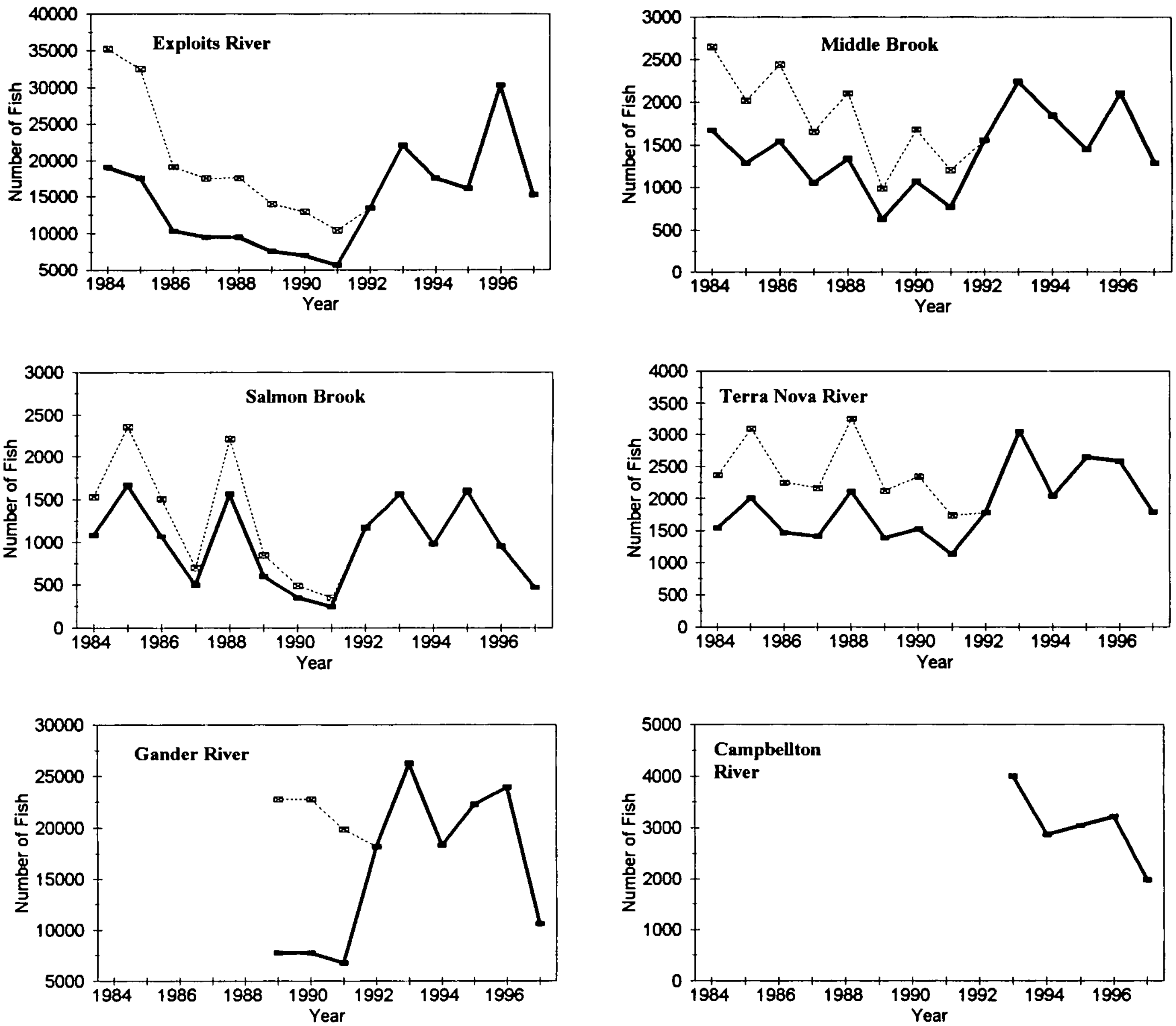


Figure 8. Estimated total returns of small Atlantic salmon to Northeast and East coast Newfoundland rivers, 1984-1997. Dashed lines represent stock size adjusted for marine exploitation.

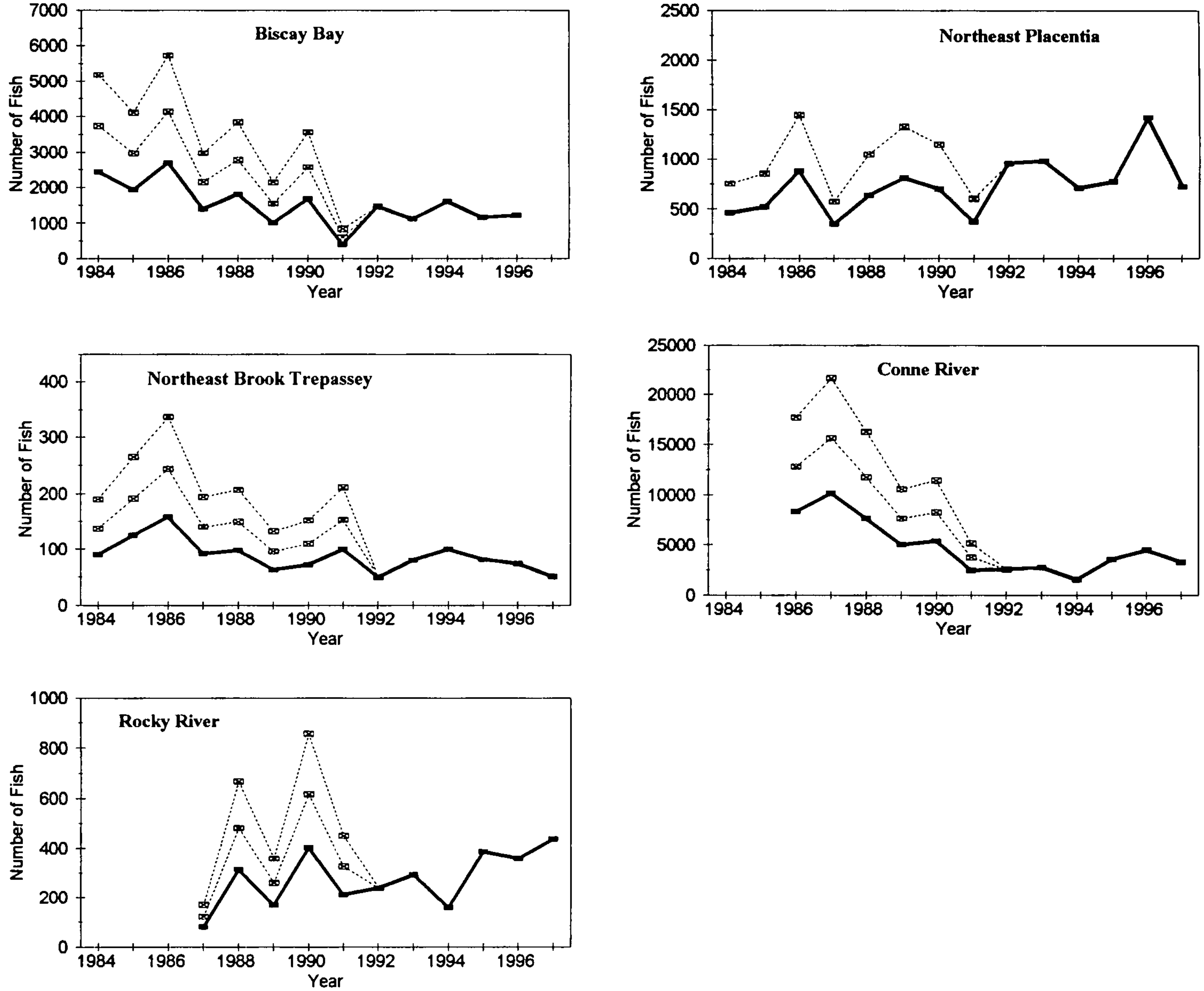


Figure 9. Estimated total returns of small Atlantic salmon to South coast Newfoundland rivers, 1984-1997. Dashed lines represent stock size adjusted for marine exploitation, here showing the upper and lower confidence intervals derived from the mean exploitation on other stocks except for Northeast Placentia River which uses its own respective value.

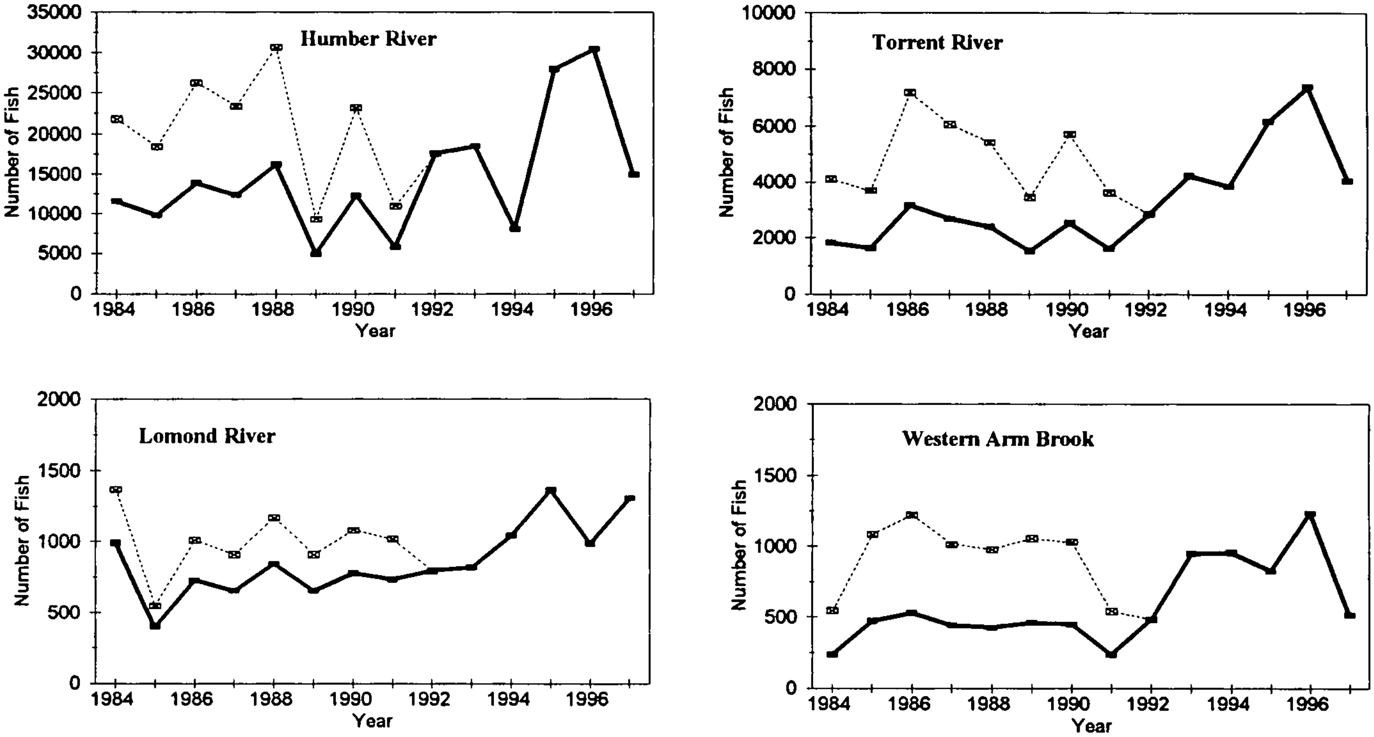


Figure 10. Estimated total returns of small Atlantic salmon to West and Northwest coast Newfoundland rivers, 1984-1997. Dashed lines represent stock size adjusted for marine exploitation.

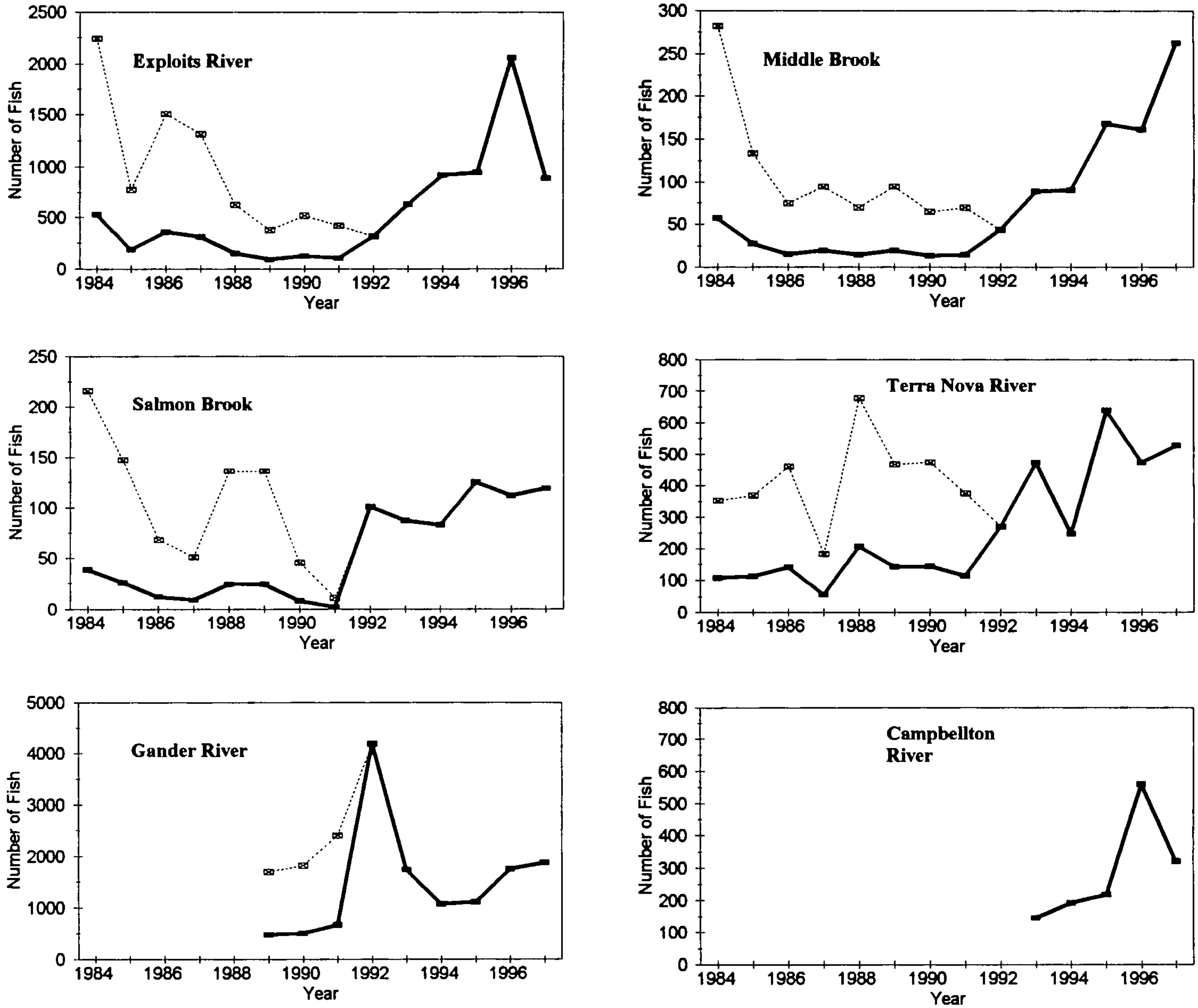


Figure 11. Estimated total returns of large Atlantic salmon to Northeast and East coast Newfoundland rivers, 1984-1997. Dashed lines represent stock size adjusted for marine exploitation.

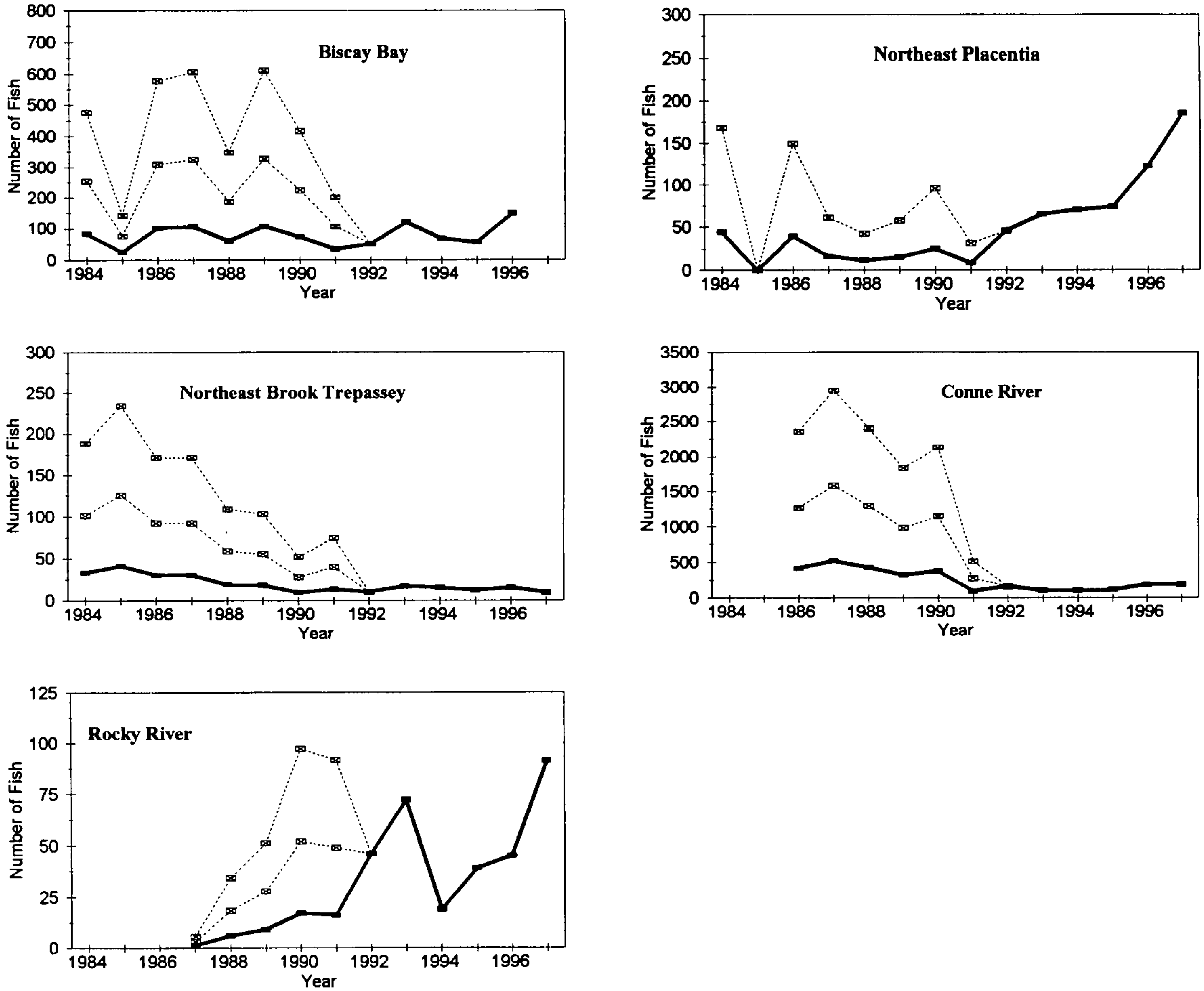


Figure 12. Estimated total returns of large Atlantic salmon to South coast Newfoundland rivers, 1984-1997. Dashed lines represent stock size adjusted for marine exploitation, here showing the upper and lower confidence intervals derived from the mean exploitation on other stocks except for Northeast Placentia River which uses its own respective value.

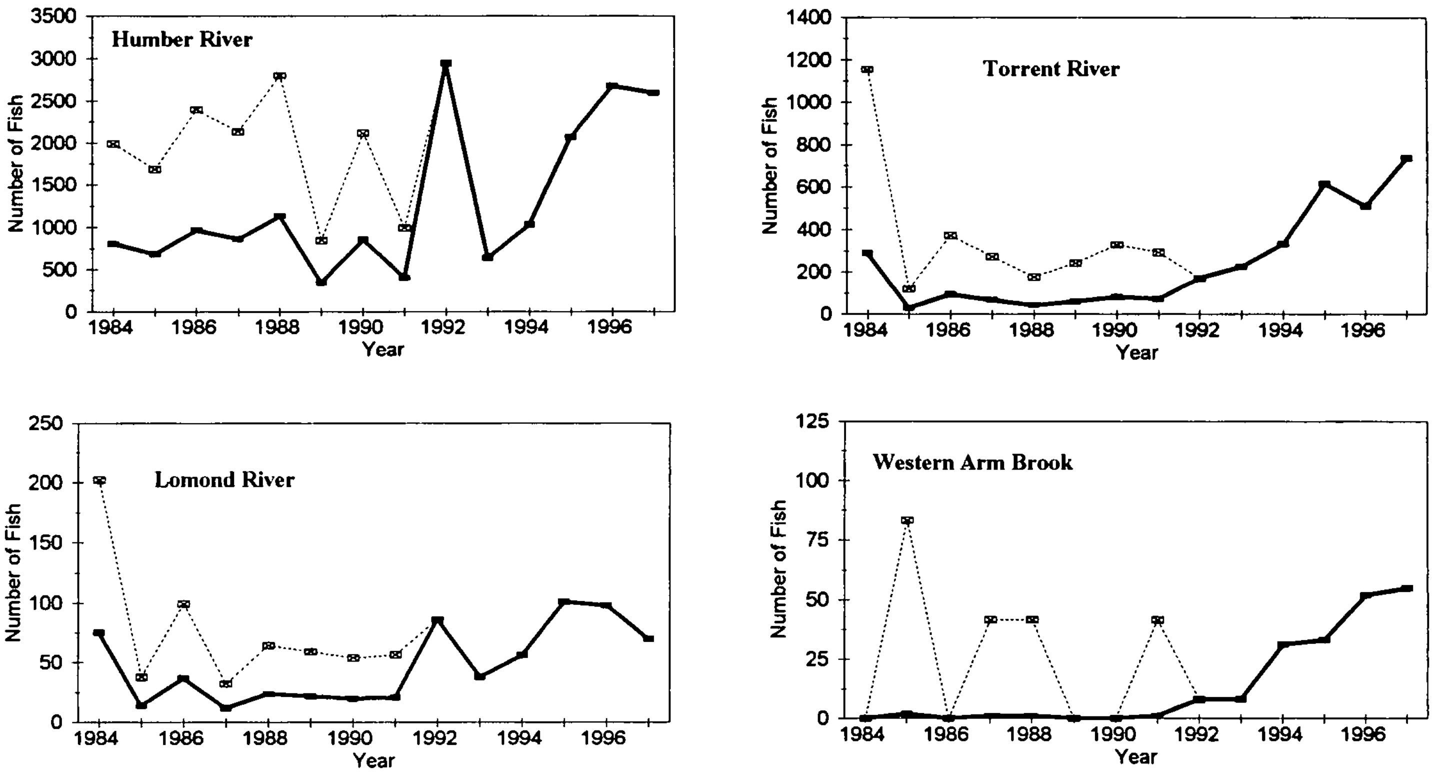


Figure 13. Estimated returns of large Atlantic salmon to West and Northwest coast Newfoundland rivers, 1984-1997. Dashed lines represent stock size adjusted for marine exploitation.

Fig. 1.1. The percent of 1SW and 2SW salmon harvested in the Labrador commercial fishery compared to the total number of North American salmon. Data are from Anon. 1997, Tables 4.5.1 and 4.5.2.

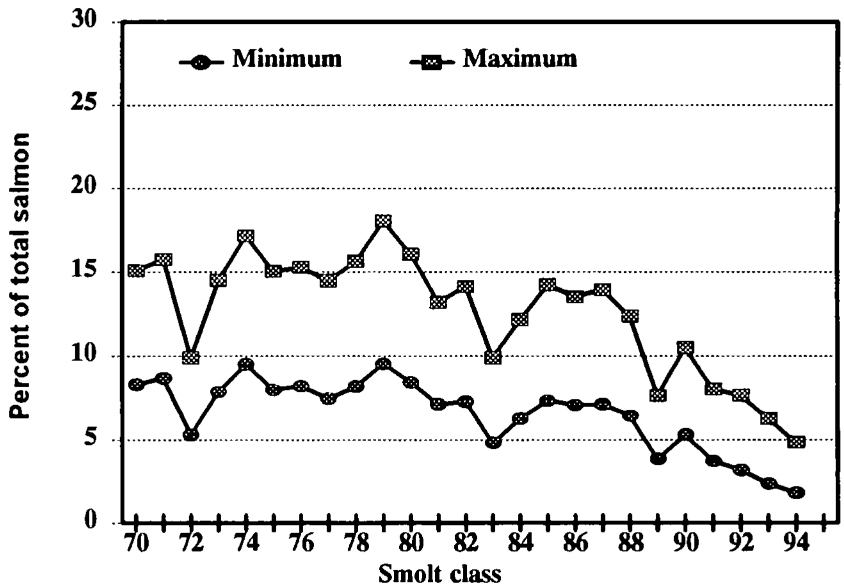
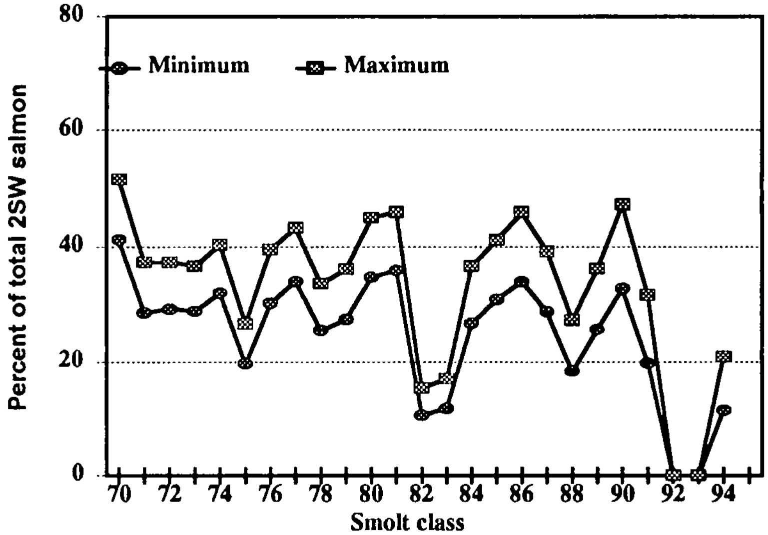


Fig. 1.2. The percent of 2SW salmon harvested at Greenland compared to the number of North American 2SW salmon.



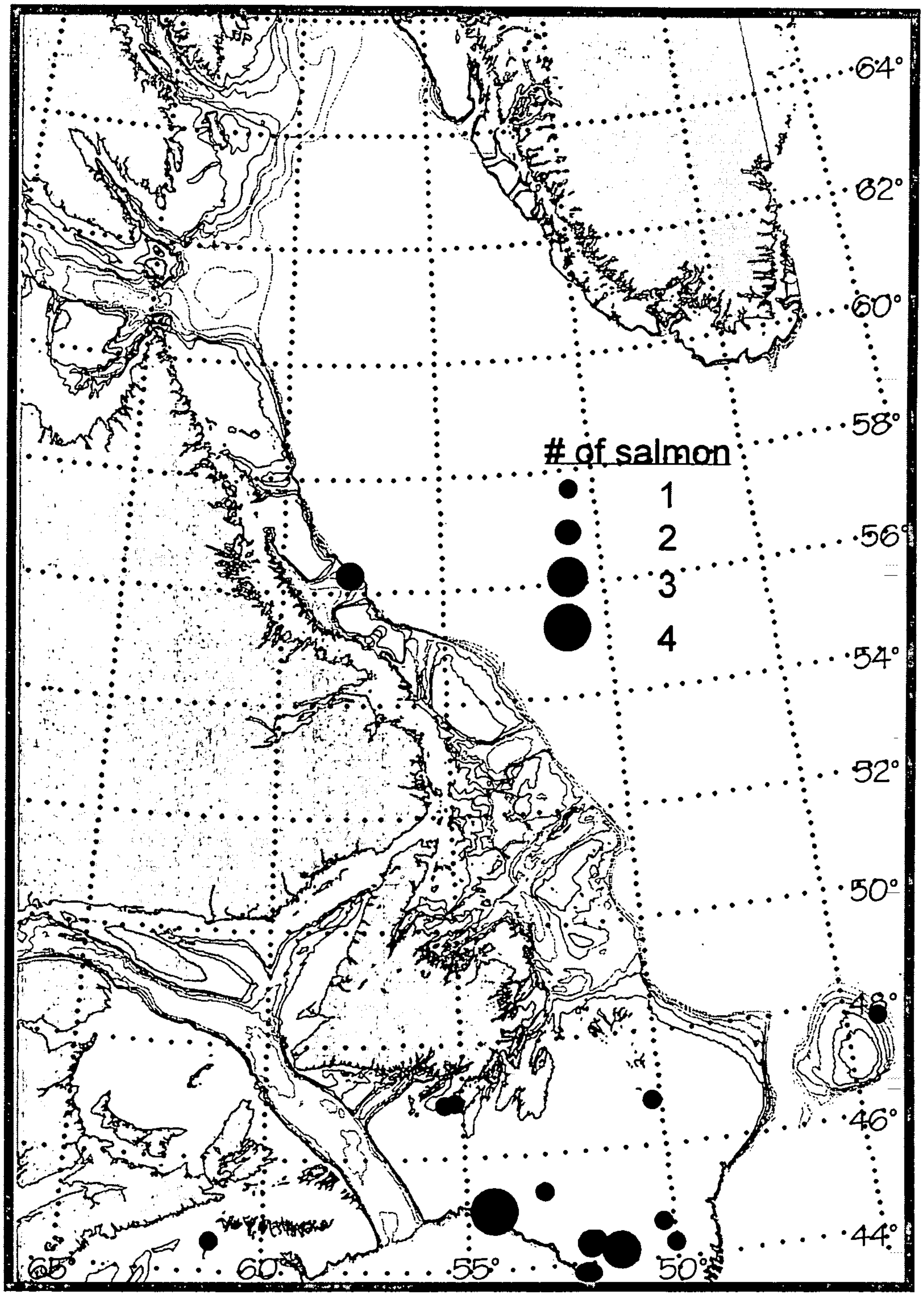


Fig. 1.3. Positional records of salmon taken as bycatch in the observed offshore fisheries.

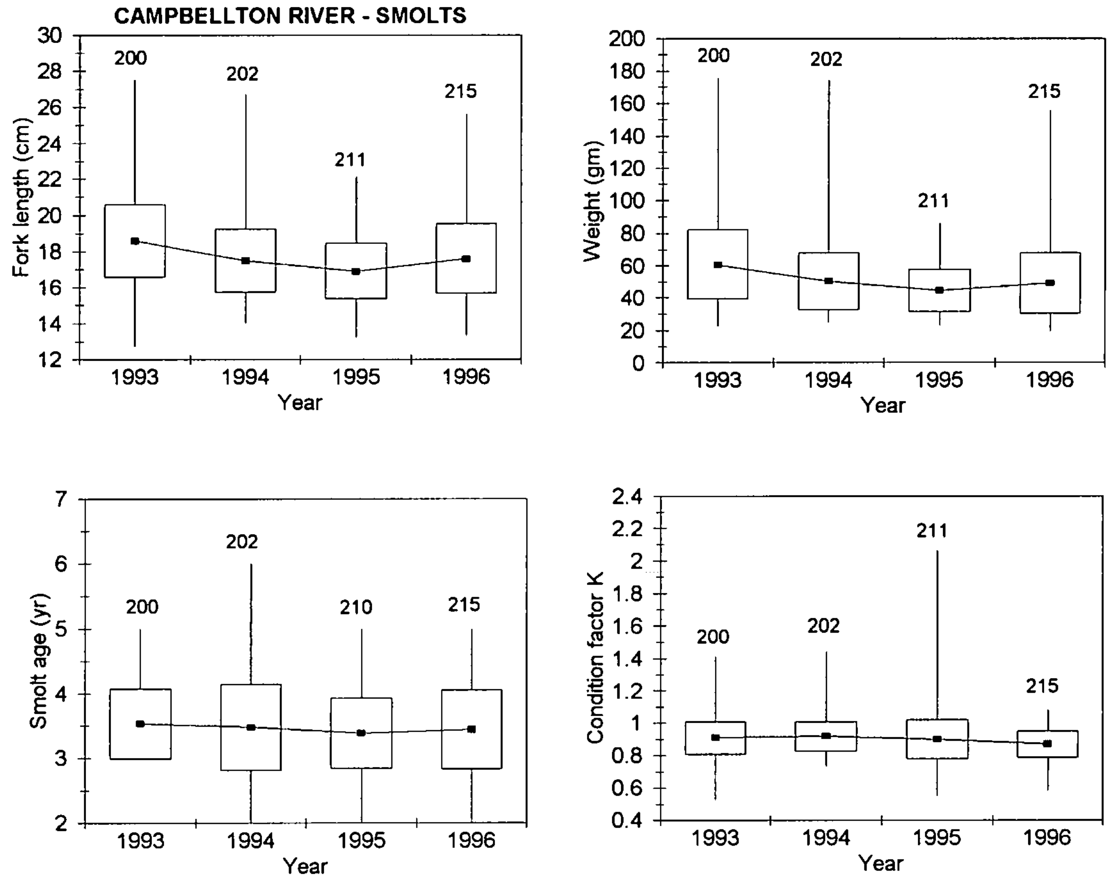


Fig. 2.1. Mean fork length, mean weight, mean smolt age, and mean condition factor for smolts from Campbellton River, 1993-96. The rectangle around each point denotes the standard deviation; the vertical line is the range; the number above the vertical line is the sample size.

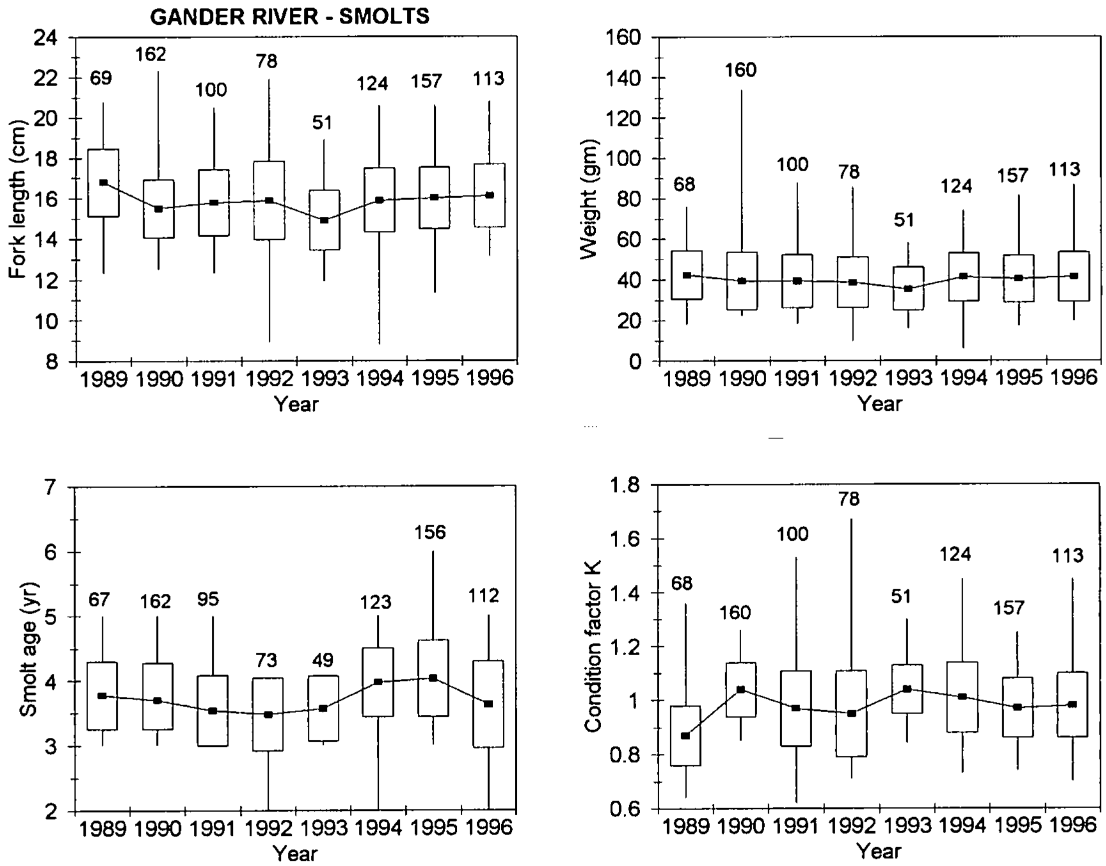


Fig. 2.2. Mean fork length, mean weight, mean smolt age, and mean condition factor for smolts from Gander River, 1989-96. The rectangle around each point denotes the standard deviation; the vertical line is the range; the number above the vertical line is the sample size.

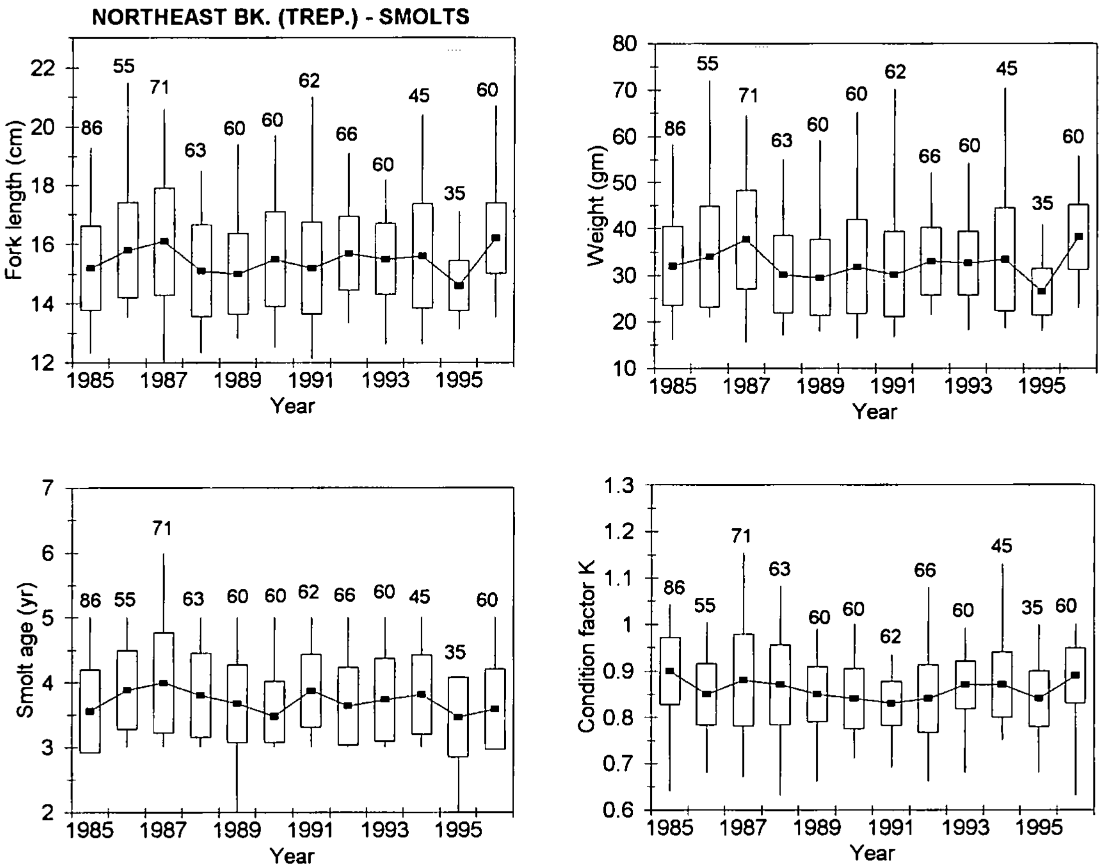


Fig. 2.3. Mean fork length, mean weight, mean smolt age, and mean condition factor for smolts from Northeast Brook (Trepassey), 1985-96. The rectangle around each point denotes the standard deviation; the vertical line is the range; the number above the vertical line is the sample size.

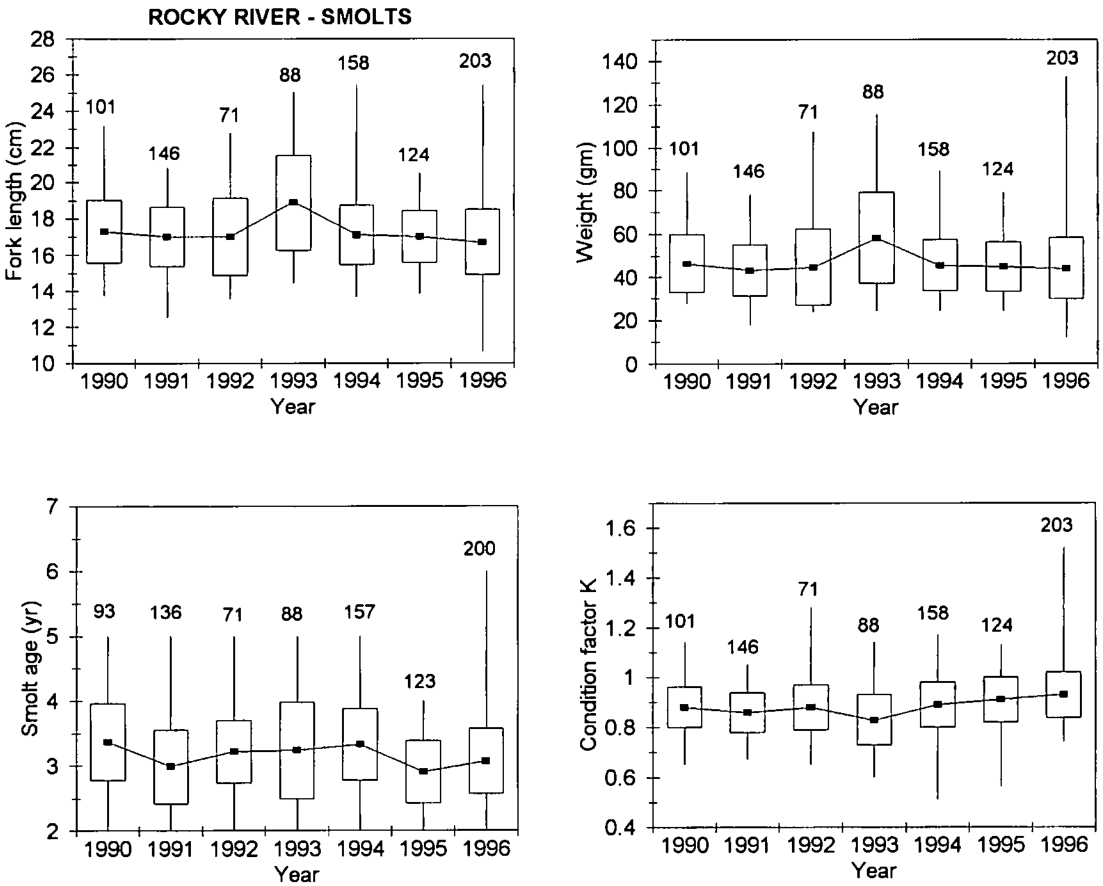


Fig. 2.4. Mean fork length, mean weight, mean smolt age, and mean condition factor for smolts from Rocky River, 1990-96. The rectangle around each point denotes the standard deviation; the vertical line is the range; the number above the vertical line is the sample size.

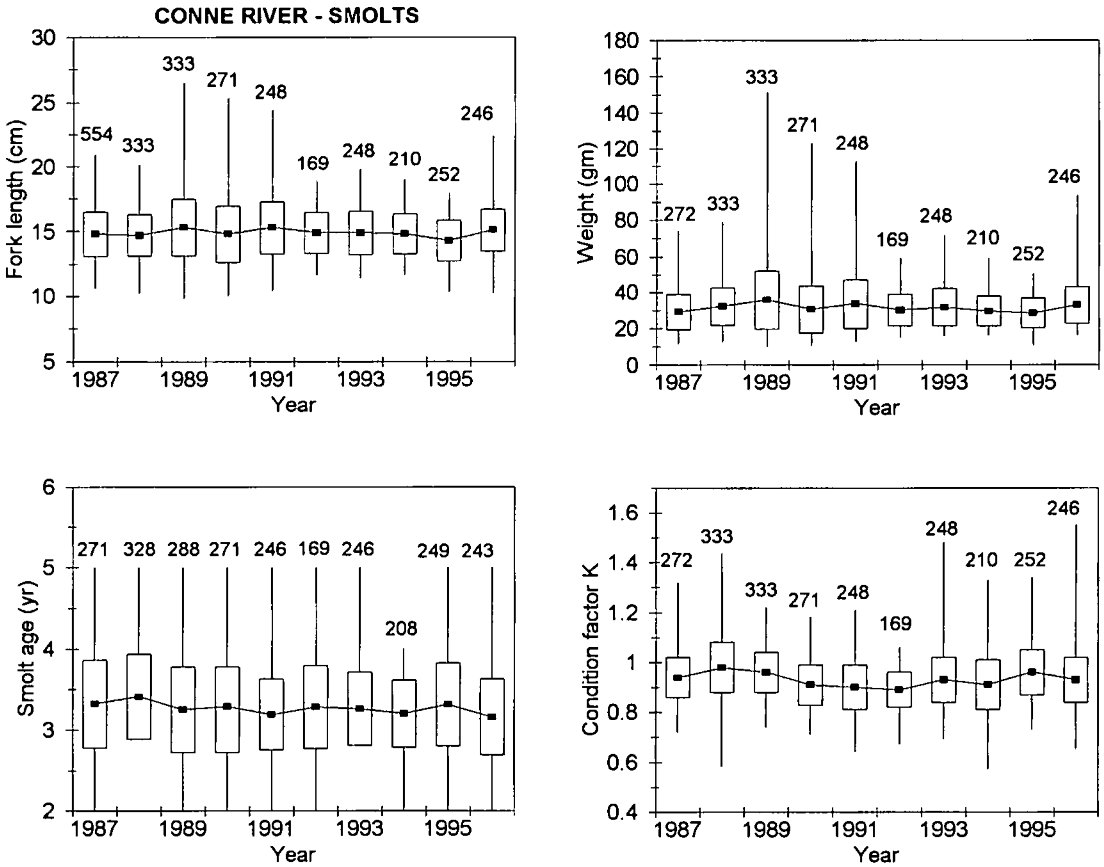


Fig. 2.5. Mean fork length, mean weight, mean smolt age, and mean condition factor for smolts from Conne River, 1987-96. The rectangle around each point denotes the standard deviation; the vertical line is the range; the number above the vertical line is the sample size.

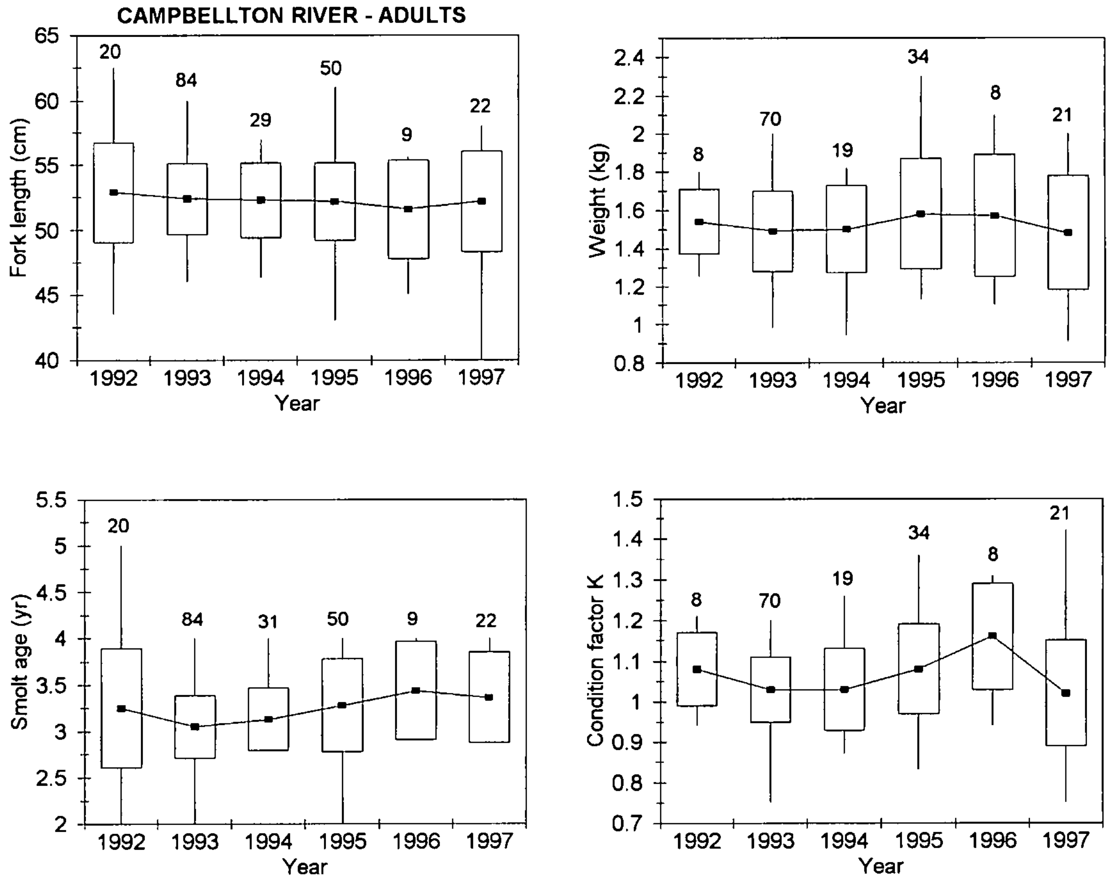


Fig. 2.6. Mean fork length, mean weight, mean smolt age, and mean condition factor for virgin grilse from Campbellton River, 1992-97. The rectangle around each point denotes the standard deviation; the vertical line is the range; the number above the vertical line is the sample size.

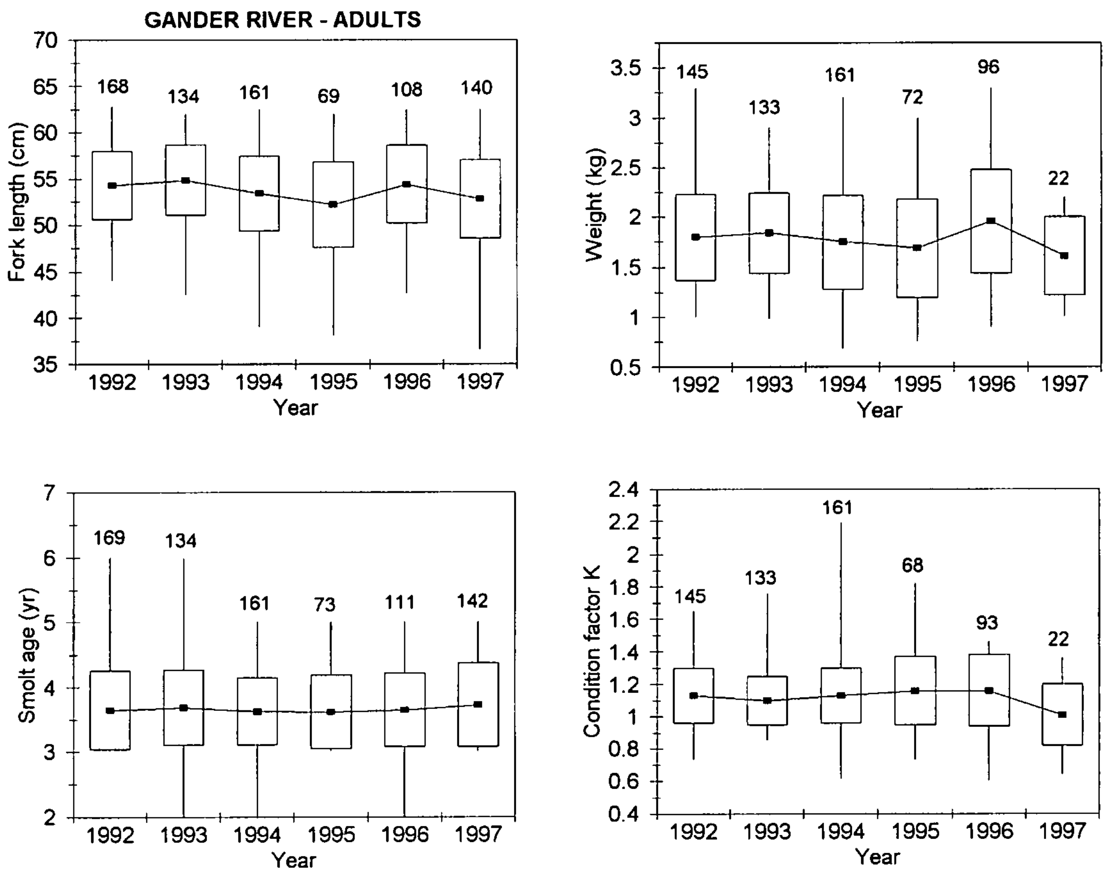


Fig. 2.7. Mean fork length, mean weight, mean smolt age, and mean condition factor for virgin grilse from Gander River, 1992-97. The rectangle around each point denotes the standard deviation; the vertical line is the range; the number above the vertical line is the sample size.

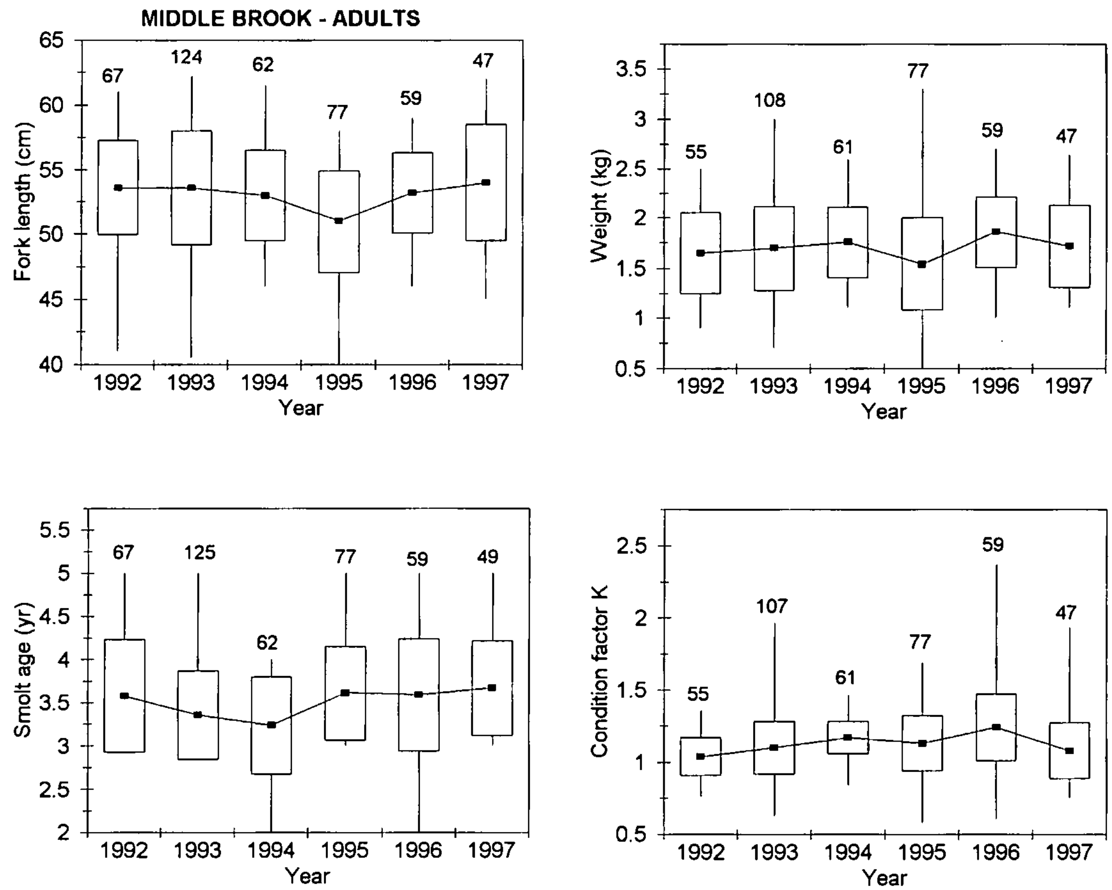


Fig. 2.8. Mean fork length, mean weight, mean smolt age, and mean condition factor for virgin grilse from Middle Brook, 1992-97. The rectangle around each point denotes the standard deviation; the vertical line is the range; the number above the vertical line is the sample size.

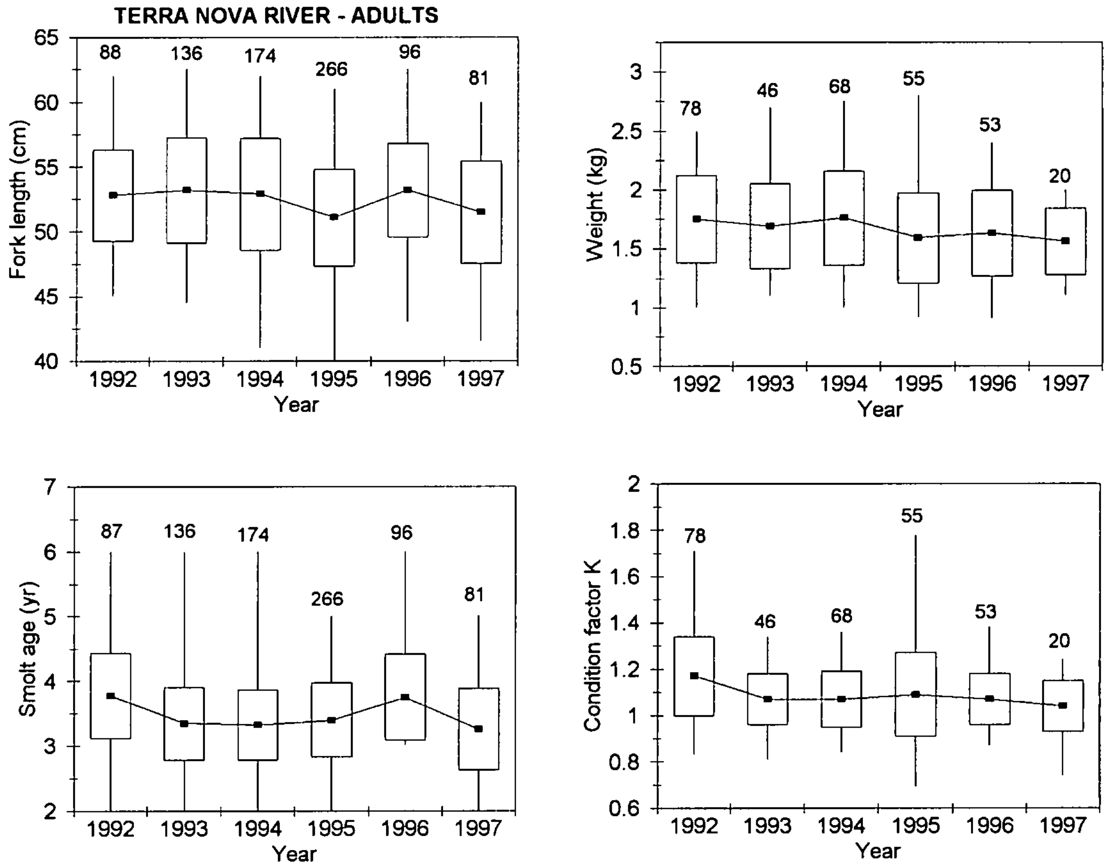


Fig. 2.9. Mean fork length, mean weight, mean smolt age, and mean condition factor for virgin grilse from Terra Nova River, 1992-97. The rectangle around each point denotes the standard deviation; the vertical line is the range; the number above the vertical line is the sample size.

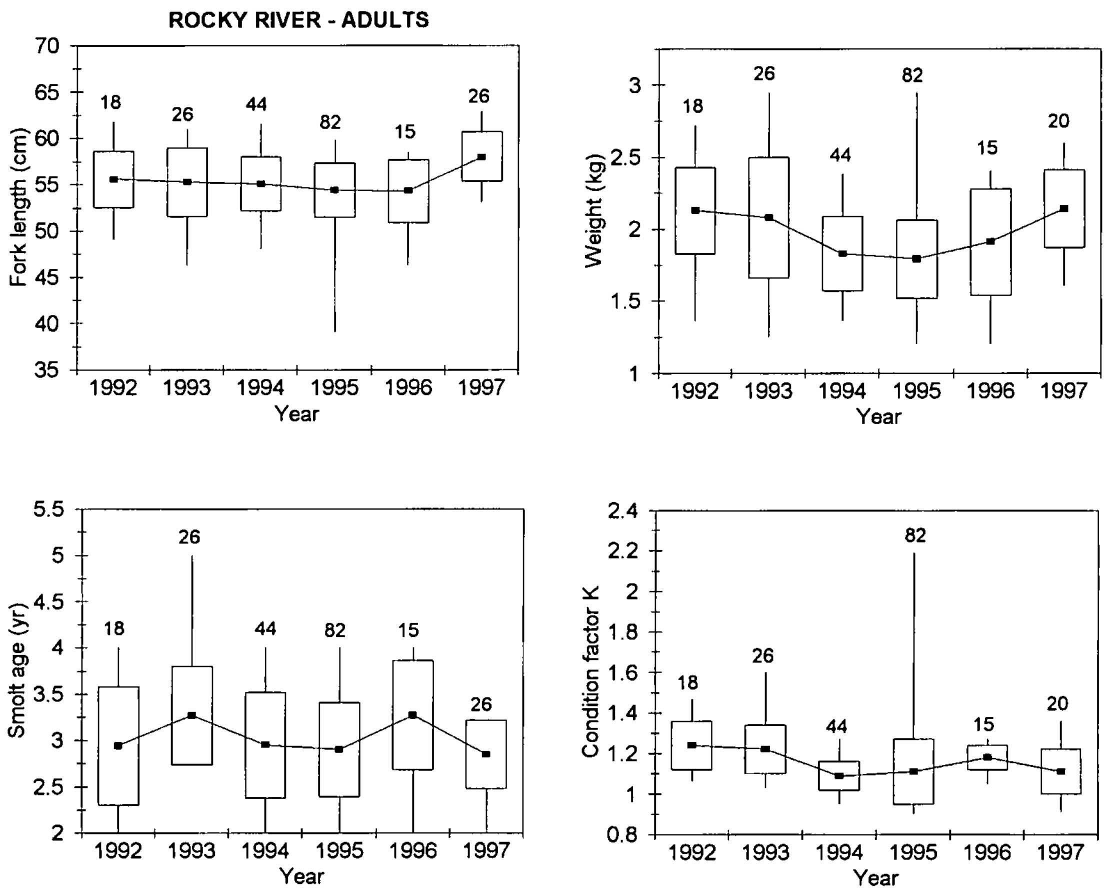


Fig. 2.10. Mean fork length, mean weight, mean smolt age, and mean condition factor for virgin grilse from Rocky River, 1992-97. The rectangle around each point denotes the standard deviation; the vertical line is the range; the number above the vertical line is the sample size.

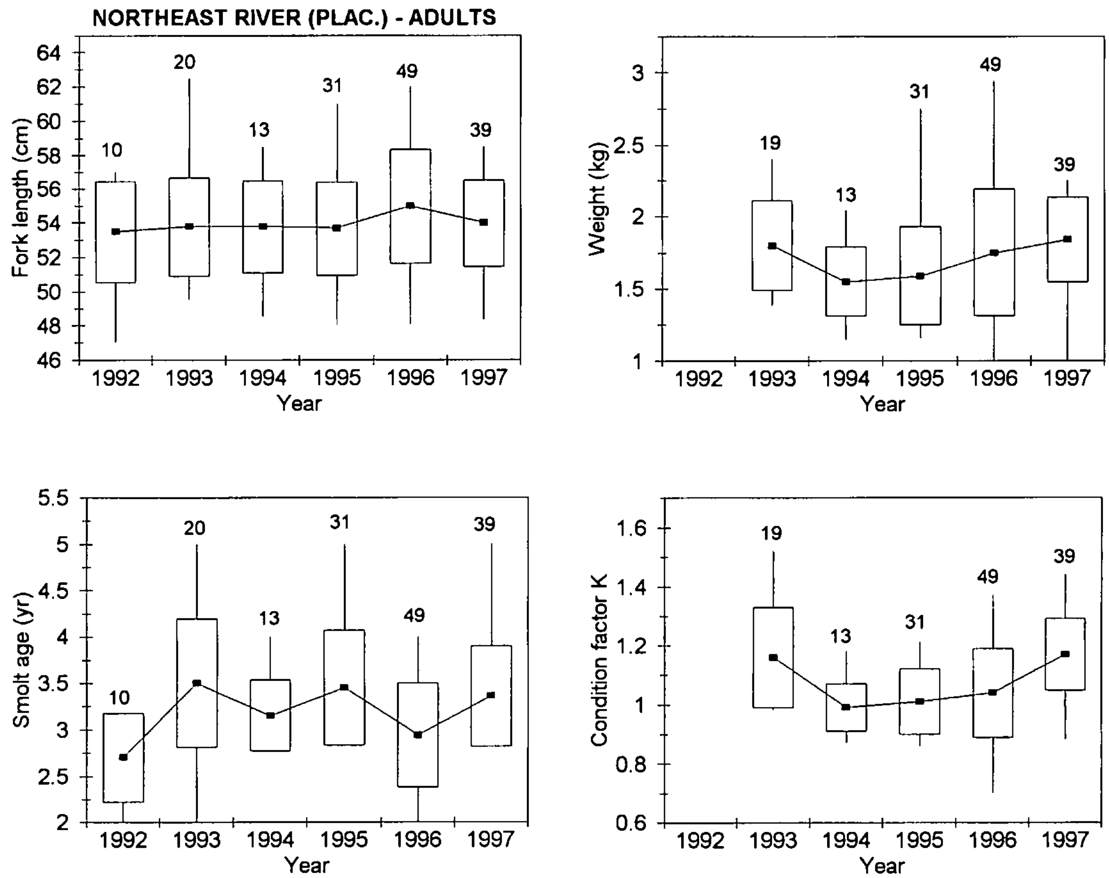


Fig. 2.11. Mean fork length, mean weight, mean smolt age, and mean condition factor for virgin grilse from Northeast River (Placentia), 1992-97. The rectangle around each point denotes the standard deviation; the vertical line is the range; the number above the vertical line is the sample size.

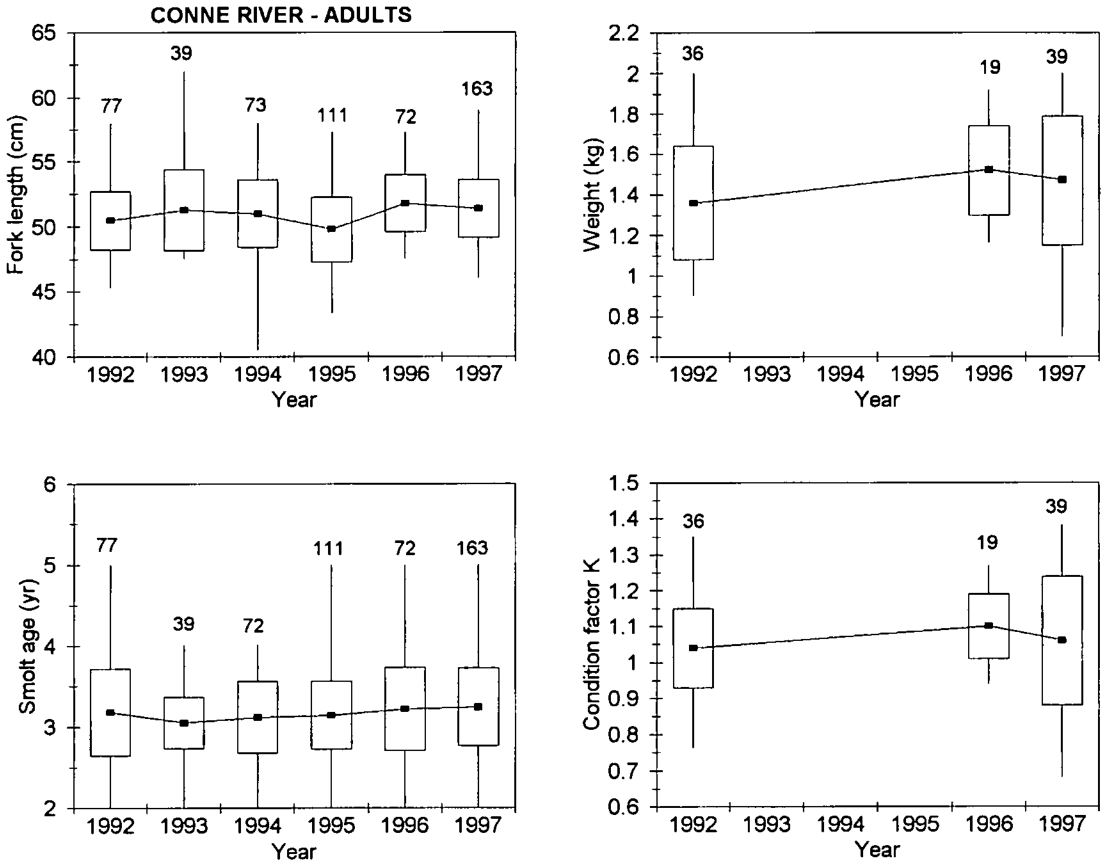


Fig. 2.12. Mean fork length, mean weight, mean smolt age, and mean condition factor for virgin grilse from Conne River, 1992-97. The rectangle around each point denotes the standard deviation; the vertical line is the range; the number above the vertical line is the sample size.

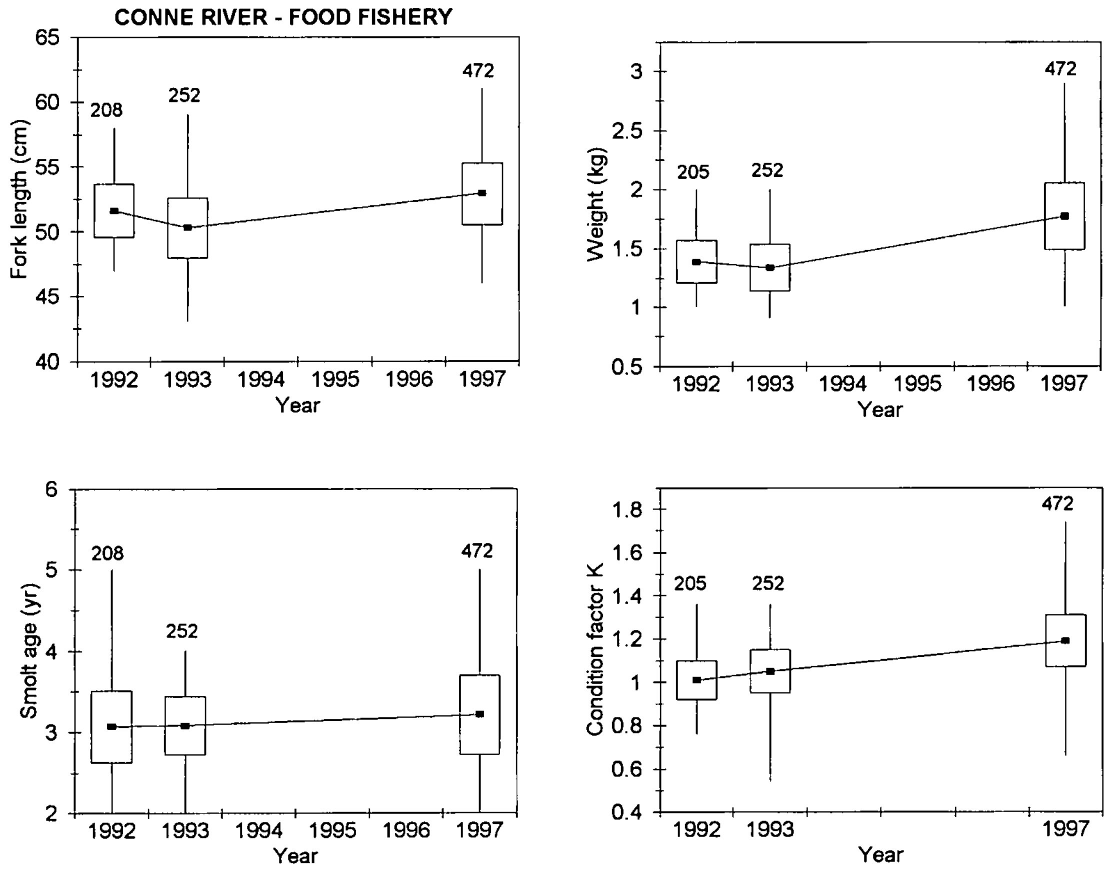


Fig. 2.13. Mean fork length, mean weight, mean smolt age, and mean condition factor for virgin grilse from the Conne River food fishery, 1992-97. The rectangle around each point denotes the standard deviation; the vertical line is the range; the number above the vertical line is the sample size.

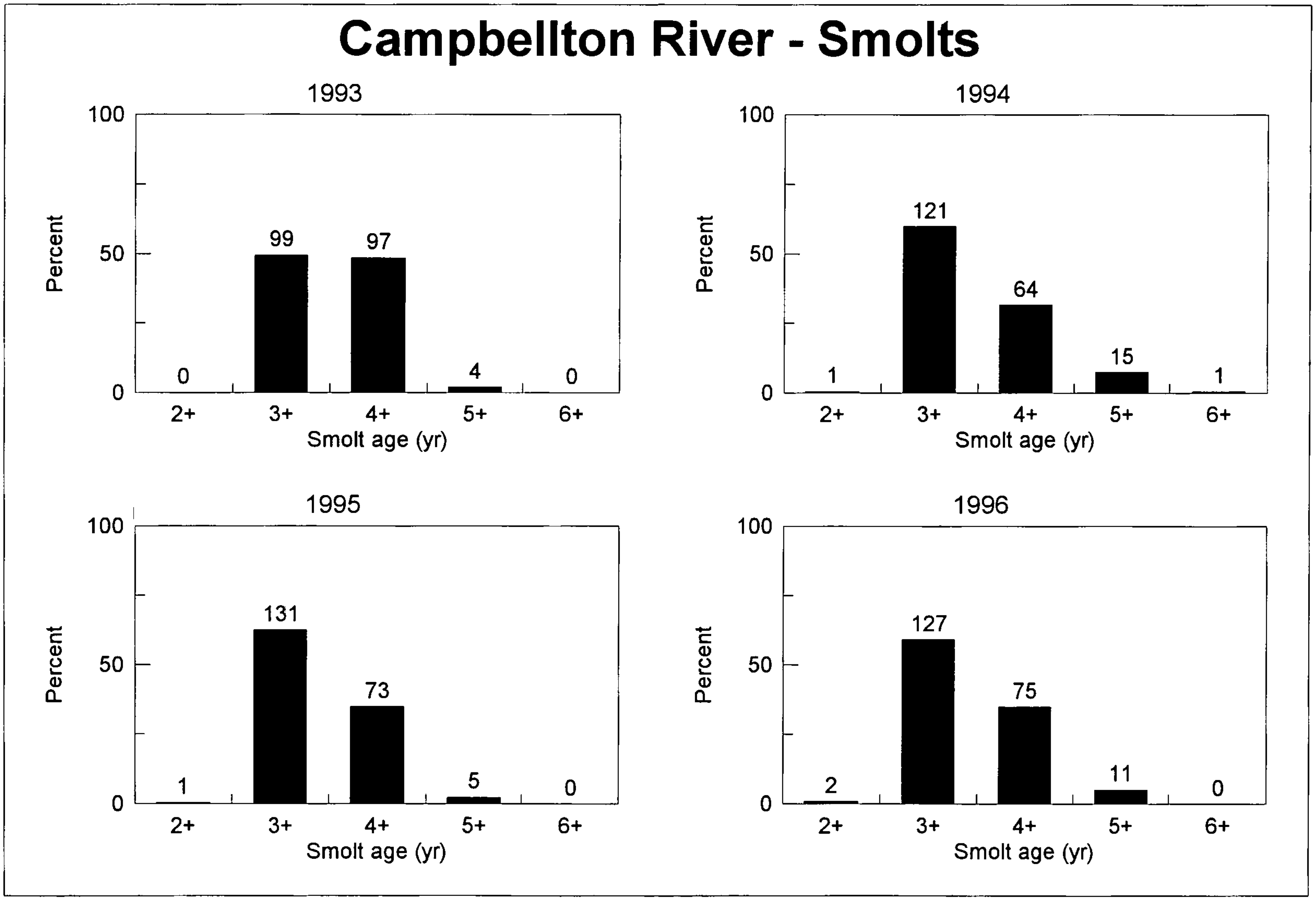


Fig. 2.14. Age composition for smolts from Campbellton River, 1993 - 96. The number above each bar denotes sample size.

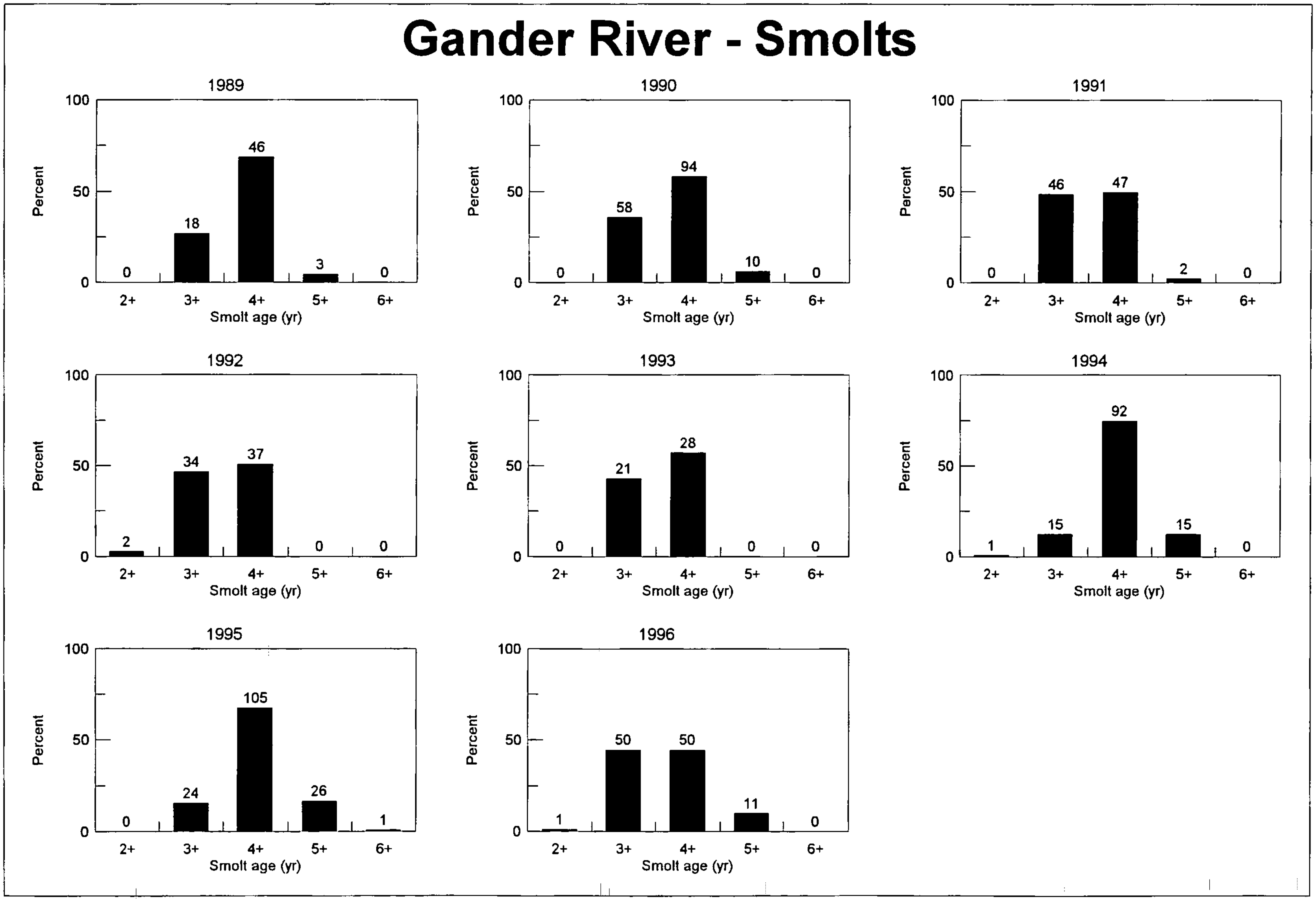


Fig. 2.15. Age composition for smolts from Gander River, 1989 - 96. The number above each bar denotes sample size.

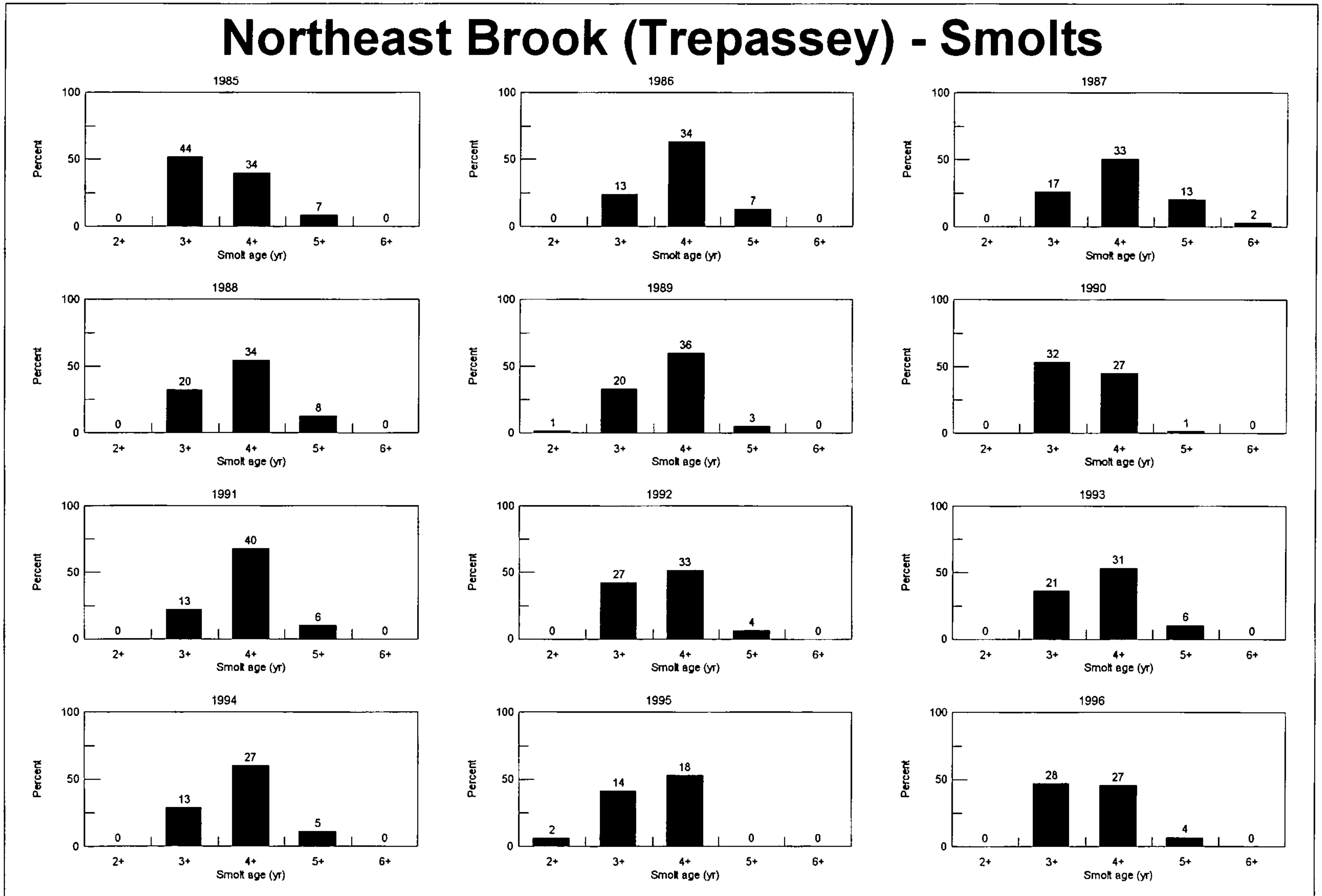


Fig. 2.16. Age composition for smolts from Northeast Brook, 1985 - 96. The number above each bar denotes sample size.

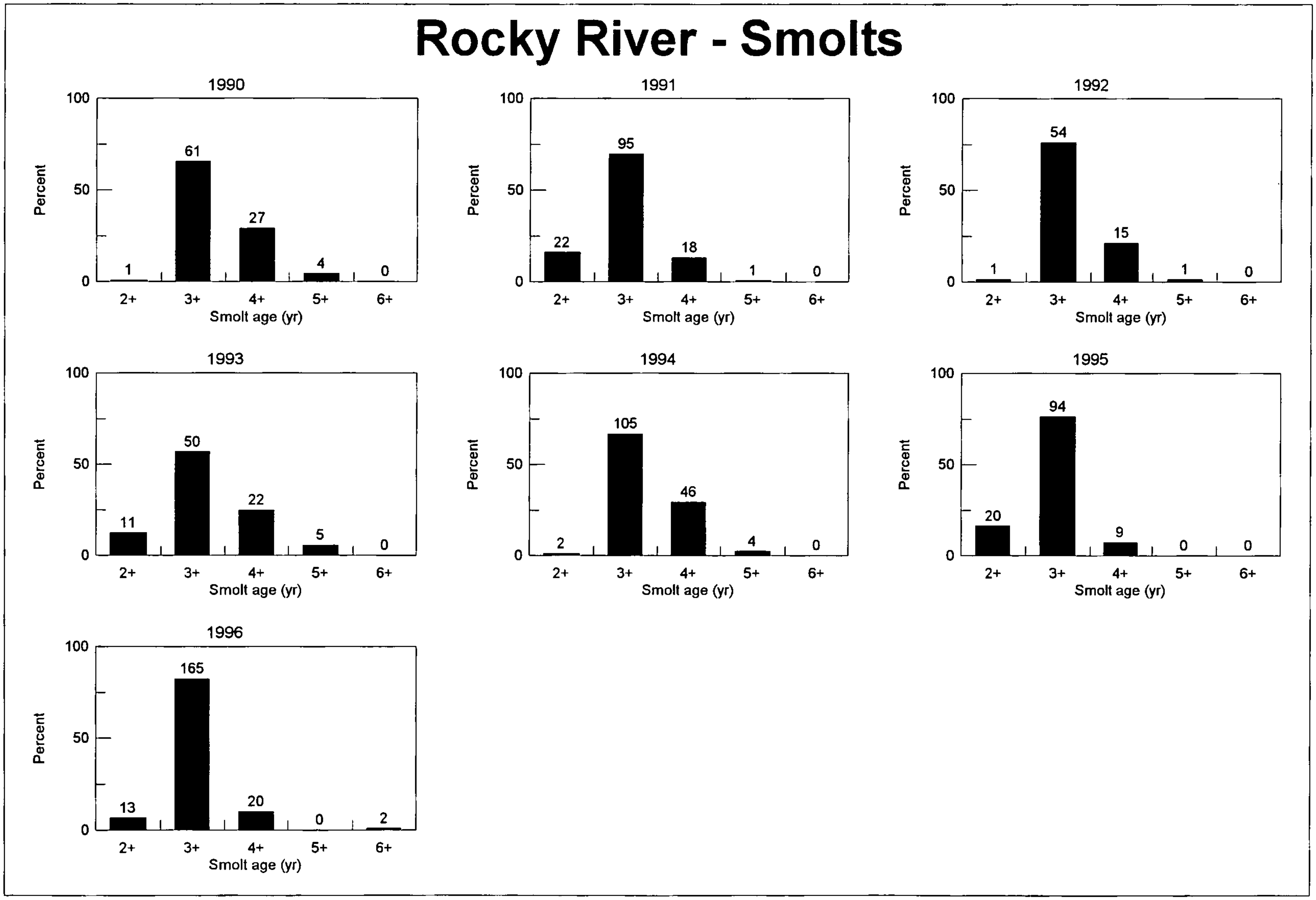


Fig. 2.17. Age composition for smolts from Rocky River, 1990 - 96. The number above each bar denotes sample size.

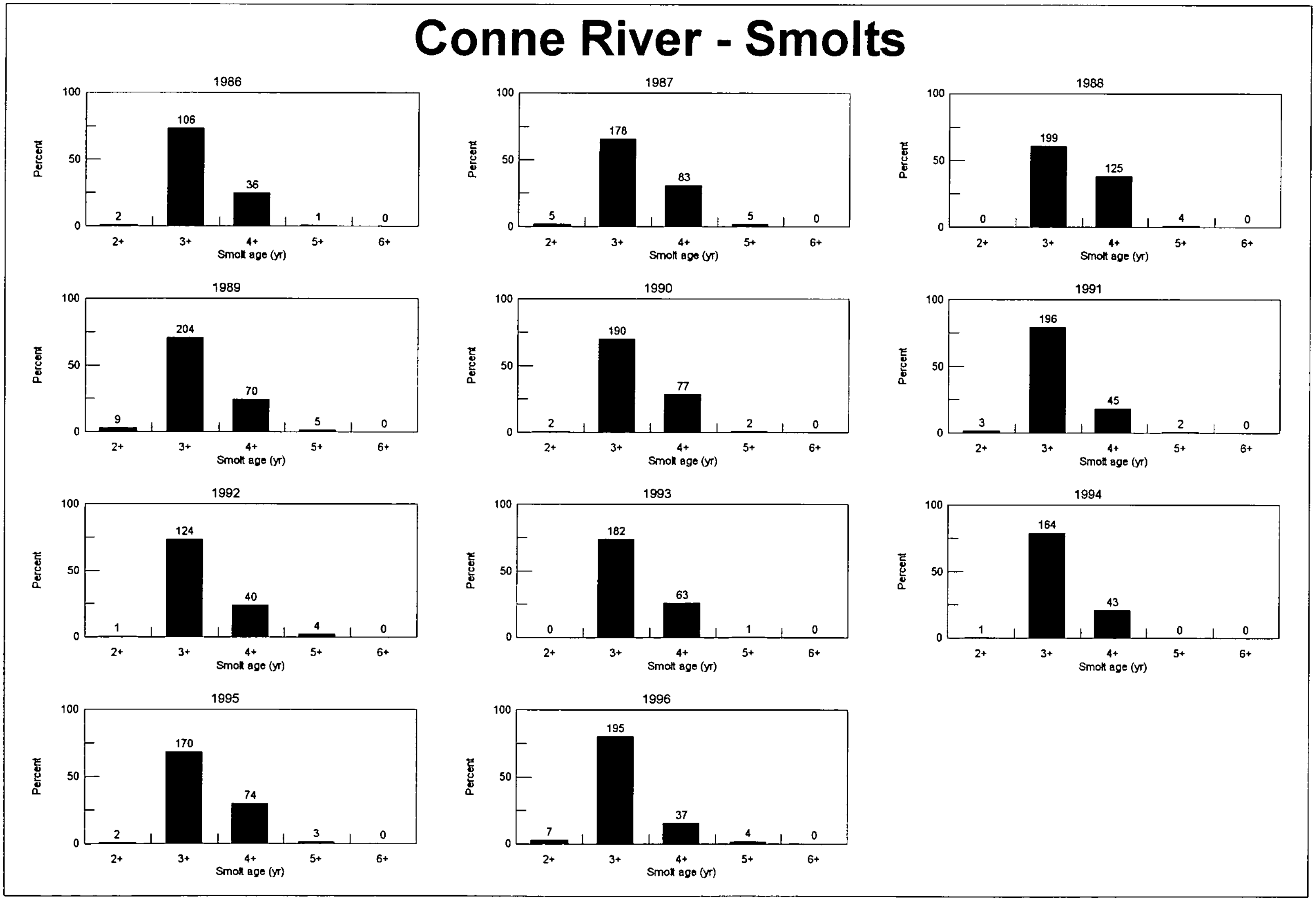


Fig. 2.18. Age composition for smolts from Conne River, 1986 - 96. The number above each bar denotes sample size.

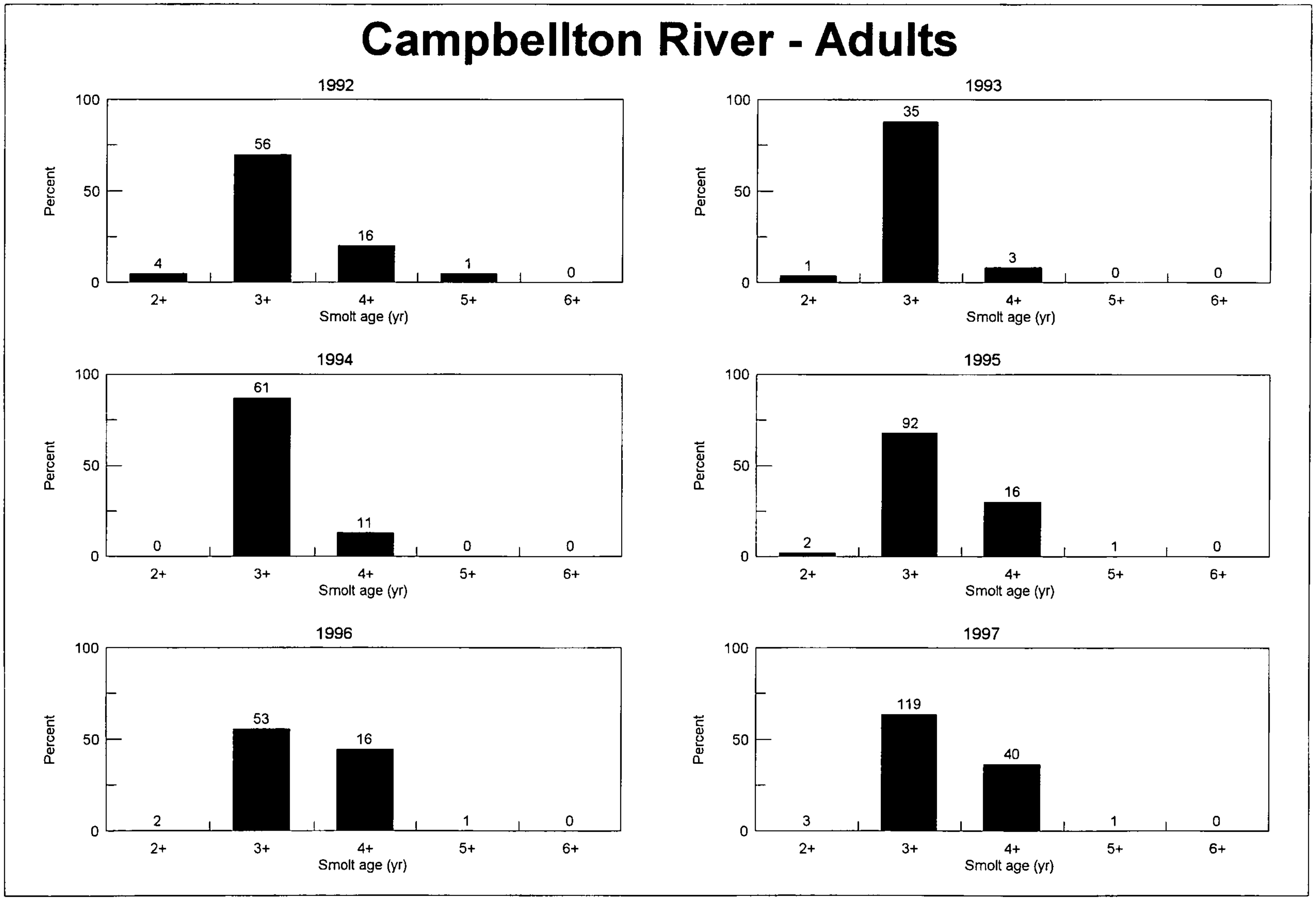


Fig. 2.19. Age composition for virgin grilse from Campbellton River, 1992-97. The number above each bar denotes sample size.

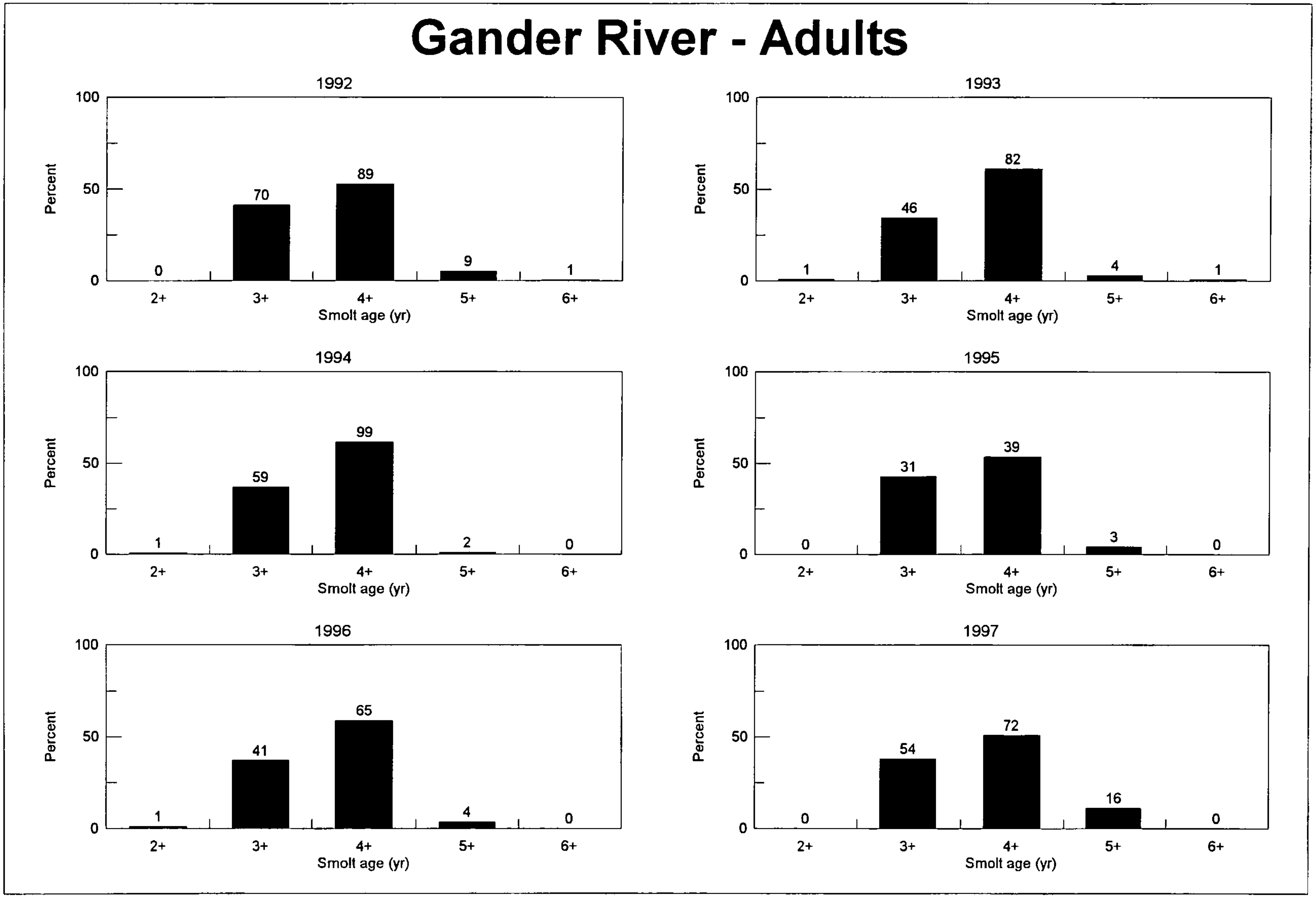


Fig. 2.20. Age composition for virgin grilse from Gander River, 1992-97. The number above each bar denotes sample size.

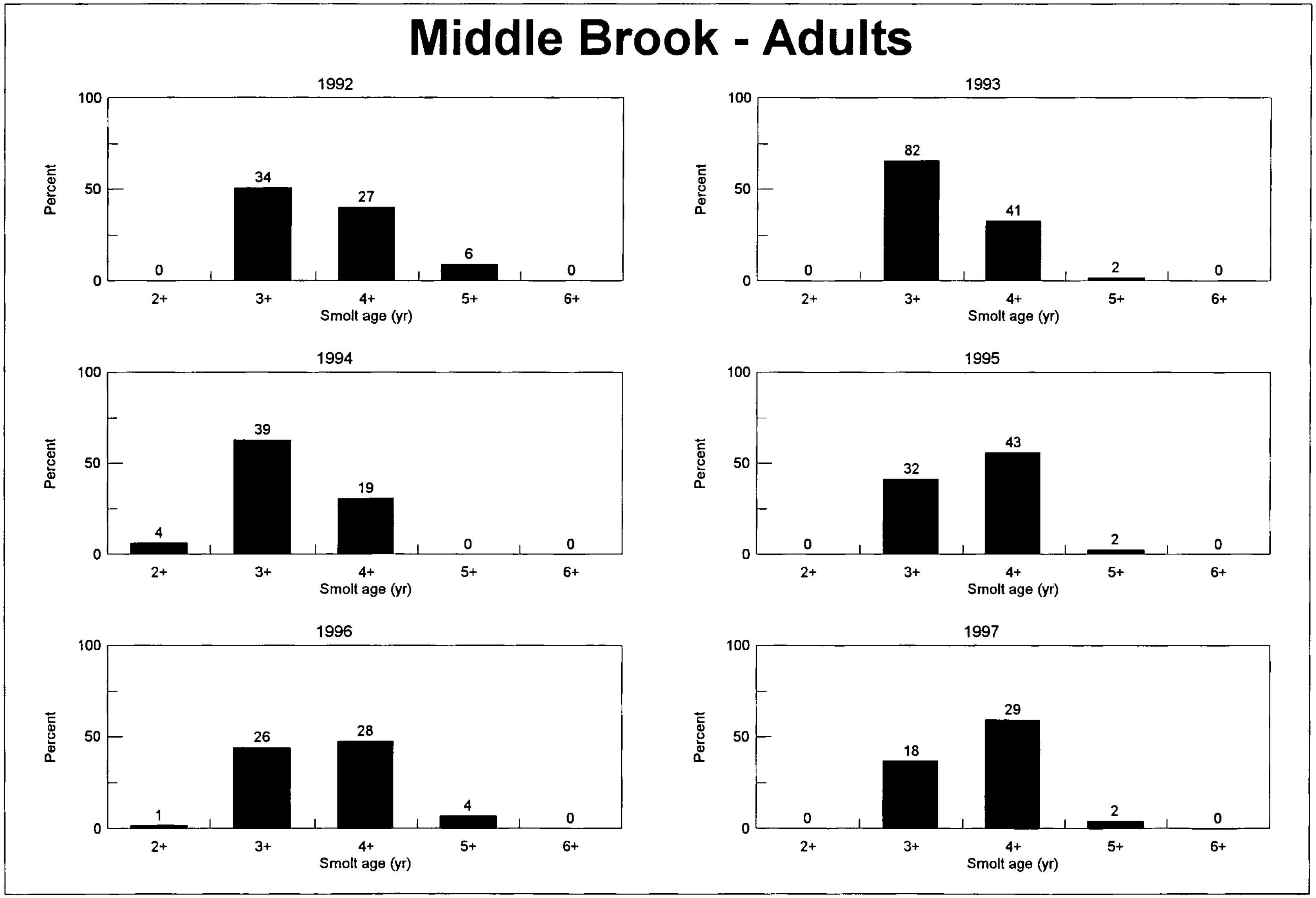


Fig. 2.21. Age composition for virgin grilse from Middle Brook, 1992-97. The number above each bar denotes sample size.

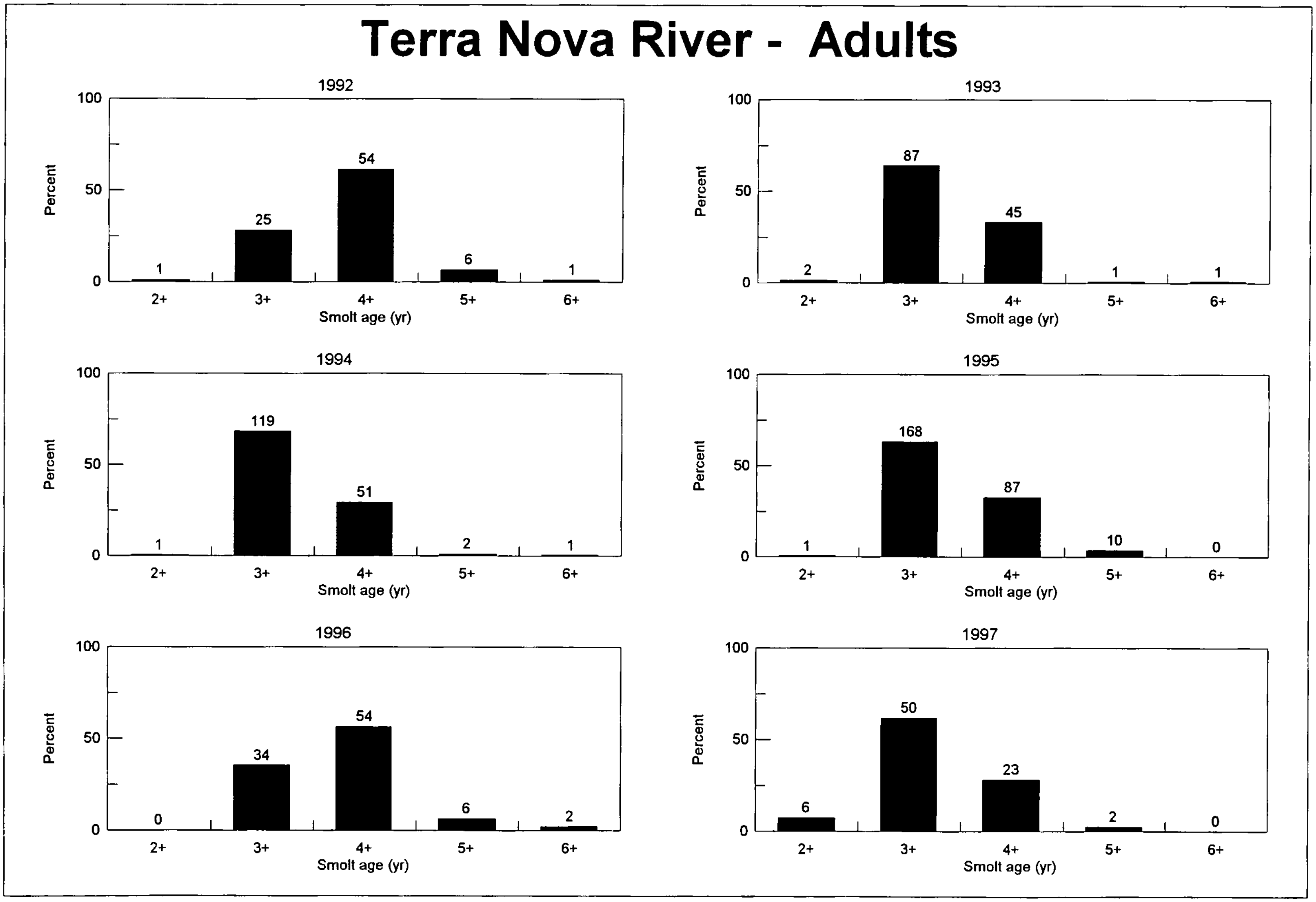


Fig. 2.22. Age composition for virgin grilse from Terra Nova River, 1992-97. The number above each bar denotes sample size.

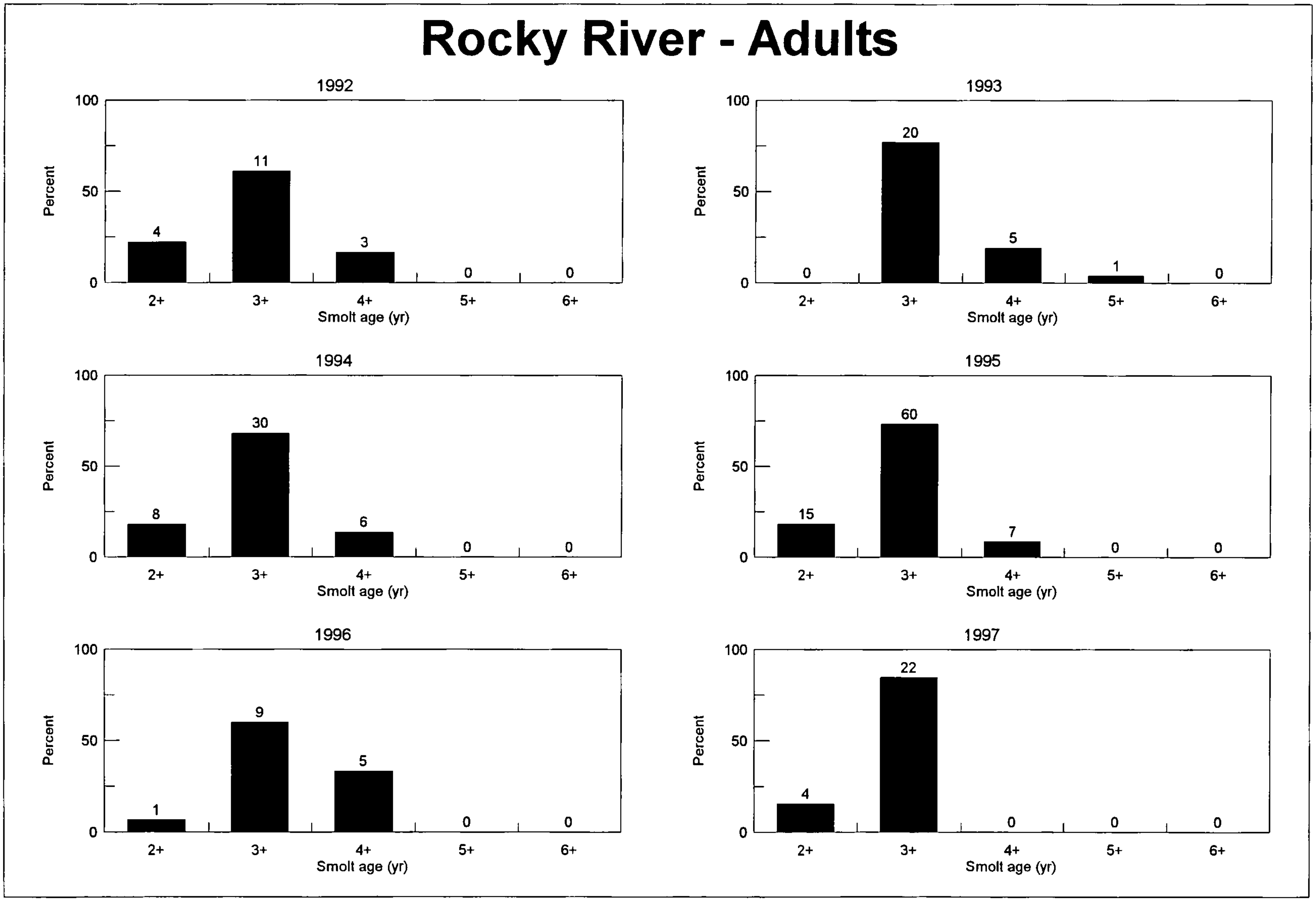


Fig. 2.23. Age composition for virgin grilse from Rocky River, 1992-97. The number above each bar denotes sample size.

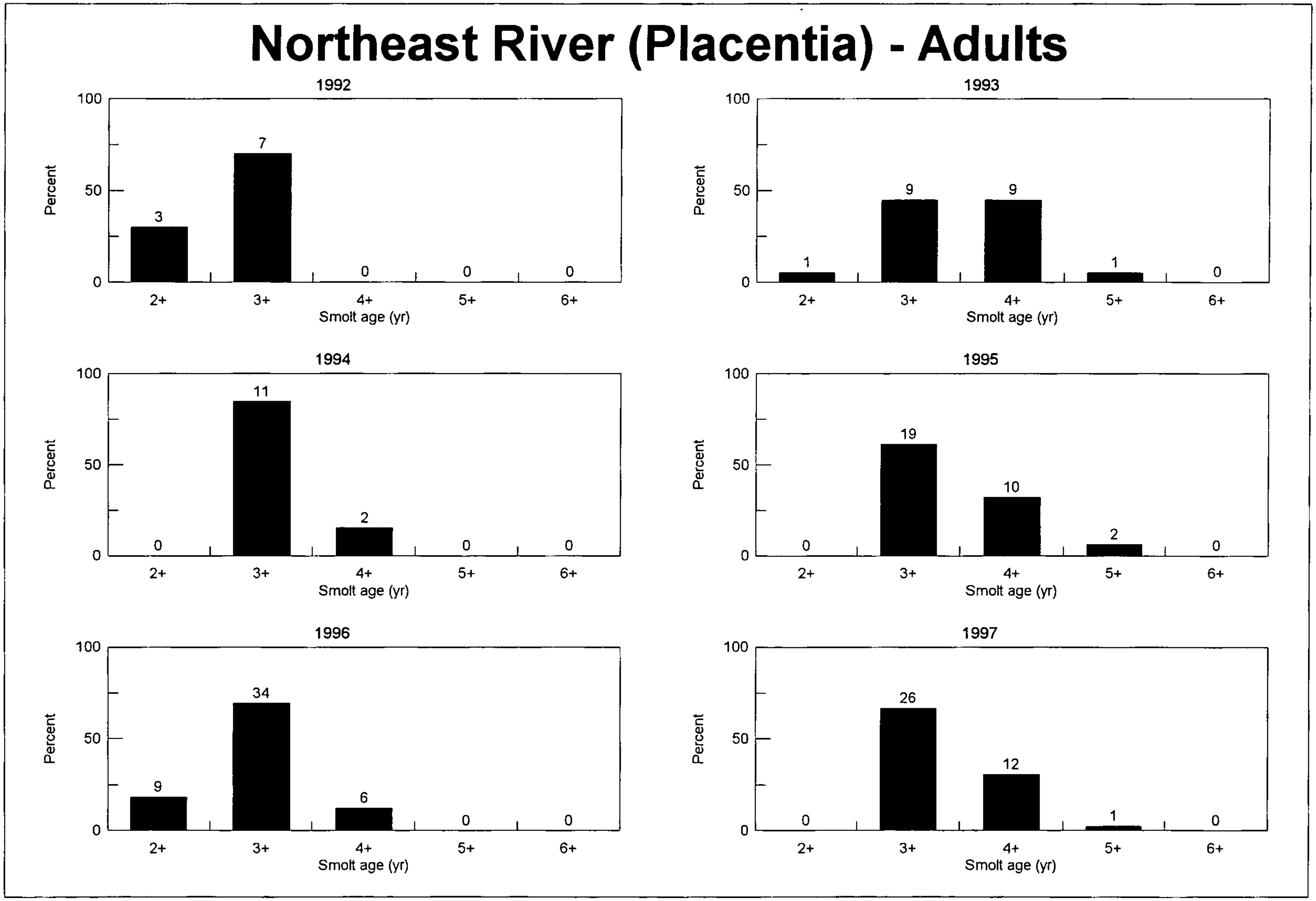


Fig. 2.24. Age composition for virgin grilse from Northeast River (Placentia), 1992 - 97. The number above each bar denotes sample size.

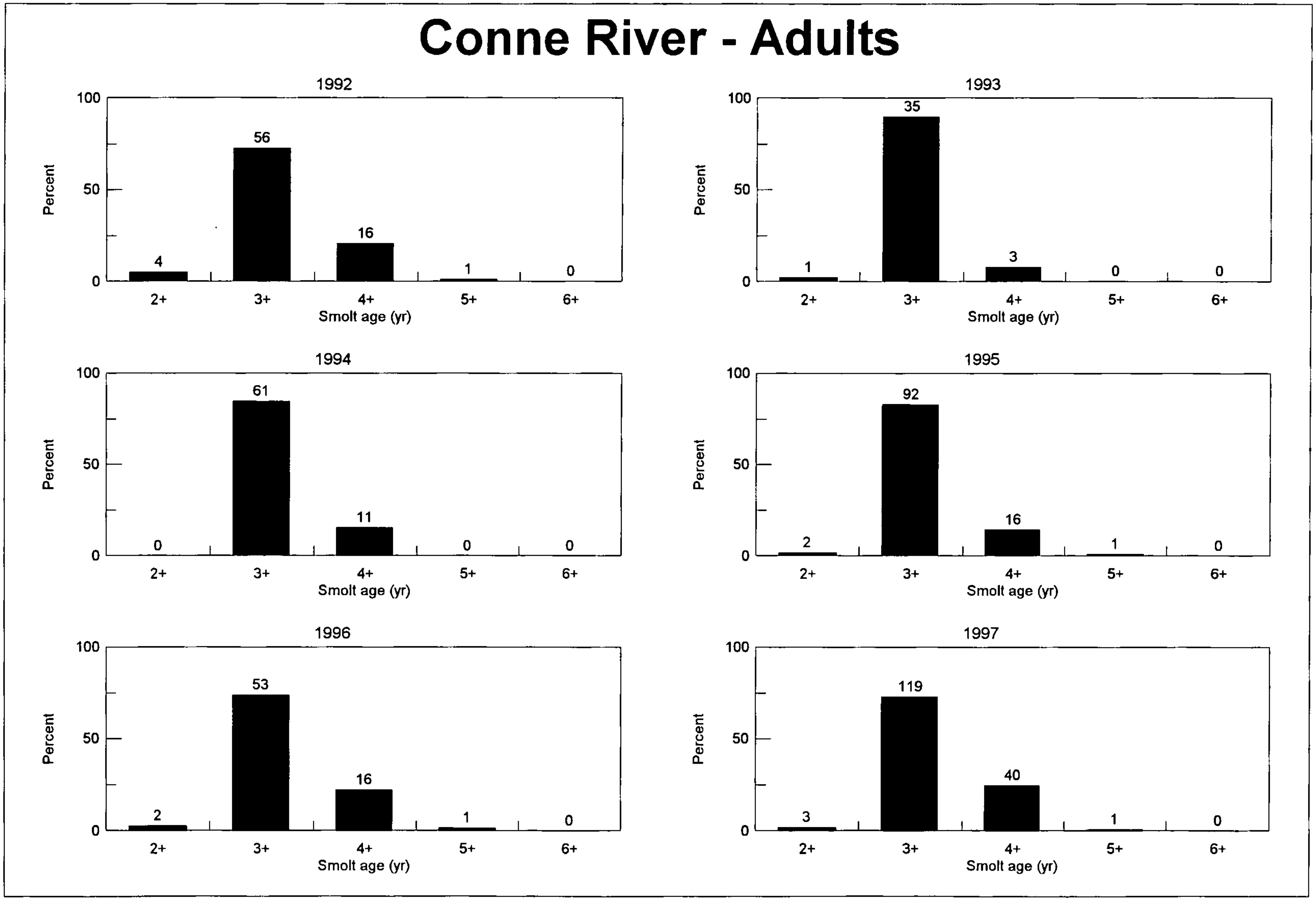


Fig. 2.25. Age composition for virgin grilse from Conne River, 1992-97. The number above each bar denotes sample size.

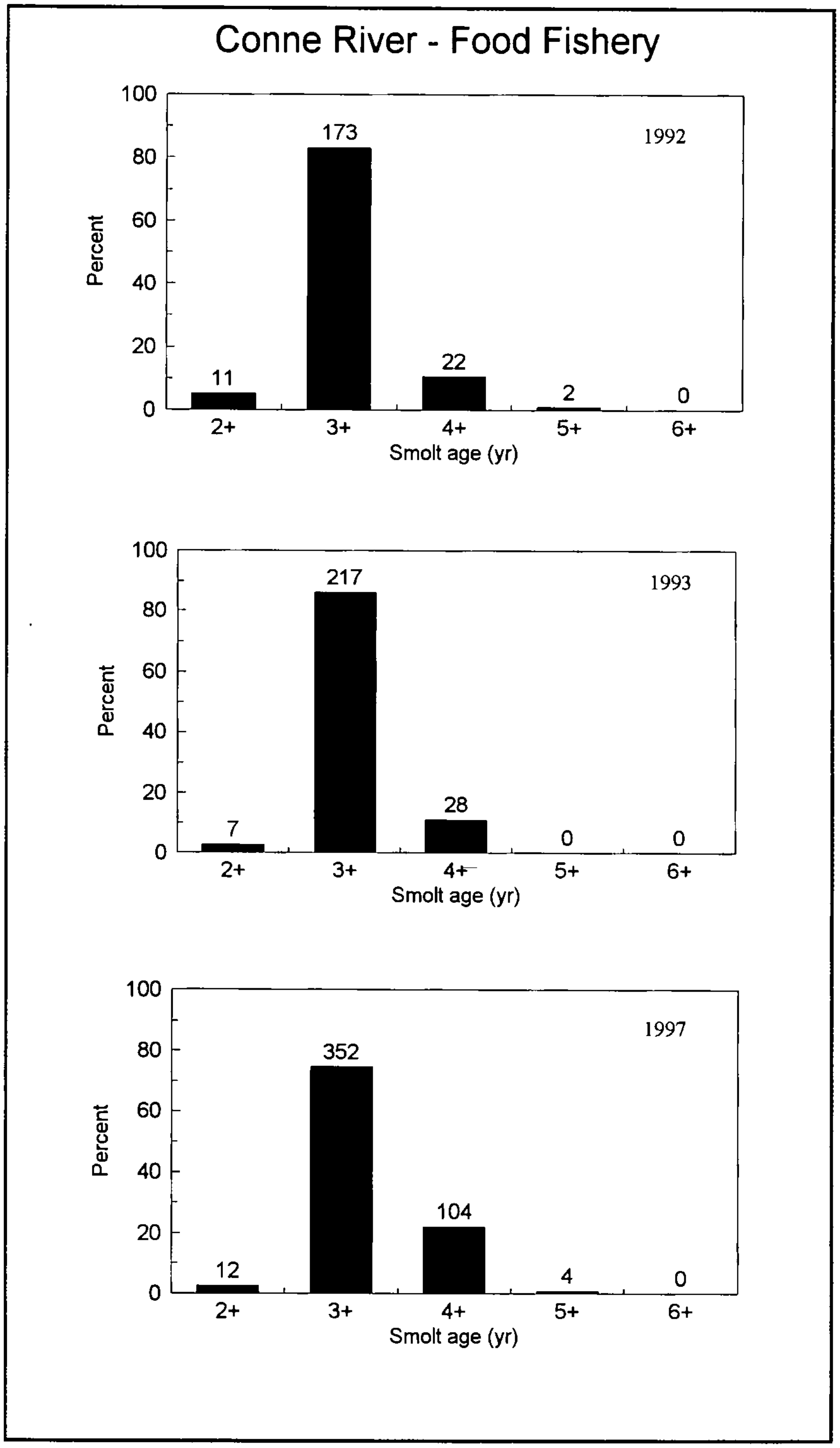


Fig. 2.26. Age composition for virgin grilse from the Native food fishery in Conne River, 1992, 1993 and 1997. The number above each bar denotes sample size.

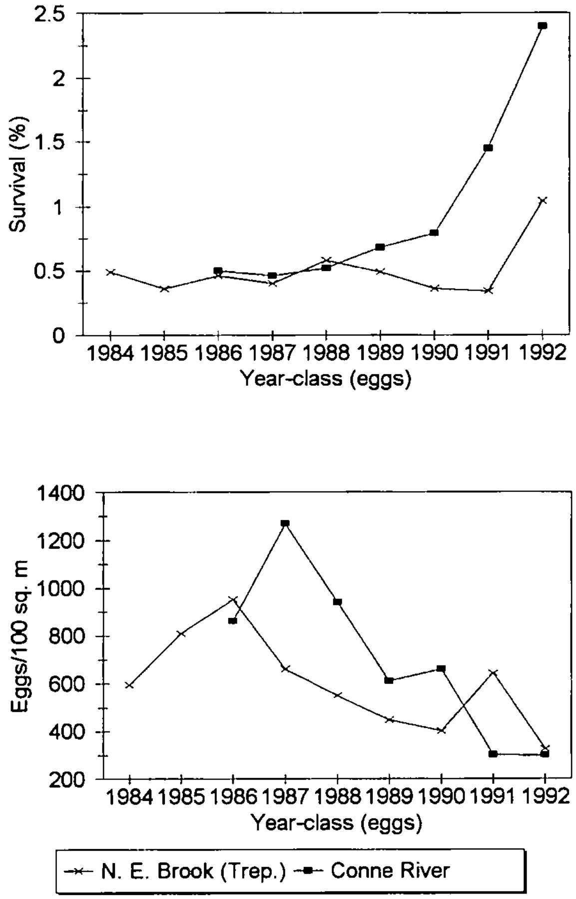


Fig. 2.27. Egg-to-smolt survival and egg deposition rate for Northeast Brook (Trepassey) and Conne River.

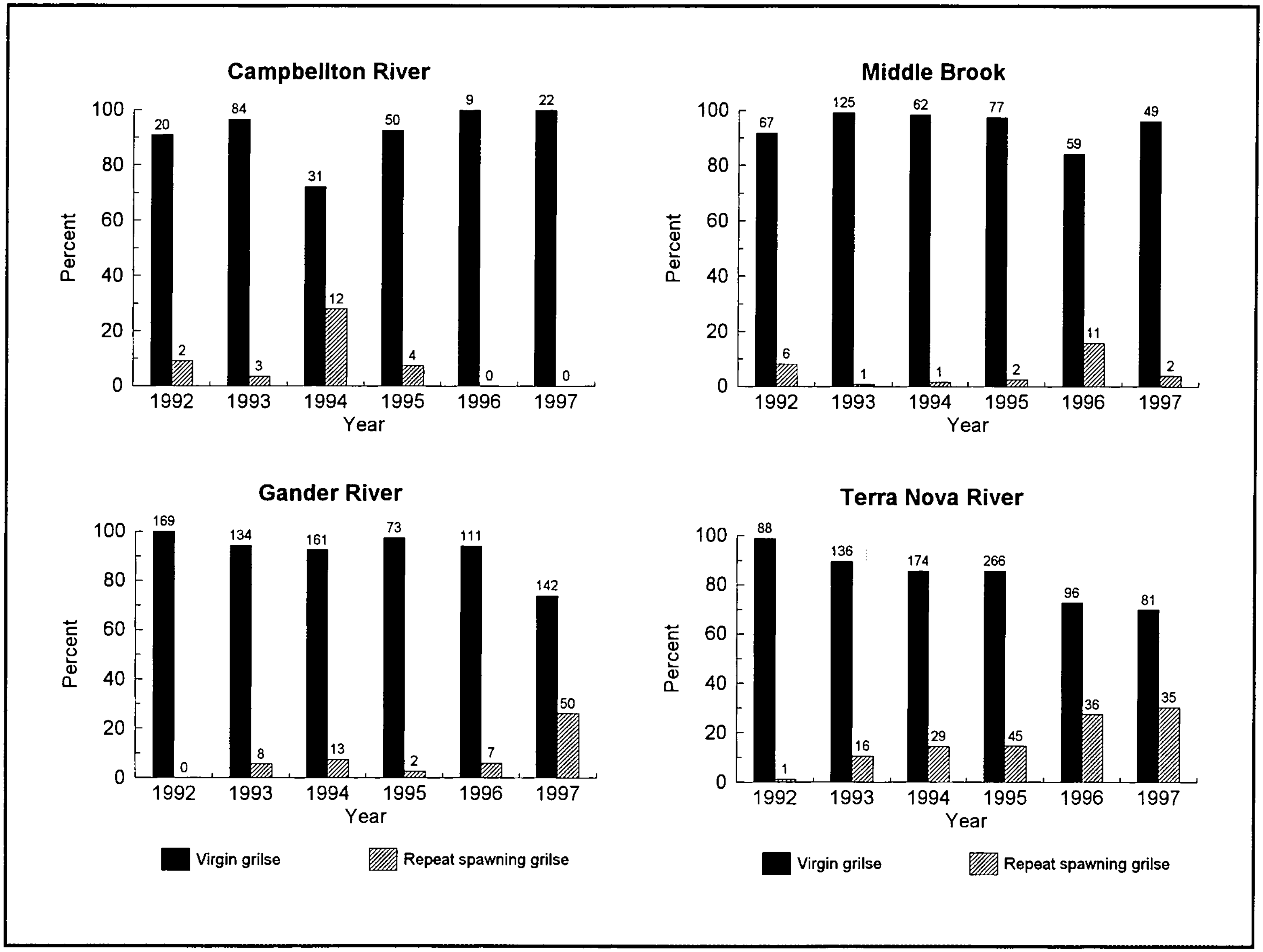


Fig. 2.28. Percentage of virgin grilse versus repeat spawning grilse for Campbellton River, Gander River, Middle Brook, and Terra Nova River, 1992 - 97. The number above each bar denotes sample size.

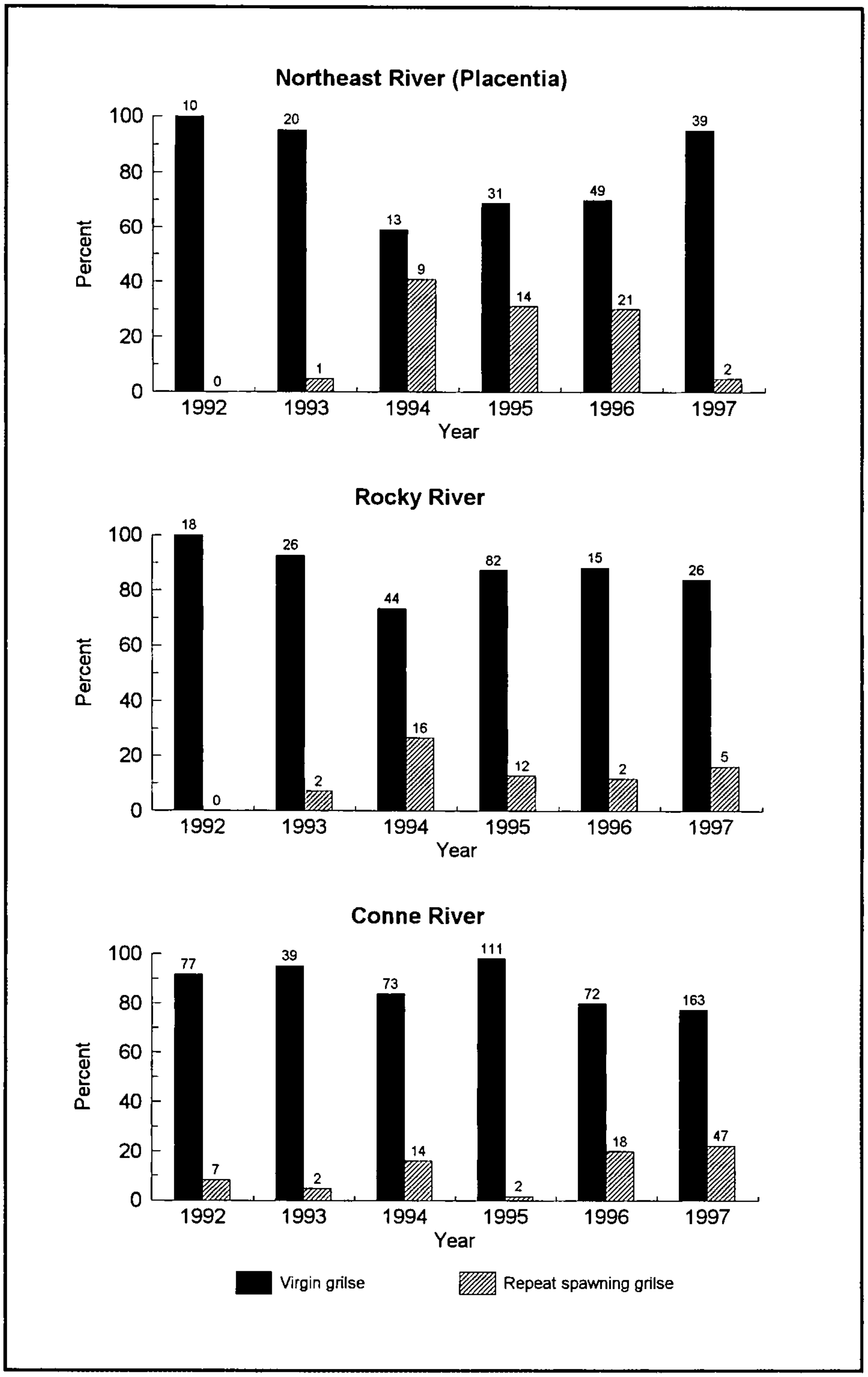


Fig. 2.29. Percentage of virgin grilse versus repeat spawning grilse for Northeast River (Placentia), Rocky River, and Conne River, 1992 - 97. The number above each bar denotes sample size.

Fig. 2.30. Prefishery abundance of North American non-maturing 1SW salmon and predicted values from the relationship of thermal habitat in February and lagged spawners.

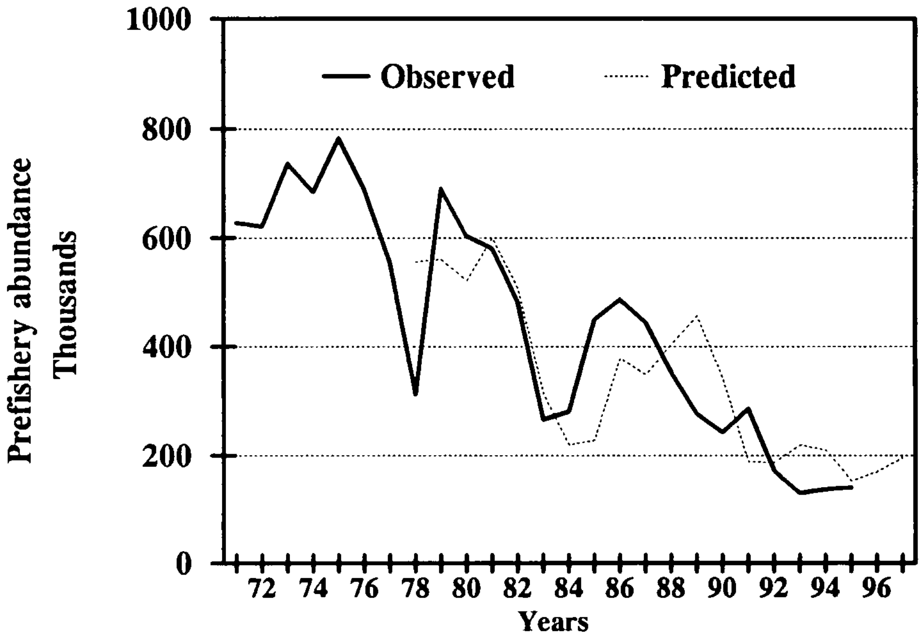


Fig. 2.31. The area in the northwest Atlantic used for the determination of thermal habitat and Reconstructed-SST data. MCSST data is available for the entire area.

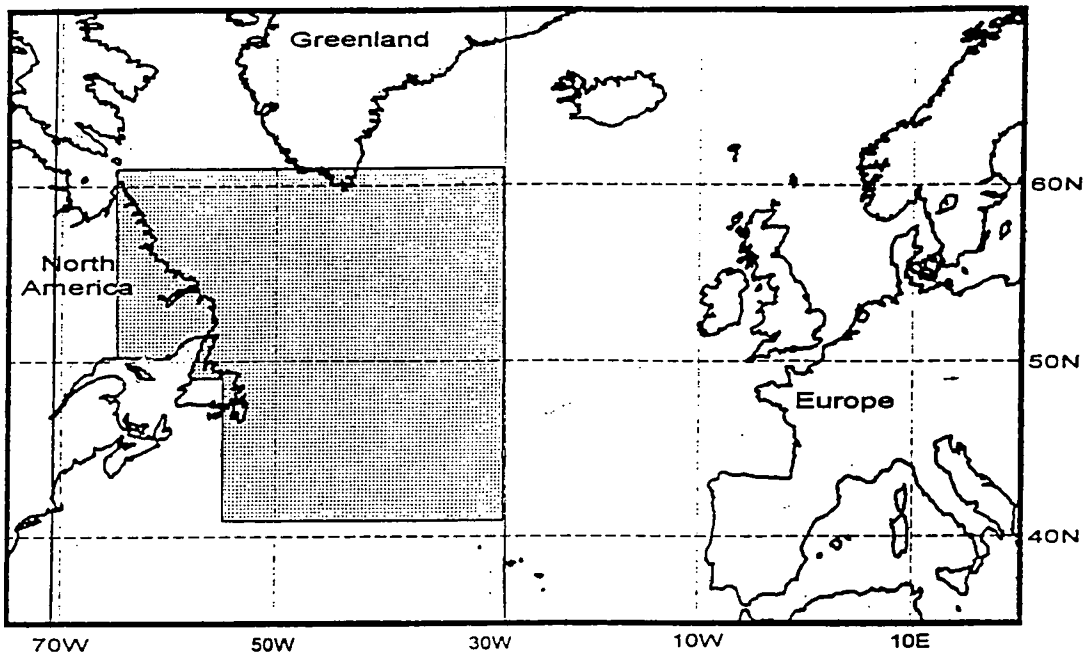


Fig. 2.32. Area and blocks used for analysis of Reconstructed Sea Surface Temperatures in the northwest Atlantic.

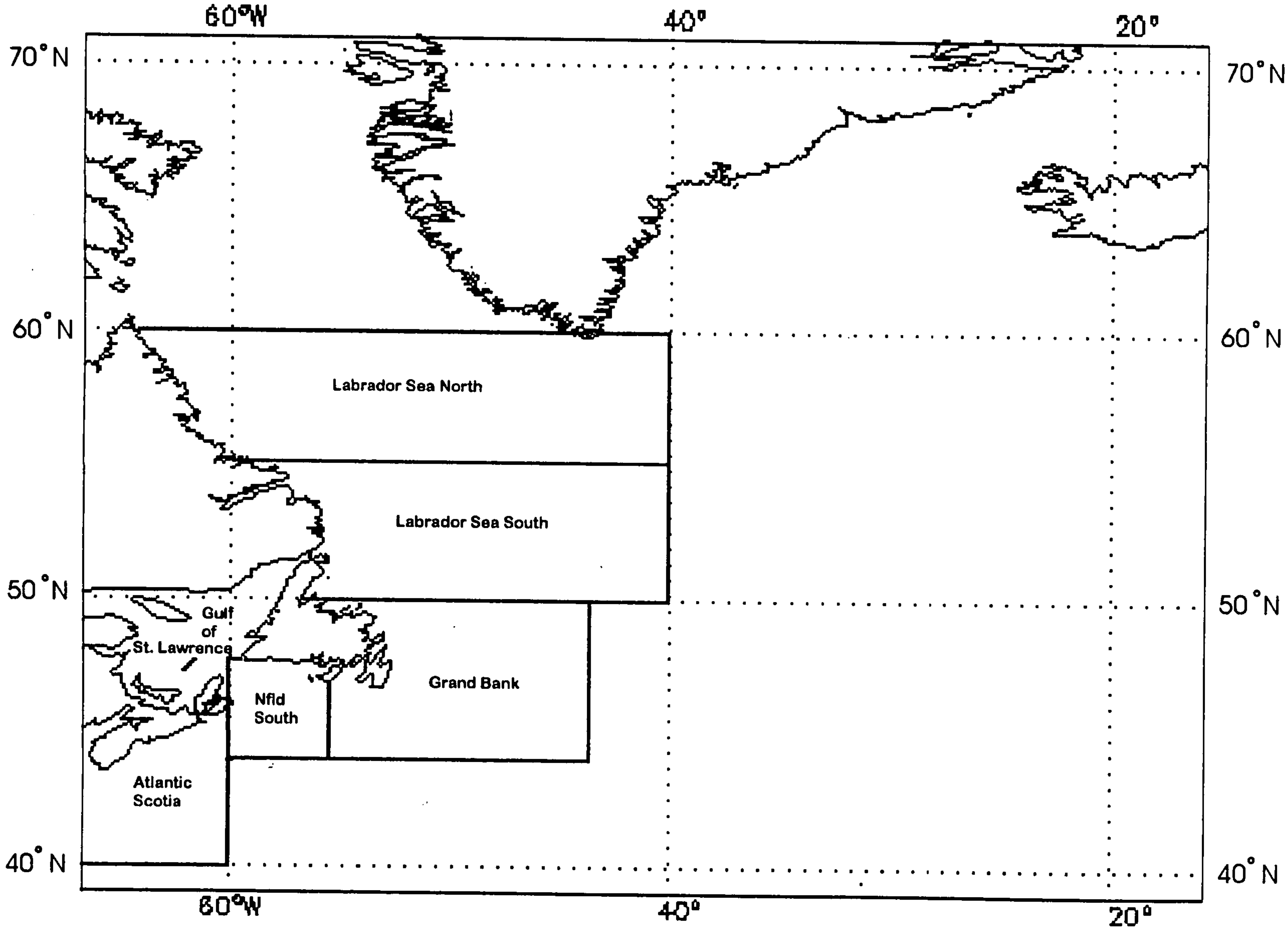


Fig. 2.33. Thermal habitat index for the northwest Atlantic, 1970-97.

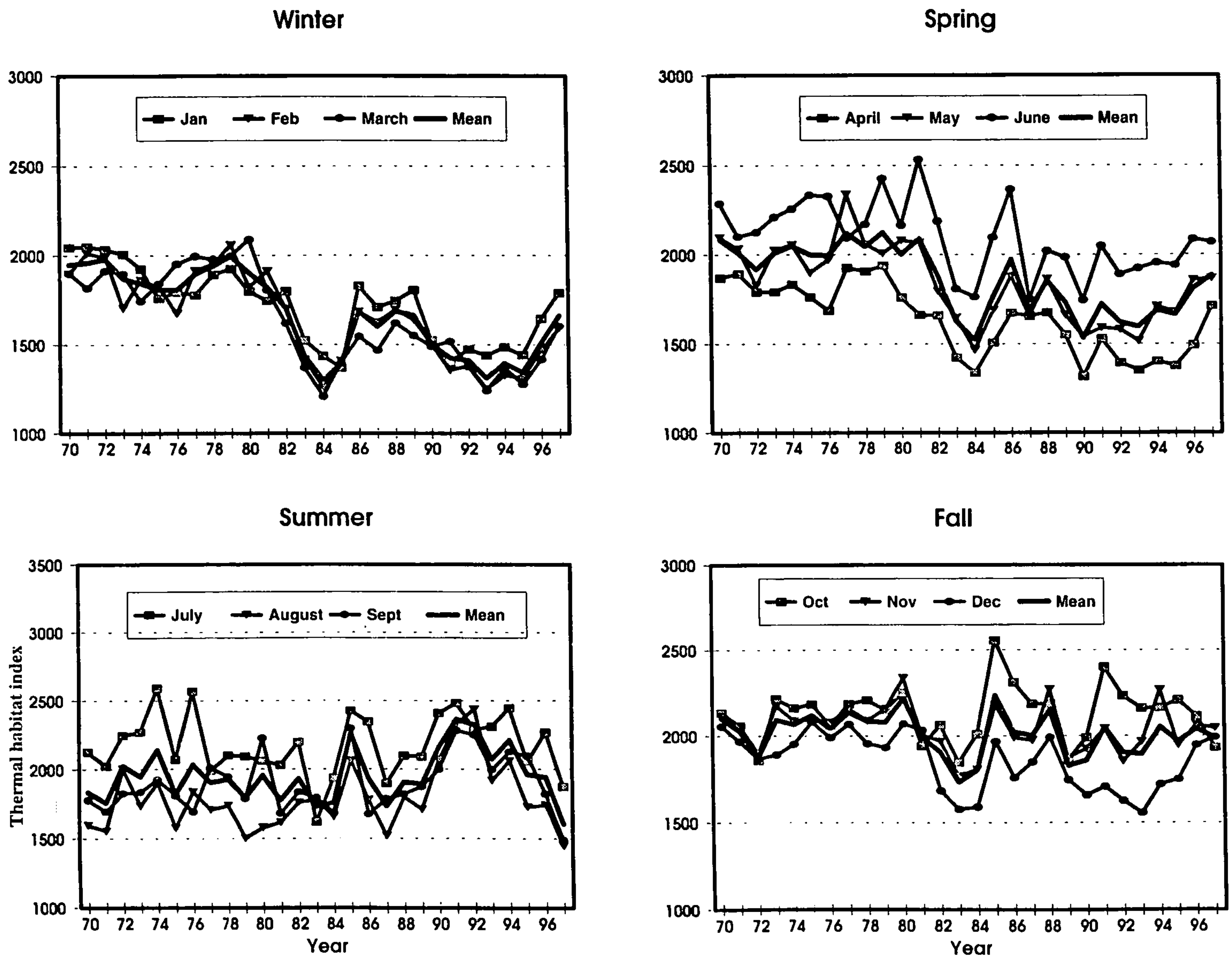


Fig. 2.34. Average annual thermal habitat for grilse and MSW salmon in the northwest Atlantic, 1970-97.

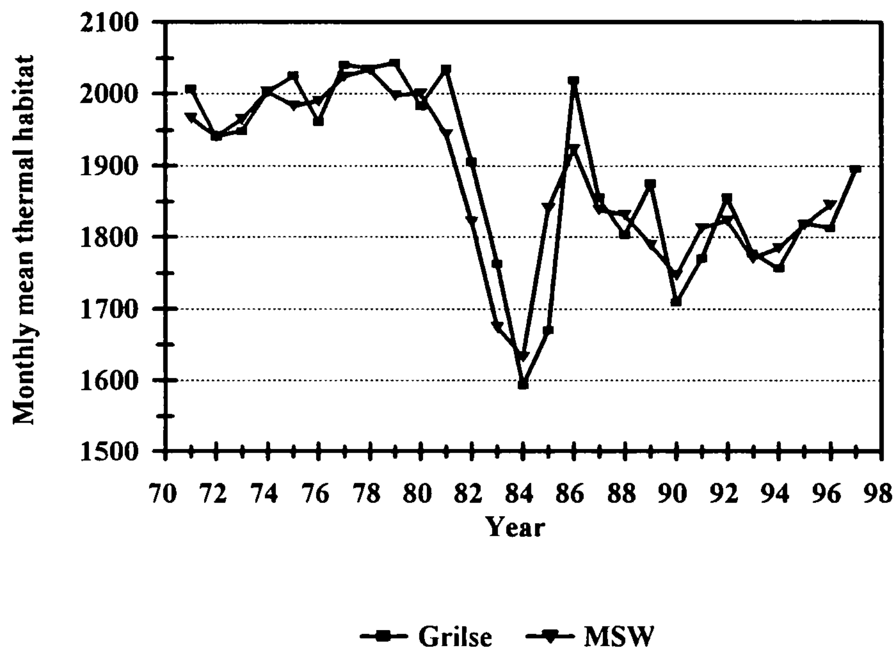


Fig. 2.35. Correlation summaries for 2SW salmon abundance and thermal habitat, 1970-96. Horizontal lines are the 5% level of significance for correlation coefficients.

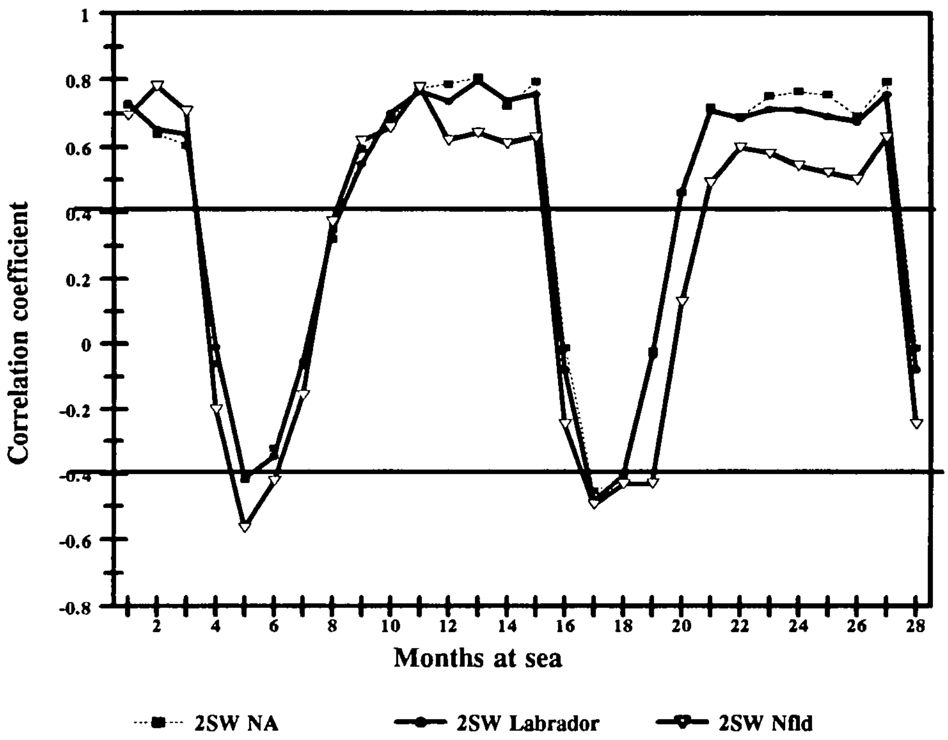


Fig. 2.36. Correlation summaries for 1SW salmon abundance and thermal habitat, 1970-96. Horizontal lines are the 5% level of significance for correlation coefficients.

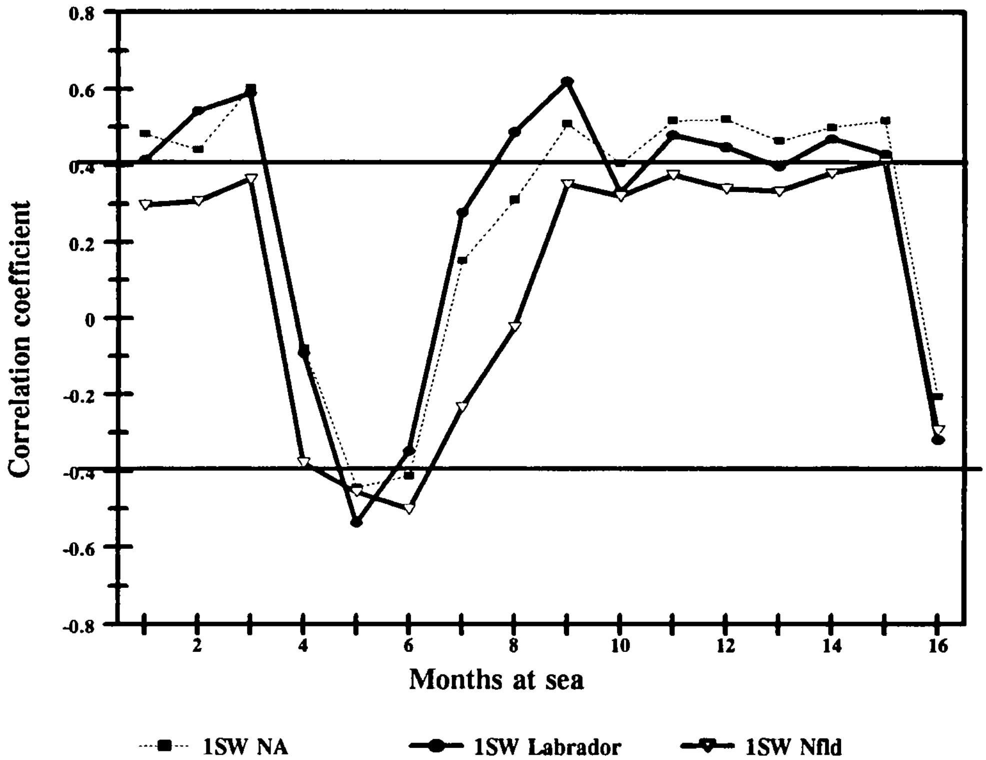


Fig. 2.37. Correlation summaries for 1SW salmon survival from Western Arm Brook and thermal habitat. Horizontal lines are the 5% level of significance for correlation coefficients.

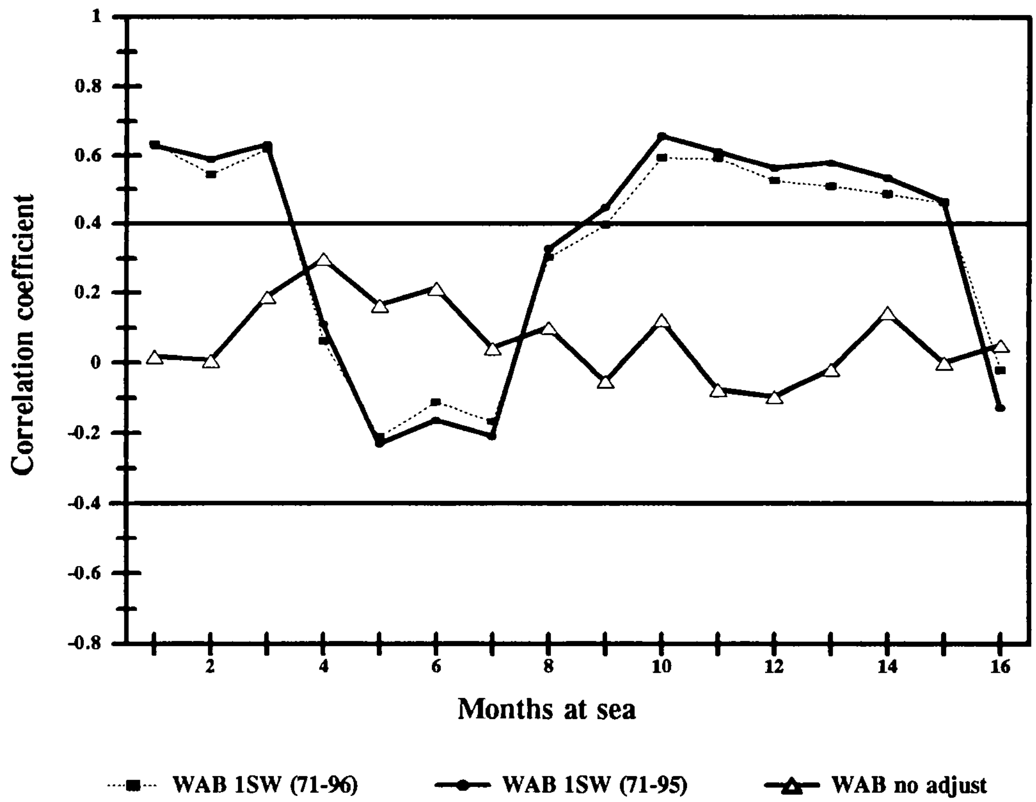


Fig. 2.38. Correlation summaries for small salmon survival from Northeast Brook (Trepassey) and thermal habitat. Horizontal lines are the 5% level of significance for correlation coefficients.

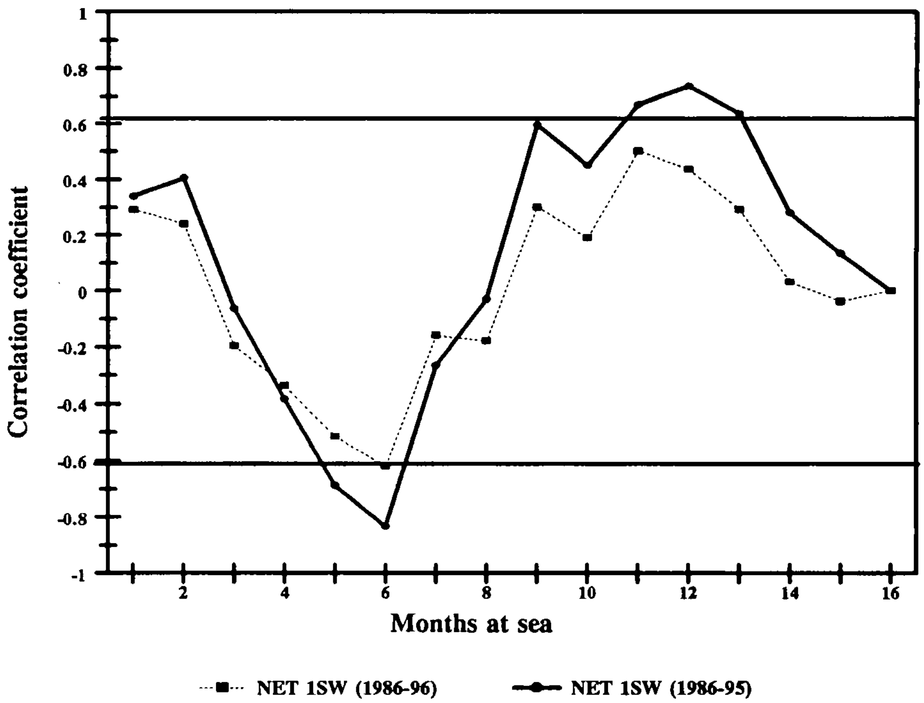


Fig. 2.39. Correlation summaries for 1SW salmon survival from Conne River and thermal habitat. Horizontal lines are the 5% level of significance for correlation coefficients.

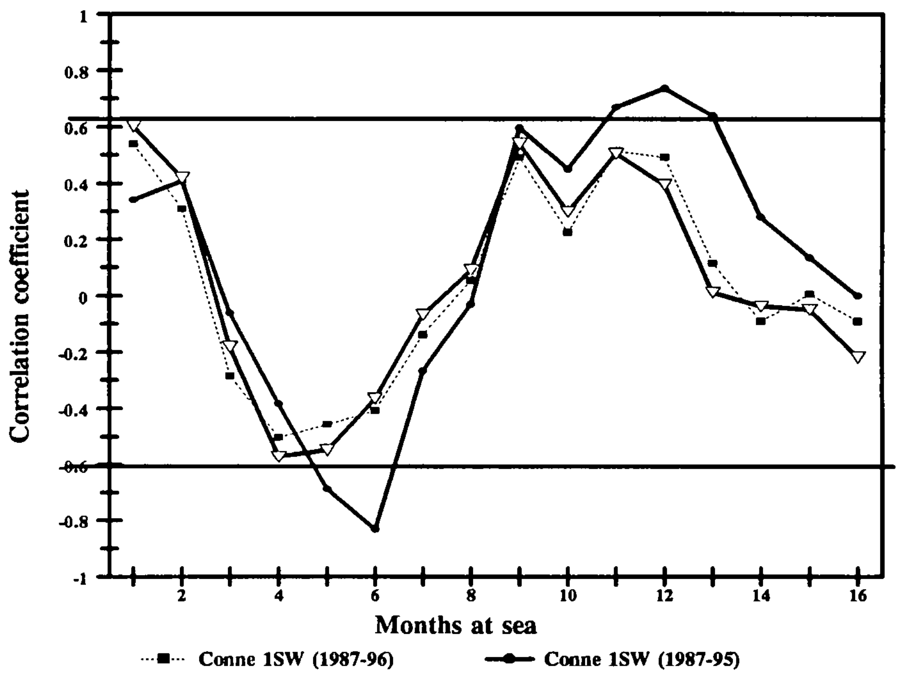


Fig. 2.40. Correlation summaries for 1SW salmon survival and abundance related to thermal habitat. Horizontal lines are the 5% level of significance for correlation coefficients.

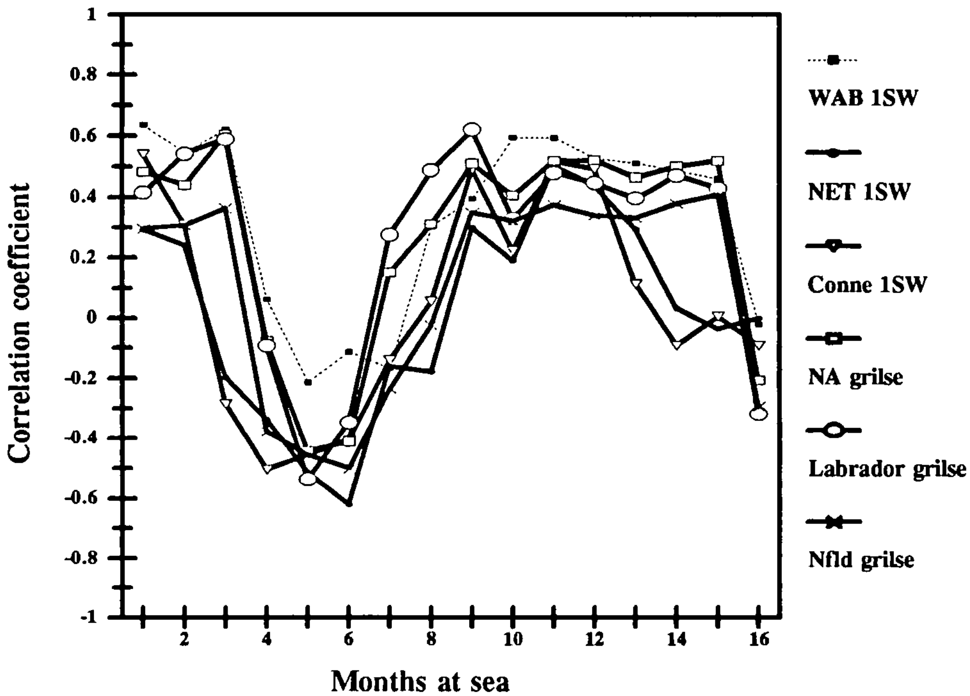


Fig. 2.41. Correlation summaries for small salmon recruits estimated prior to the commercial fishery for Middle Brook, Gander River, and Exploits River and thermal habitat. Horizontal lines are the 5% level of significance for correlation coefficients.

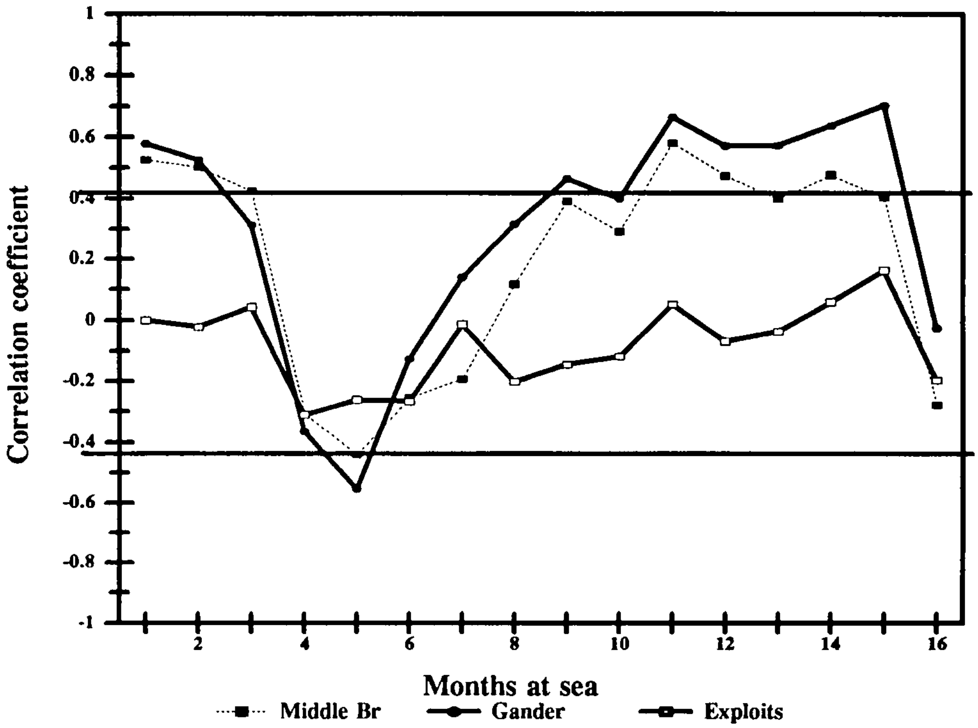


Fig. 2.42. Correlation summaries for small salmon recruits estimated prior to the commercial fishery for Biscay Bay River and Conne River and thermal habitat. Horizontal lines are the 5% level of significance for correlation coefficients, solid for Conne River and dashed for Biscay Bay.

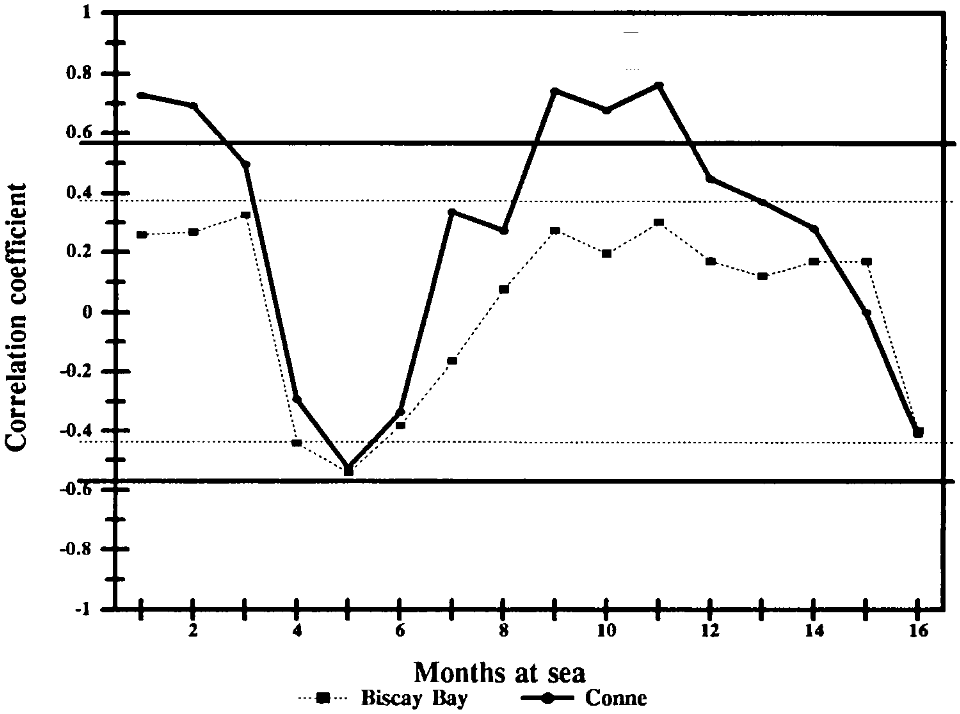


Fig. 2.43. Correlation summaries for small salmon recruits estimated prior to the commercial fishery for Humber River, Torrent River, Lomond River and Western Arm Brook and thermal habitat. Horizontal lines are the 5% level of significance for correlation coefficients.

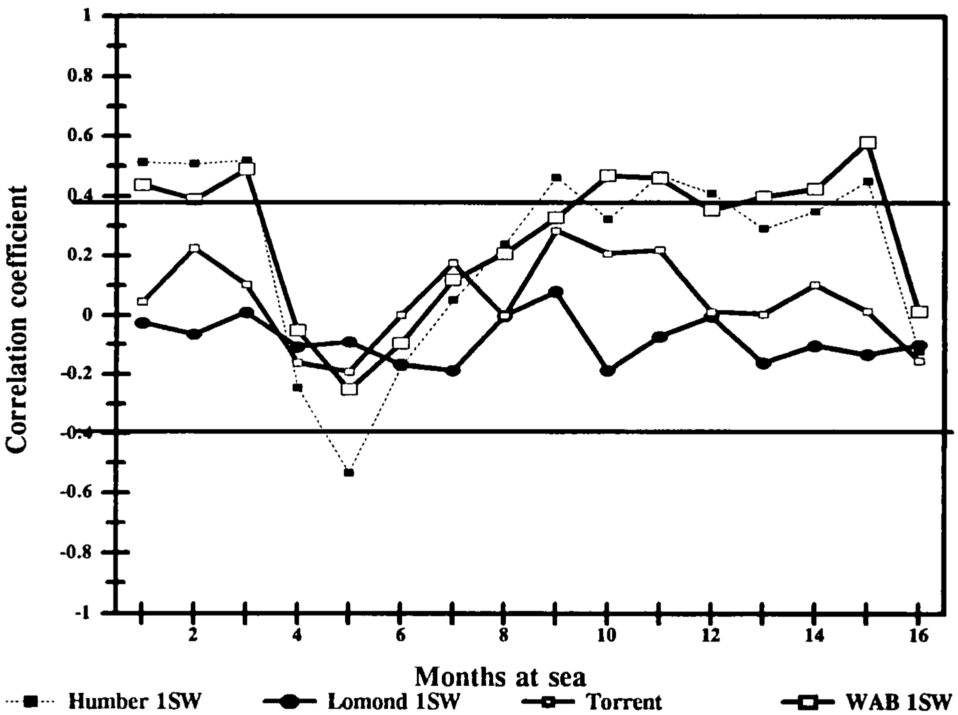


Figure 2.44. Inshore Newfoundland sea surface temperatures from MCSST data. Locations are 1 - Bay d'Espoir, 2 – Trepassey, 3 – Bonavista Bay, 4 – Humber, 5 – Bay St. George, and 6 – near Western Arm Brook, 1984-96.

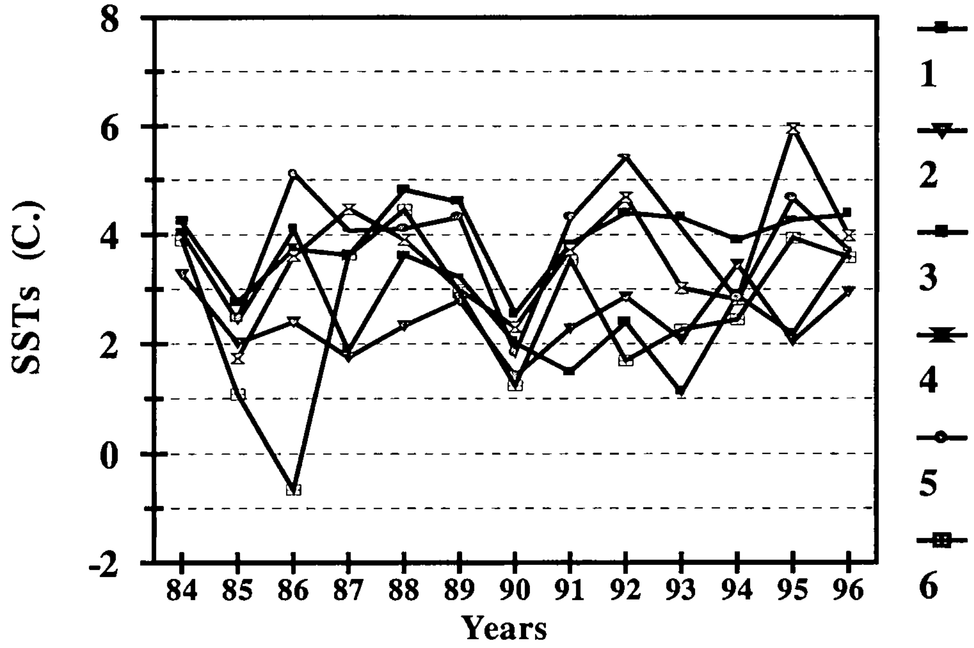


Fig. 2.45. Mean seasonal SSTs for 6 blocks in the northwest Atlantic, 1950-97. Blocks are labelled and correspond to those of Fig. 2.32. Seasons from bottom to top in each graph are 1-winter, 2-spring, 3-fall, & 4- summer.

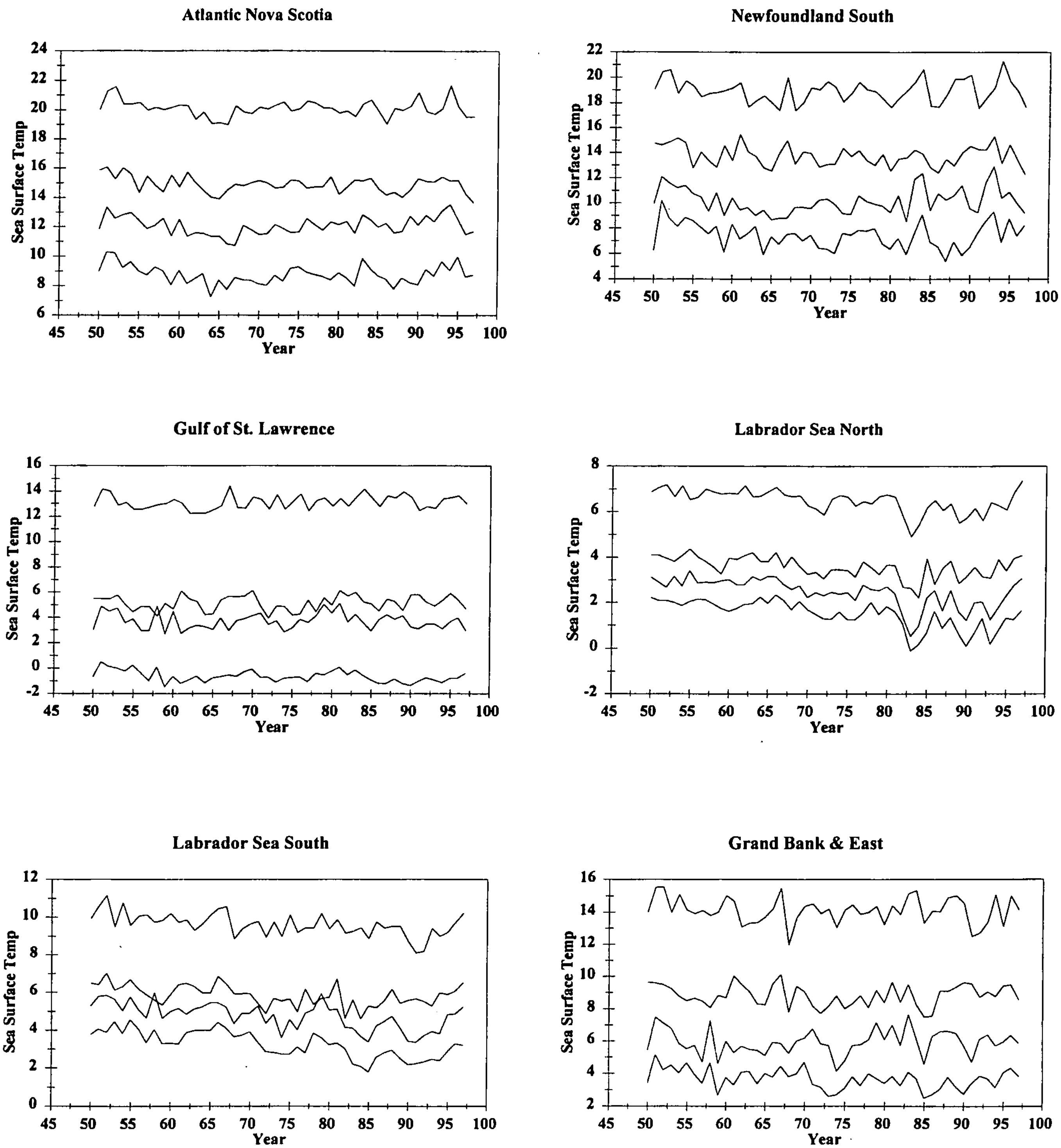


Fig. 5.1. Proportion of the smolt class of total North American salmon maturing at 1-sea-winter (grilse), 1971-95