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Recruitment Indices of Exploited Fishes and Invertebrates on the Newfoundland Shelf, the Grand Bank and St. Pierre Bank.

Indices de recrutement des poissons et des invertébrés exploités du plateau de Terre-Neuve, du Grand Banc et du banc Saint-Pierre

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Abstract
An initiative to compile a list of recruitment indices in Atlantic Canada has been undertaken by the Fisheries Oceanography Committee. Here we summarize information relating to species and stocks assessed within the Newfoundland Region, including those stocks assessed through the Northwest Atlantic Fisheries Organization (NAFO). Currently there are 24 species, or species groups, assessed and approximately 39 stocks for which status is evaluated including groundfish, pelagic fish, benthic invertebrates and marine mammals. Selected examples of recruitment indices are provided for yellowtail flounder (Limanda ferruginea), capelin (Mallotus villosus), Atlantic cod (Gadus morhua) and Atlantic salmon (Salmo salar). The assessment of these species provide examples of different methodolgies used in deriving recruitment indices for fish with widely differing life histories. Comparison of the indices across similar time periods demonstrates declines, increases and no change in recruitment of these different species within the Newfoundland Region. This information is intended to provide a background for developing a comprehensive approach to evaluating ecosystem responses in fish and invertebrate production within Atlantic Canada.

Résumé
Une initiative de compilation d'une liste d'indices de recrutement dans le Canada atlantique a été entreprise par le Comité d'océanographie des pêches. Voici un résumé des renseignements sur les espèces et les stocks évalués dans la région de Terre-Neuve, y compris les stocks évalués par l'Organisation des pêches de l'Atlantique nord-ouest (OPANO). Pour le moment, 24 espèces ou groupes d'espèces sont évalués et l'état d'environ 39 stocks est évalué, y compris des poissons de fond, des poissons pélagiques, des invertébrés benthiques et des mammifères marins. Divers exemples d'indices de recrutement sont donnés, notamment pour la limande à queue jaune (Limanda ferruginea), le capelan (Mallotus villosus), la morue franche (Gadus morhua) et le saumon atlantique (Salmo salar). L'évaluation de ces espèces donne des exemples des diverses méthodes utilisées pour établir les indices de recrutement de poissons ayant des cycles de vie très différents. La comparaison des indices correspondant à des périodes analogues signale des diminutions, des augmentations ou la stabilité du recrutement de ces différentes espèces dans la Région de Terre-Neuve. Cette information a pour but de permettre d'élaborer une approche globale à l'évaluation des réactions de l'écosystème en matière de production de poissons et d'invertébrés dans le Canada atlantique.

Introduction

Recently, the Fisheries and Oceanography Committee (FOC) was asked to compile a comprehensive list of recruitment indices for all species and stocks assessed within Atlantic Canada. This initiative is being done in association with the Atlantic Zone Monitoring Program (AZMP) and many of the details remain to be worked out regarding data formats, products and intended use. The information provided here is intended to provide a background for developing a comprehensive approach to evaluating ecosystem responses in fish and invertebrate production within Atlantic Canada. These issues were discussed during the annual FOC meeting in March 2001.

FOC Core Members in each region were asked to take the lead in bringing together the required information. Our approach has been to compile a list of species and stocks currently assessed in the NF region, including stocks assessed by NAFO. The information requested from assessment staff was a brief written summary addressing three questions:

1. What indices are available, both currently and historically?
2. Are all indices readily available in electronic format?
3. Are there any conditions that must be specifically addressed in using or interpreting any individual index?

We have undertaken an initial attempt to provide recruitment index data for selected species of fish, including: salmon (anadromous); capelin (pelagic); Atlantic cod (semi-demersal); yellowtail flounder (demersal). These fish species represent different components of the ecosystem and different approaches to providing recruitment indices. Evaluating the indices and the methods used should provide a starting point for developing broad scale measures of recruitment in fish and invertebrates of the Newfoundland region.

Newfoundland Region Stocks

Currently, there are 24 species, or species groups, assessed within the Newfoundland Region and approximately 39 stocks for which status is evaluated (Table 1). Here we have lumped some assessments together as a single evaluation. For example, White Hake is a single category where status is assessed for Divisions 3L, 3N, 3O and 3Ps which may represent different stocks. A list of common and scientific names is provided for reference (Appendix A).

Stock Summaries

Gadoids

There is recruitment data for 3 stocks: 3Ps, 3NO and 2J3KL cod. The first and second have sequential population analysis (SPA) estimates of year-class strength from SPA reconstructions of population size. The third has model estimates of relative recruitment strength derived from a number of indices. One can also use individual sources of data as information on recruitment (eg. research vessel survey catches, commercial and sentinel catch data etc…). All this info is available in the Research Documents and SCR documents and can be cited. The author's permission is required for citation of the Research Documents.

Redfish

Analytical assessments for redfish are not conducted thus a recruitment to the stock index is not available from a population model. A catch at length index from the research vessel surveys is available; however, a recruitment index from the smallest lengths observed in the survey has not been presented separately in the past as results are highly variable and redfish are likely not fully selected to the survey gear until they are a few years old. Nonetheless, with revision to the existing spreadsheets a recruitment index could be ascertained.

Flatfish

Indices for 3Ps American plaice and witch flounder include: Numbers at age and/or length from winter/spring surveys. There is no age data for Newfoundland witch flounder stocks since early 1990's. The numbers at age/length from GEAC (industry) surveys exist from 1998-2000.

Indices for 3LNO American plaice, 3LNO yellowtail flounder, and 3NO witch flounder include: numbers at age and/or length from spring surveys 1971-2000, fall surveys 1990-2000 (also 1981-89 for 3L only), juvenile surveys 1986-94, Spanish surveys of NAFO regulatory area in 3NO from 1995-2000. In addition, there is an index for 3LNO American plaice detailing recruitment at age 5 as established from VPA. Also an index exists for 3LNO yellowtail, showing numbers at length from industry grid surveys from 1996-2000.

Existing indices for 2+3K American plaice, 2+3KLMNO Greenland halibut, 2J3KL witch flounder include: numbers at age and/or length from fall surveys in 2J3K (1978-2000), 3L (1981-2000), 3NO (1990-2000), 2GH (sporadic 1978-99), and spring surveys (3LNO, 1971-2000). Specifically for Greenland halibut indices, numbers at age established from VPA, numbers at age/length from EU survey in 3M (1988-2000), and Spanish surveys of NAFO regulatory area in 3NO from 1995-2000 are also available.

The numbers at age indices are usually presented in NAFO and CSAS Research Documents for most stocks. The numbers at age for witch flounder have not been available since early 1990's. The numbers at length generally are not readily accessible.

Some major concerns in interpreting the above indices include: variations in survey coverage (temporal, spatial, depth), partial stock coverage in some survey series (eg. for 2+3KLMNO Greenland halibut, 2GH was not covered in most years), changes in vessel-gear (Yankee to Engel to Campelen), limitations of conversions used to make different vessel-gear combinations comparable. For stocks with VPA's, concerns exist with regards to catch at age, discarding, misreporting, etc."

Skates, Monkfish, Wolfish, Winter Flounder, White Hake

There are no recruitment indices for skate, monkfish, wolfish (spotted, striped, and northern), winter flounder, and white hake. Previously, the O-group survey (1994-1999) data was used particularly for white hake.

Herring

VPA based recruitment indices are available for three out of the five Newfoundland herring stocks: White Bay-Notre Dame Bay, Bonavista Bay-Trinity Bay, and St. Mary's Bay-Placentia Bay. These indices include research gill net catch rates and acoustic survey biomass estimates extending back to the early 1980's, and commercial gill net catch rates commencing in 1996. Gill net fisher and purse seine fisher observations were also available since 1996. These were derived from questionnaires in which fishers were asked to rate herring abundance on a scale of one to ten, with one being the lowest and ten being the highest. All of these abundance indices are available in spreadsheet format.

Capelin

Recruitment indices available for capelin (1972-1999) are summarised in Table 3. Currently, there is only one annual index remaining for capelin. Caution must be exercised when using these indices as the 95% confidence intervals are very large and thus there is much uncertainly associated with them.

Atlantic Salmon

Indices available for Atlantic Salmon include: 1. Campbellton River total returns to river and survival, 1993-2000; 2. total estimated numbers of North American maiden fish that have spent 2 sea-winters (2SW) at sea before spawning and grilse salmon, 1971-1999; and, 3. the total estimated numbers of Newfoundland and independently Labrador grilse and 2SW salmon. These indices consists of smolt and adult counts which represents total returns to the river. An interpretation of these indices requires knowledge of salmon life history and migration of specific stocks. It is also important to note, that the latter two indices are estimates not counts and evidently some reservation is required with regards to accuracy.

Shrimp

The only reliable recruitment index for shrimp is information collected during the fall surveys in SFA 6 (Hawke Channel + Division 3K) This index is contained within composite length

frequency distributions for each survey which is available in electronic format. However, quantitative indices by age have not yet been determined. They will subsequently become available as the time series increases, provided their reliability can be clearly demonstrated. In using or interpreting these indices one must recognize that it is an index under construction and there is some work to be done before it is truly quantitative.

In addition, for the past two years data has been collected from a small-meshed bag attached to the Campelen research trawl. This information can be useful information for a variety of fish and shellfish species. For example regarding shellfish, information has been collected that will improve the recruitment indices for both shrimp and snow crab.

Snow Crab

Catch rates from small-meshed traps are available dating back to 1981. These may be used as rough indicators of potential recruitment. Also, catch rates of pre-recruits (small-clawed males that are 76-94 mm carapace width) from the multispecies survey and the inshore trawl survey are also available (1995-2000). These indices are readily available in electronic format. Summaries of the results of these surveys are also available in Research Documents. In using these indices, it is important to understand that the relationship between pre-recruit abundance and subsequent commercial abundance has been assumed but not proven.

Short-Finned Squid

There is a recruitment index (number and kg per tow) for short-finned squid, that is based on July bottom trawl surveys on the Scotian Shelf, since 1970. This index does not correlate real well with annual abundance as inferred from commercial catches. It is also late with respect to practical use for assessment purposes as this species has a life cycle of only one-year. This index is readily available electronically.

Selected Examples of Recruitment Indices

As a starting point, we have selected four fish species within the Newfoundland region that have been formally assessed in terms of stock abundance and recruitment. These four species include: Yellowtail flounder (*Limanda ferruginea*); capelin (*Mallotus villosus*); Atlantic cod (*Gadus morhua*); Atlantic salmon (*Salmo salar*). Recruitment indices are available for these species for different time periods using different data sources and different estimation methods (Table 2).

Yellowtail flounder

Relative cohort strength was estimated from a multiplicative model using abundances for ages three and four years from the 1984-1999 Canadian spring and 1990-1999 Canadian fall research vessel surveys. The model took the form:

$$\log(N_{ijk}) = \tau + \alpha_i + \beta_j + \delta_k + \varepsilon$$

where: N_{ijkt} = number at age i from survey j belonging to cohort k

τ = intercept

α_i = age effect for i = 3 and 4

β_j = survey effect for j = spring and fall

δ_k = cohort effect

ε = residuals from the fitted model

The model showed no obvious pattern in the residuals and there was a significant fit to the data in the most recent assessment (Walsh et al. 2000). However there was no significant cohort effect, suggesting that there has been little contrast in cohort size over the time period.

R^2=0.51, n=51

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	1	18.37488273	18.37488273	15.79	0.0004
COHORT	16	20.26955625	1.26684727	1.09	0.4027
SURVEY	1	0.06940278	0.06940278	0.06	0.8086

Although there was no significant difference among cohorts, the estimates for 1993 and 1994 are somewhat higher than the other cohorts in the time series (Figure 1). However, there was a switch gears in the autumn survey of 1995 and the spring survey of 1996. The research trawl indices back to 1984 are converted Engel trawl indices to Campelen equivalents. The Engel trawl was poor at catching small flatfish, which suggests that year-classes may have been under estimated for the 1980 to 1990 year-classes. The first year-class captured by the Campelen trawl was the 1991 year-class at age four.

Capelin

Recruitment in capelin is considered to occur at age two. There have been a number of different recruitment and pre-recruit estimates for capelin that have included directed acoustic surveys, commercial catch rates, pelagic 0-group surveys, aerial surveys and egg depositional studies and totalled 13 indices (Table 3). These indices extend from as early as 1972 for Russian commercial catch rates. Presently, there is only one annual index remaining due to program cutbacks. By the year 2000, sampling effort had been reduced to a single beach sampling site. Until 1999, a multiplicative model was run combining the different indices into a single estimate. The method has the advantages of combining different indices over the life span of capelin, for ages 0 to 5 years (Nakashima and Evans 1999). The model used was

$$N_{ijkt} = I \cdot C_k \cdot S_j \cdot A_i \cdot \in$$

where I = intercept
C_k = cohort effect for k = 0…5
S_j = survey effect for j = 1…13
A_i = age effect for i = 0…5
$\in$ = residuals from fitted model

In addition, the method uses an inverse variance weighting method which allows indices with similar trends to have a greater influence on the model. Finally, confidence limits were estimated for each year-class.

Recruitment varied by a factor of 15.6 over the time period 1975-1999 (Figure 2). The high variance associated with the final years reflects greater uncertainty associated with a reduction to three in the number of indices used for the most recent year-class estimates.

Atlantic cod

Recruitment in Newfoundland cod stocks was traditionally estimated as the abundance of age four cod based on Sequential Population Analysis (SPA). More recently, recruitment has been based on the abundance of age three cod using both SPA models and research vessel standardized catch per tow data. In recent years, neither the northern cod (2J3KL) or St. Pierre Bank cod (3Ps) SPA models were considered acceptable (Lilly et al. 1998, Stansbury et al. 1999, Brattey et al. 2000). Therefore, SPA estimates since the 1990 year-class for the northern cod and since the 1993 year-class in the St. Pierre Bank stock are uncertain (Figure 3). Significant problems also exist for the northern cod and St. Pierre Bank cod research vessel data. In the case of northern cod, there are virtually no fish left offshore within the traditional survey area. During most of the 1990's the majority of cod within the 2J3KL stock area have occurred inshore. Juvenile cod appear to recruit to the offshore from inshore nursery areas beginning with age three (Dalley and Anderson 1997). However, the degree to which offshore juvenile cod accurately represent year-class strength is not known. Recent research vessel survey data for year-classes estimated at ages 3-5 years are not stable. For the St. Pierre Bank research vessel survey, different estimates of recruitment occur with, or without, the inclusion of the Burgeo Bank portion

of the survey area and with, or without, one large catch in the 1995 survey (Anderson and Colbourne 2000). Finally, a broad scale pelagic juvenile fish survey was carried out from 1994-1999 from southern Labrador to the southern Grand Banks (2J3KLNO) including the inshore to estimate the pre-recuit abundance of northern and southern Grand Bank cod (Dalley et al. 2000). These indices provide a stock-wide estimate of pre-recruits for both the northern cod (2J3KL) and southern Grand Banks cod (3NO) stocks (Figure 3).

Atlantic salmon

The salmon recruitment indices were developed in order to provide catch advice for the west Greenland and North American salmon fisheries. The material has been available since 1993 and updated since then (Rago et al. 1993; Anon. 2000). The techniques and updates are fully described and referenced in Anon. (2000). Basically, the run reconstruction model used to estimate numbers of salmon prior to fisheries is based on separate estimates for six geographic areas in North America. The areas are: Labrador, Newfoundland, Québec, Gulf of St. Lawrence, Scotia-Fundy, and USA. Within each area a variety of techniques are used but largely depend on counts at the approximate 90-100 enumeration facilities raised to larger areas based on watersheds.

Recruitment index for Labrador salmon was based on commercial catches raised to total recruits prior to fishing using exploitation rates adjusted for changes in licenced effort in the commercial fishery. Since the commercial fishery was closed in Labrador in 1998, the time series also ended as of the 1997 fishing year.

The recruitment index of Labrador salmon for 1 sea-winter and 2 sea-winter age classes are shown in Table 1 and plotted in Figure 4.

Recruitment index for insular Newfoundland salmon was based on estimates of total recruits prior to fisheries exploiting them. Estimates were developed from separate parameter values grouped as follows: northeast Newfoundland (SFAs 3-8), south coast (SFAs 9-11), southwest coast (SFAs 12-13), and northwest coast (SFAs 14A). Returns of 1SW and 2SW salmon to each area were derived using a variety of methods using data available for individual river systems and groupings of various SFAs. The methods used to derive these estimates include counts of salmon at various enumeration facilities throughout each region, population estimates from mark-recapture studies, and the application of angling and commercial catch statistics, angling exploitation rates, and measurements of freshwater habitat.

The recruitment index of Newfoundland salmon for 1 sea-winter and 2 sea-winter age classes are shown in Figure 4.

Estimation of an aggregate measure of abundance has utility for identifying trends, evaluating management measures, and investigating the influence of the marine environment on survival, distribution, and abundance of salmon. In order to provide a recruitment index for North American salmon return estimates to six geographic areas in North American were summed along with commercial catches from Newfoundland and Labrador and at west Greenland (Rago et al. 1993; Anon. 2000). The estimation methods for calculating total returns to the six geographic regions included direct methods such as traps, counting fences, and mark-recapture studies. Indirect methods include reliance on catch data (both recreational and commercial) and plausible ranges of in-river and commercial fisheries exploitation rates. This includes transferring these rates to areas and rivers with no enumeration facilities. Some of the parameters used to estimate abundance in this section are known with poor precision, are difficult or impossible to determine, and vary annually; where this is so plausible ranges of values are used instead.

The recruitment index of North American salmon for 1 sea-winter and 2 sea-winter age classes are shown in Table 1 and plotted in Figure 4.

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Table 1. Summary of fish, invertebrate and marine mammal species that are assessed for different NAFO Divisions and Sub-Areas within the Newfoundland Region.

Groundfish:

2J3KL Cod
3Ps Cod
2GH Cod
3LNO Haddock
3Ps Haddock
White Hake 3L, 3N, 3O, and 3Ps
3Ps Pollock
2J3KL Witch Flounder
3Ps Witch Flounder
Blackback (Winter Flounder) 3K, 3L, and 3Ps
2J3KL American Plaice
3Ps American Plaice
Redfish Unit 2
Redfish 3O
Redfish SA2+3K
Wolfish 2J, 3K, 3L, 3N, 3O, and subdivision 3Ps
Lumpfish 3K, 3L, and 3P
Skate 3L, 3N, 3O, and 3Ps
Monkfish 3L, 3N, 3O, and 3Ps

Pelagics:

Herring - 5 Stocks :	White Bay – Notre-Dame Bay
	Bonavista bay – Trinity Bay
	Conception Bay – Southern Shore
	St. Mary's Bay – Placentia Bay
	Fortune Bay

Capelin in 2J3KL
3Ps Capelin

Invertebrates:

Snow Crab - Div. 2J, 3K, 3LNO, 3Ps, 4R
Lobster - LFAs 3-14
Shrimp - Div. OB to 3L, 3M
Iceland Scallop - Div. 3LNO, 3Ps, 4R
Sea Scallop - Div. 3Ps

Diadromous:

Newfoundland:	Exploits River
	Campbellton River
	Gander River
	Indian Bay Brook
	Middle Brook
	Terra Nova River
	Northwest River
	Northeast Brook
	Rocky River
	Northeast River

Little River
Conne River
Highlands River
Crabbes River
M. Barachois River
Robinsons River
Fishells River
Flat Bay Brook
Harry's River
Lomond River
Torrent River
Western Arm Brook

Labrador: Big Brook
English River

Marine Mammals:

Harp Seals

NAFO Stocks:

Newfoundland lead: Cod 3NO
American plaice 3LNO
Yellowtail Flounder 3LNO
Witch Flounder 3NO
Greenland Halibut Subarea 2 3KLMNO
Redfish 3LN
Shrimp 3LN
Witch Flounder 2J3KL
Skates 3LNOPs

Non- Newfoundland lead: Cod 3M (Spanish)
Shrimp 3M (Icelandic)
Squid 3 &4 (US)
Capelin 3LNO (Russian)
Greenland Halibut 0+1 (Denmark)
Grenadiers
3M American plaice
Shrimp 0 +1 Denmark Strait and East Greenland
Redfish 3M
Redfish Subarea 1
Other Finfish Subarea 1

Table 2. Summary of recruitment indices for selected species of fish in the Newfoundland region. + - index no longer available.

Species	n	Stocks	Years	Methods
Capelin	1	2J3KL	1975-1999+	Multiplicative Model
Yellowtail flounder	1	3LNO	1980-1996+	Sequential Population Analysis
			1984-1999	Cohort Model (RV – Spring)
			1990-1999	" (RV – Autumn)
Atlantic Cod	3	2J3KL	1959-1990+	Sequential Population Analysis
			1981-1999	RV – Autumn
			1994-1999+	0-Group Survey
		3NO	1959-1999	Sequential Population Analysis
			1971-1999	RV – Spring
			1994-1999+	0-Group Survey
			1989-1999	RV – Autumn
		3Ps	1959-1993+	Sequential Population Analysis
			1983-1999	RV - Spring
Atlantic salmon	24	NF & Lab	1983-1999	Run Reconstruction Model

Table 3. Summary of capelin recruitment indices used in the multiplicative model for the Newfoundland region. * - currently only a single beach is sampled. + - index is no longer available.

Index	Survey Years	Ages (y)
Egg Deposition	1990-1999*	2-5
Aerial Survey	1982-1998+	2-5
Purse Seine Catch Rate	1981-1996+	2-5
Trap Catch Rate	1981-1993+	2-5
Russian 2J3K Commercial Catch Rate	1972-1991+	2-5
Groundfish 2J3K Fall Bycatch	1980-1994+	2-4
Groundfish 3L Fall Bycatch	1985-1993+	1-3
Offshore 0-Group	1994-1999+	0
Offshore 1-Group	1994-1999+	1
Conception Bay Sediment Larval	1987-1993+	0
Bellevue Emergent Laval	1990-1999*	0
Canadian Spring Acoustic Survey	1982-1996+	1-5
Canadian 2J3K Fall Acoustic Survey	1981-1994+	1-5

Appendix A

Common and scientific names of fish, invertebrate and mammal species currently managed by the Department of Fisheries and Oceans in the Newfoundland Region.

Common Name	Scientific Name
Fish	
American plaice	**Hippoglossoides platessoides**
Atlantic cod	**Gadus morhua**
Atlantic salmon	**Salmo salar**
Capelin	**Mallotus villosus**
Greenland halibut	**Reinhardtius hippoglossoides**
Haddock	**Melanogrammus aeglefinus**
Herring	**Clupea harengus**
Lumpfish	**Cyclopterus lumpus**
Monkfish	**Lophius americanus**
Pollock	**Pollachius virens**
Redfish	*Sebastes* sp.
Thorny skate	**Raja radiata**
White hake	**Urophyscis tenuis**
Winter flounder (Blackback)	**Pleuronectes americanus**
Witch flounder	**Glyptocephalus cynoglossus**
Wolfish spotted	**Anarhichas minor**
Wolfish striped	**Anarhichas lupus**
Wolfish northern	**Anarhichas denticulatus**
Invertebrates	
Lobster	**Homarus americanus**
Scallop Iceland	*Chlamys islandica*
Scallop Sea	*Placopecten magellanicus*
Shrimp Northern	*Pandalus borealis*
Shrimp	*Pandalus montagui*
Snow crab	*Chionoecetes opilio*
Mammals	
Harp seal	**Phoca groenlandica**

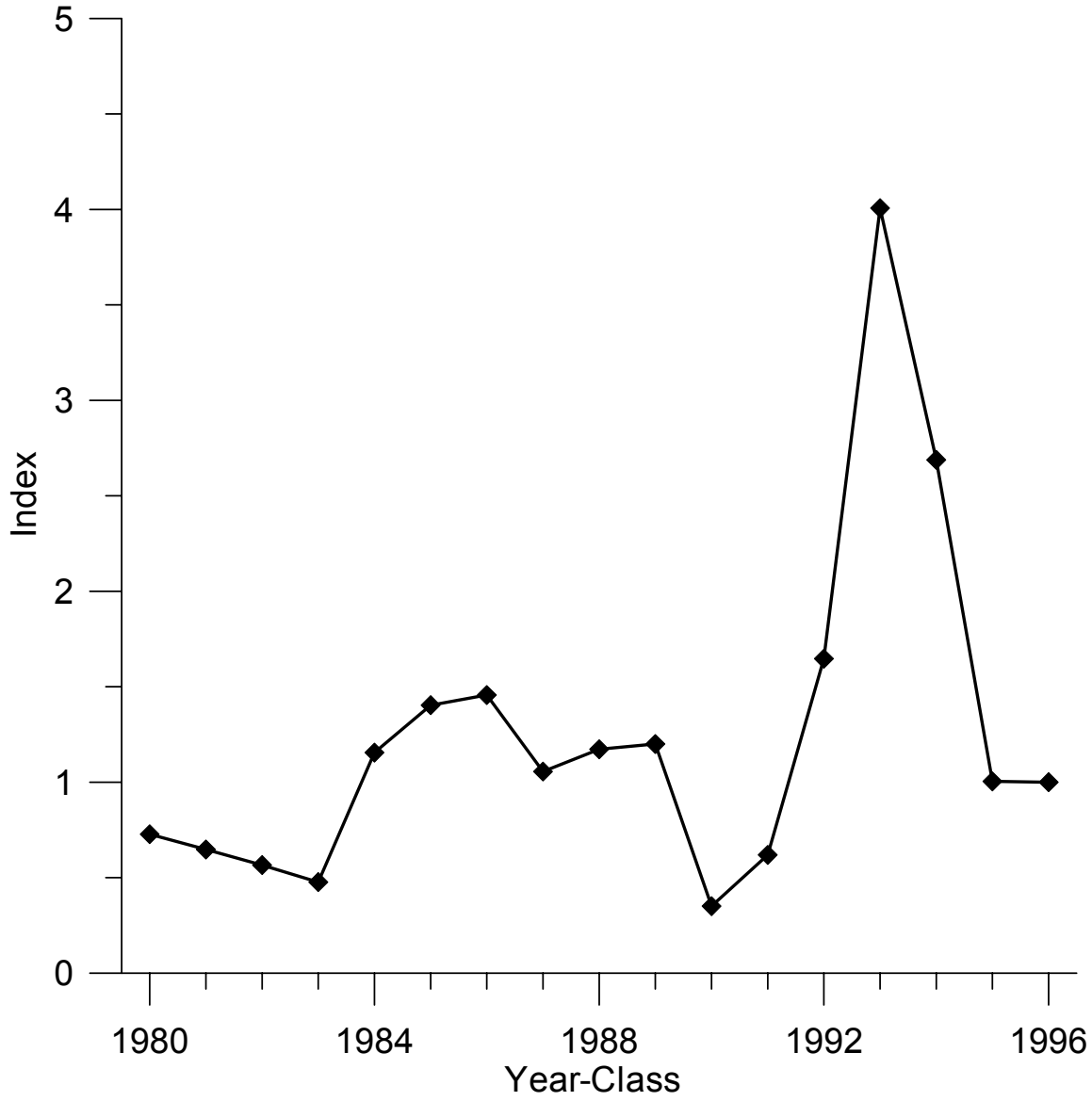

Figure 1. Year-class strength of yellowtail flounder on the Grand Banks of Newfoundland, 3LNO, as estimated by a multiplicative cohort model.

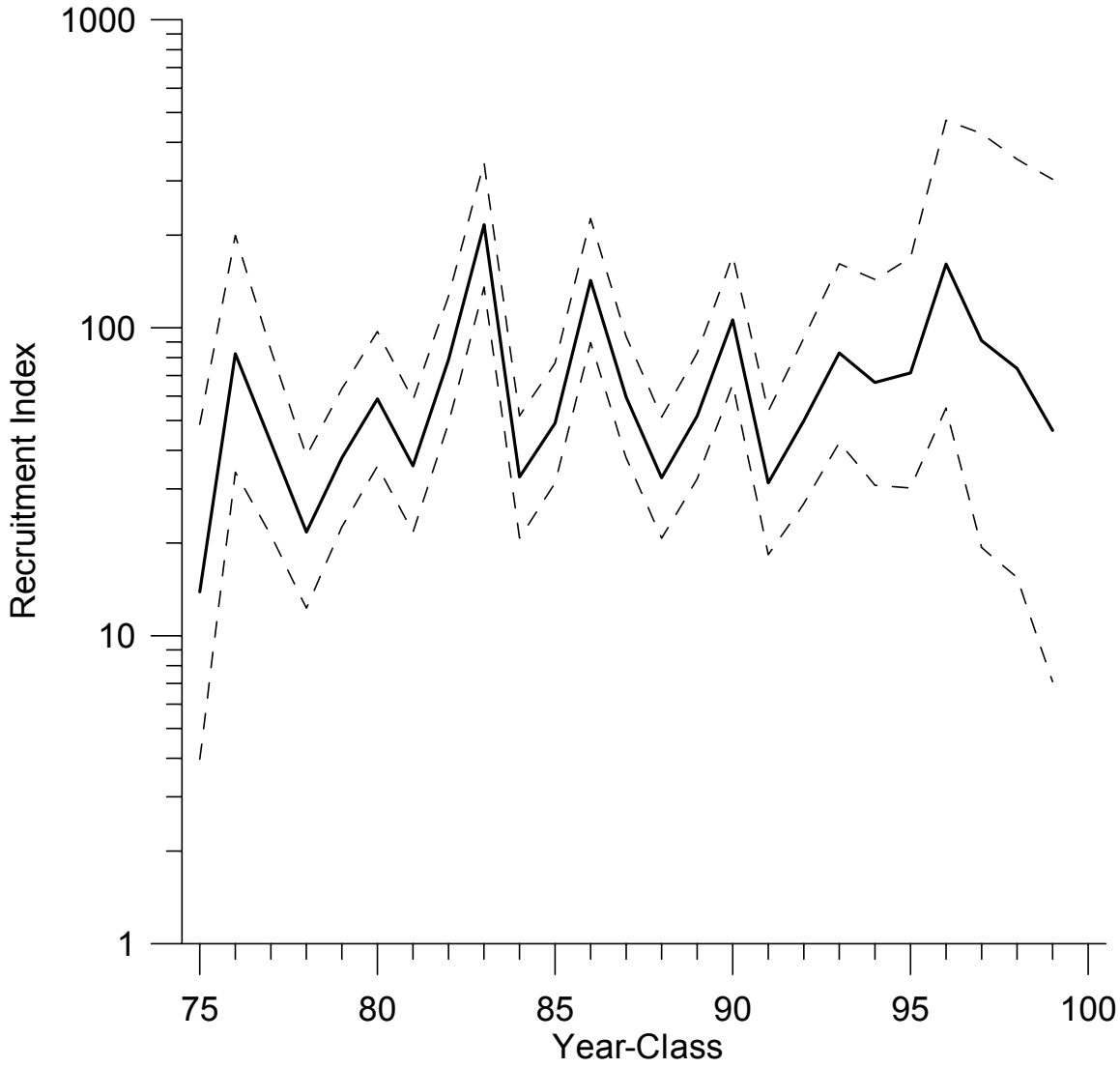

Figure 2. Year-class strength estimates of capelin, 2J3KL, using a multiplicative variance weighted model for the years 1975 to 1999. The dashed lines are the 95% confidence limits.

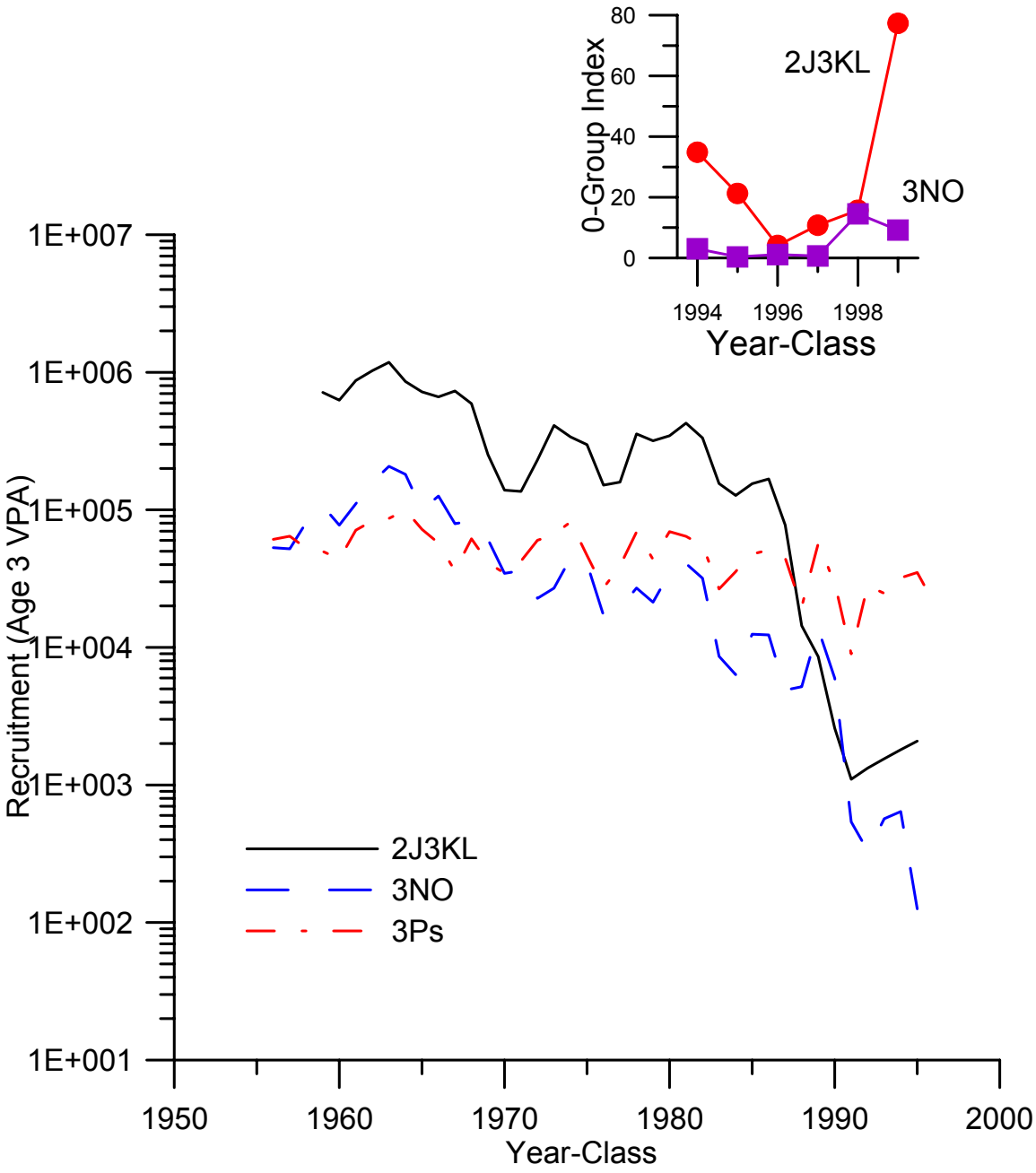

Figure 3. Recruitment in the northern cod (2J3KL), southern Grand Banks cod (3NO) and St. Pierre Bank cod (3Ps), as abundance estimated at age three years by Sequential Population Analyses. The inset figure demonstrates pre-recruit abundance for the northern and southern Grand Banks cod stocks estimated by the Pelagic Juvenile Fish Survey.

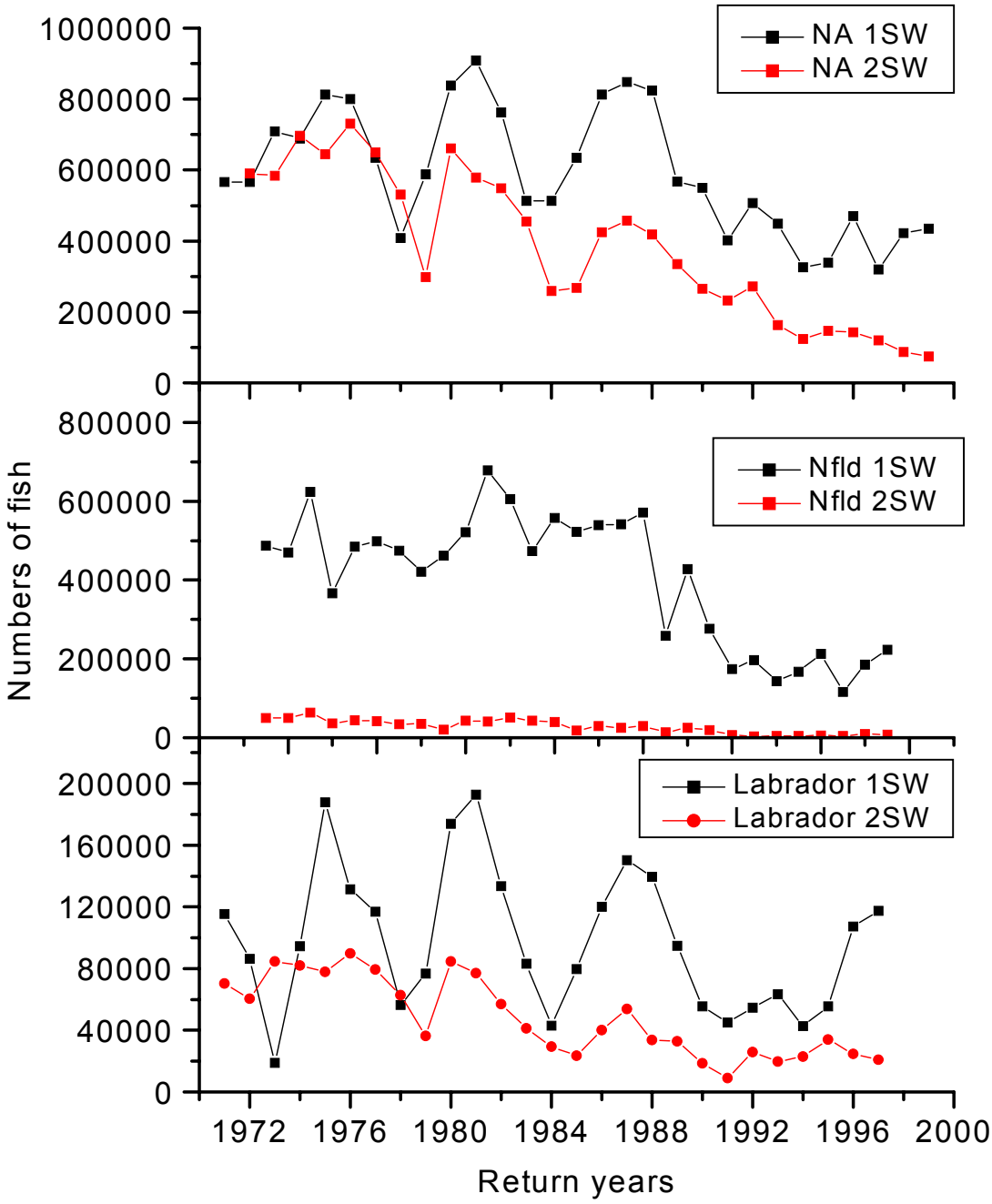

Fig. 4. Recruitment indices for North American, Newfoundland and Labrador 1 sea-winter and 2 sea-winter salmon, 1971-1999.