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Recent Changes in the Distributions of Atlantic Cod and American Plaice in the Southern Gulf of St. Lawrence

by

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[1]This series documents the scientific basis for the evaluation of fisheries resources in Atlantic Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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[1]La présente série documente les bases scientifiques des évaluations des ressources halieutiques sur la côte Atlantique du Canada. Elle traite des problèmes courants selon les échéanciers dictés. Les documents qu'elle contient ne doivent pas être considérés comme des énoncés définitifs sur les sujets traités, mais plutôt comme des rapports d'étape sur les études en cours.

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Abstract

The distribution of Atlantic cod (*Gadus morhua*) and American plaice (*Hippoglossoides platessoides*) in the southern Gulf of St. Lawrence was compared between recent years (1994 and 1995) and earlier periods of low or high abundance using data from bottom trawl surveys conducted each September since 1971. Cod distribution differed between the earlier periods of low and high abundance. In the low abundance period in the mid-1970s, cod densities were highest in shallow water in the western half of the southern Gulf. In the high abundance period in the early to mid-1980s, cod distribution expanded into the central Magdalen Shallows and eastern half of the southern Gulf, with peak densities shifting to intermediate depths. In recent years when cod abundance was again low, cod distribution shifted back to the pattern seen in the previous low abundance period, with peak densities in shallow water in western regions of the southern Gulf. An index of cod depth distribution was significantly correlated with cod abundance but was unrelated to indices of environmental conditions. These results support the hypothesis that cod distribution is density-dependent during the summer and early fall feeding season in the southern Gulf. Cod distribution differed between the current period and the previous period of low abundance in one respect: a higher proportion of cod occurred in eastern regions of the southern Gulf in recent years. In recent years, cod biomass has fallen to levels similar to those of the early to mid-1970s in western strata but has remained well above the earlier low levels in eastern strata. Plaice distribution was similar between the high abundance period in the late 1970s and the low abundance period in the mid to late 1980s. However, distribution in recent years has shifted sharply to the east. Declines in plaice biomass since 1991 have been confined to western strata.

Résumé

Nous avons comparé la répartition de la morue (*Gadus morhua*) et de la plie canadienne (*Hippoglossoides platessoides*) dans le sud du golfe du Saint-Laurent entre différentes périodes, soit entre la période récente (1994 et 1995) et des périodes de grande ou de faible abondance. Les relevés de la répartition ont été obtenus par des chalutages de fond menés en septembre depuis 1971. La répartition de la morue n'est pas la même selon que l'on examine les périodes antérieures de grande abondance ou celles de faible abondance. Dans ce dernier cas, au milieu des années 1970, la densité des morues était la plus élevée dans les eaux peu profondes du secteur ouest de la partie sud du golfe du Saint-Laurent. Au cours de la période de grande abondance allant du début au milieu des années 1980, la morue était trouvée jusque dans la partie centrale du banc des Îles de la Madeleine et dans la moitié est de la partie sud du golfe; les densités les plus élevées ont été observées à des profondeurs intermédiaires. Ces dernières années, marquées à nouveau par la faible abondance de la morue, la répartition de celle-ci est revenue à ce qu'elle était pendant la période antérieure de faible abondance, les densités les plus élevées étant observées dans les eaux peu profondes du secteur ouest de la partie sud du golfe. Il existe une corrélation statistiquement significative entre un indice de la répartition de la morue selon la profondeur et l'abondance, mais pas entre cet indice et des indices des conditions du milieu. Ces résultats confirment l'hypothèse à l'effet que la répartition de la morue est fonction de sa densité pendant la période d'alimentation estivale et du début de l'automne dans la partie sud du golfe. La répartition de la morue au cours de la période actuelle de faible abondance diffère de celle de la précédente période de faible abondance en ce qu'on observe une proportion accrue de morues dans le secteur est de la partie sud du golfe ces dernières années. Au cours de cette dernière période, la biomasse de la morue est tombée à des niveaux semblables à ceux de la période allant du début au milieu des années 1970, observés dans les strates du secteur ouest, mais elle est demeurée bien supérieure aux faibles valeurs mesurées dans les strates du secteur est. La répartition de la plie a peu varié entre la période de grande abondance de la fin des années 1970 et celle de faible abondance s'étalant du milieu à la fin des années 1980. Ces dernières années, toutefois, les populations se sont déplacées de manière prononcée vers l'est. Les déclins de la biomasse de la plie depuis 1991 sont limités aux strates de l'ouest.

Introduction

The geographic distribution of individuals in a population reflects their environmental preferences and the results of intra- and interspecific interaction. Changes in distribution may reflect changes in environmental conditions (e.g., deYoung and Rose 1993), changes in environmental preferences (e.g., Swain and Kramer 1995), changes in the distribution or abundance of prey, competitors or predators, or changes in the relative abundance of stock components, and can have important implications for fisheries production and management.

The two dominant groundfish species in the southern Gulf of St. Lawrence are Atlantic cod (*Gadus morhua*) and American plaice (*Hippoglossoides platessoides*). The abundance of both these species has varied widely in the southern Gulf since 1971 (Fig. 1). Cod abundance was low in the early to mid-1970s, increased rapidly in the late 1970s to high levels in the early to mid-1980s, and then decreased in the late 1980s to low levels in the early to mid-1990s. Plaice abundance was low in the early 1970s, increased to high levels in the mid- to late 1970s, and decreased in the early 1980s, remaining stable at a relatively low level since the mid-1980s. The distribution of cod in the southern Gulf in September differed between the 1970s and 1980s (Swain and Wade 1993, Swain 1993). In the 1970s, cod were most concentrated in relatively shallow inshore areas in the western portion of the southern Gulf. In the early to mid-1980s, cod distribution shifted further offshore, with highest densities at intermediate depths. In contrast to cod, plaice distribution has remained remarkably stable in the southern Gulf throughout the 1970s and 1980s (Swain and Morin 1996).

A possible explanation for the shift in cod distribution in the southern Gulf between the 1970s and 1980s is that this shift was a response to the increase in cod abundance. Bioenergetic considerations suggest that fish should occupy colder water at higher levels of abundance in order to reduce metabolic costs when food rations are low (e.g., Swain and Kramer 1995). Swain (1993) suggested that the shift in cod distribution between the 1970s and 1980s reflected a shift from high-cost, resource-rich habitats at low abundance to low-cost habitats at high abundance. If this hypothesis is correct, then a shift in cod distribution back to shallow inshore areas is expected for recent years of low abundance. One purpose of this report is to test for this shift in distribution.

Powles (1965) recognized two groups of plaice in the southern Gulf in summer: a northwest group occupying Chaleur Bay and the western Shallows from the Shediac Valley to the Orphan Bank area, and a southeast group occupying areas off the west coast of Cape Breton Island. Tagging studies revealed little movement of adults between the two areas, but meristic studies failed to reveal differences between the two areas, perhaps reflecting mixing via larval drift. Recent genetic analyses (Stott et al. 1992) and analyses of variation in yearclass strength in the west and east (Swain and Morin 1996) support the view that plaice in the southern Gulf represent a single population. Eastern and western stock components have also been suggested for southern Gulf cod (e.g., Templeman 1962), though evidence for population subdivision is equivocal (e.g., Campana et al. 1995). For example, cod size-at-age and age composition are very similar for eastern and western 4T and distinct from those in neighbouring areas (e.g., 4Vn; Sinclair and Fanning 1995, Sinclair 1996). A second purpose of this report is to describe changes in the distribution of biomass between eastern and western areas of the southern Gulf for both cod and plaice.

Methods

These analyses use data from the bottom trawl survey conducted in the southern Gulf each September since 1971.

Geographic Distribution

I mapped geographic distribution for age-5 cod and for commercial-sized plaice (>30 cm TL). In order to emphasize changes in distribution rather changes in abundance, I used a measure of local density U_{ij} that was adjusted for variation in overall population size:

$$U_{ij} = Y_{ij} \frac{\overline{Y}_{\bullet}}{\overline{Y}_i}$$

where Y_{ij} is the catch in tow j in year i, $\overline{Y}_i$ is the stratified mean catch rate in year i, and $\overline{Y}_{\bullet}$ is a scaling factor (approximately equal to the average stratified mean catch rate in the time series). $\overline{Y}_{\bullet}$ was 25 for age-5 cod and 70 for commercial-sized plaice. I mapped the log-transformed catch rate $L_{ij}=\ln(U_{ij}+1)$ for 5 yr of low abundance, 5 yr of high abundance, 1994 and 1995. The low abundance period was 1972, 1974-1977 for cod and 1984-87, 1989 for plaice. The high abundance period was 1980-82, 84, 85 for cod and 1976-80 for plaice. For each case, I calculated variograms and fitted spherical models to these variograms using GS^+ (Gamma Design 1994; Fig. 2 and 3). I estimated fish density at each point on a 11.75x9.75 km grid using ordinary point kriging, calculated using the MATLAB program COKRI (Marcotte 1991). Interpolations used the five nearest neighbours. Contours were drawn using SURFER (Golden Software 1991).

Bathymetric Pattern

The mean and variance of trawl survey catches are positively related. Thus, I analyzed the bathymetric pattern of age-5 cod using generalized linear models (McCullagh and Nelder 1989). Following Smith (1990), I assumed a Poisson error distribution. This distribution is often appropriate for counts data, including counts of organisms in sampling units (Pielou 1977). Models were of the form:

$$\mathrm{E}[U_i] = \mu_i = \exp(\beta_0 + \beta_1 X_i + \beta_2 X_i^2)$$
$$\mathrm{Var}[U_i] = \phi\mu_i$$

where X_i is the depth of tow i and ϕ is a parameter for extra-Poisson variation. Extra-Poisson variation was expected because organisms typically show a clumped rather than a random spatial pattern (Pielou 1977). I tested the significance of effects of depth on cod density using analysis of deviance. I used pseudo-R^2 values to assess the importance of each model term. These values are the percent of the deviance of the null model accounted for by each model term.

East/West Biomass

I estimated trawlable biomass of cod and plaice (all ages/sizes) in each stratum by multiplying the mean weight per standard tow in a stratum by the number of trawlable units in the stratum. For each year, I calculated the trawlable biomass in western strata (415-429) and eastern strata (431-439). Plaice catches by the *E. E. Prince* were divided by 0.642 to make them equivalent to catches by the *Lady Hammond*. This conversion factor was derived from an analysis of weights caught by the two vessels in the 1985 comparative fishing experiment (G. A. Nielsen, unpublished analyses). Although comparative fishing experiments in 1985 and 1992 revealed differences in fishing efficiency among the *E. E. Prince*, *Lady Hammond*, and *Alfred Needler* in terms of numbers of cod caught (Nielsen 1994), analyses in terms of the weight of cod caught failed to reveal significant differences in fishing efficiency among these vessels (G. A. Nielsen, unpublished analyses) and no adjustments have been made here to weights of cod caught to account for the vessel changes in 1986 and 1992.

Results

Cod

In the low abundance period in the mid-1970s, age-5 cod densities were highest in inshore areas of the western half of the southern Gulf, in Chaleur Bay and the Miramichi-Shediac Valley area (Fig. 4). During this period, densities of age-5 cod were relatively low in the central Magdalen Shallows between the Magdalen Islands and Gaspé Peninsula and in the eastern half of the southern Gulf. In the high abundance period in the early to mid-1980s, the distribution of age-5 cod expanded into the central Magdalen Shallows and the eastern half of the southern Gulf. The center of distribution (i.e., area of highest densities) shifted offshore to areas off the Gaspé Peninsula and in the central Magdalen Shallows. In 1994 and 1995, the distribution of age-5 cod in the western part of the southern Gulf shifted back to the pattern seen in the mid-1970s. Cod densities were highest in near-shore regions of Chaleur Bay and the Miramichi-Shediac Valley area, and were relatively low in the central Magdalen Shallows. However, the relative density of cod is clearly higher in the east in recent years compared to the low abundance period in the mid-1970s (or even compared to the high abundance period in the early to mid-1980s).

Depth distribution of age-5 cod differed between the low abundance period in the mid-1970s and the high abundance period in the early to mid-1980s (Fig. 5, Table 1). In both periods, the effect of depth on cod catch rates was highly significant (Table 1). In the mid-1970s, cod density was highest in shallow water (Fig. 5). Depth explained 9% of the deviance in cod catch rates, but the quadratic term was not significant, accounting for only 0.6% of the deviance. In the early to mid-1980s, cod density tended to be highest at intermediate depths (maximum predicted density at 86 m, Fig. 5). Depth explained 22.5% of the deviance in cod catch rates, and the quadratic term was highly significant, accounting for 19% of the deviance. In 1994 and 1995, depth distribution resembled the mid-1970s pattern (Fig. 5). In both years, cod density tended to be highest in shallow water. Depth explained 12% (1994) or 6% (1995) of the deviance in cod catch rates, and the quadratic term was not significant, accounting for only 0.2% (1994) or 1.1% (1995) of the deviance.

In order to examine annual variation in the September depth distribution of age-5 cod, I fit Poisson regression models to cod catch rates for each year from 1971 to 1995. I used the percent of the deviance accounted for by the quadratic depth term as an indication of the strength of the tendency for cod densities to be highest at intermediate depths (see Swain (1993) for more detailed analyses). The quadratic term explained 10% or more of the deviance in the catch rates of age-5 cod in 1971 and 1980-1988 (Fig. 6). The strength of the quadratic term was low in the mid-1970s and in the 1990s. This index of bathymetric pattern was positively correlated with cod abundance (R=0.65, P=0.0005 for age-5 abundance; R=0.75, P=0.0001 for 4^+ abundance) but was unrelated to environmental conditions (near-bottom temperature: R=0.34, P=0.10 for median temperature available; R=0.04, P=0.86 for mean temperature available).

The percent of the cod trawlable biomass occurring in eastern strata has tended to increase since 1971 (Fig. 7). Declines in cod biomass in the late 1980s and early 1990s were steeper in the western strata than in the eastern strata. In recent years, biomass has fallen to levels similar to those of the early to mid-1970s in the western strata but has remained well above the earlier low levels in the eastern strata.

Plaice

Plaice distribution was similar between the high abundance period in the late 1970s and the low abundance period in the mid to late 1980s (Fig. 8). In both periods, plaice densities were highest in Chaleur Bay, in a second area extending from the Gaspé Peninsula to the central Magdalen Shallows, and in a third area off the Cape Breton coast. Distributions in 1994 and 1995 show striking departures from this pattern. In both years, plaice distribution has shifted sharply to the east. In 1995, the percent of the plaice biomass occurring in eastern strata was the highest in the time series (Fig. 7). Plaice biomass has fluctuated less widely in the eastern strata than in the western strata, neither rising as sharply as the western biomass in the early 1970s nor falling as sharply as the western biomass in the early 1980s. Recent declines in plaice biomass have been confined entirely to the western strata (Fig. 7).

Discussion

When cod abundance decreased in recent years, cod distribution in the southern Gulf shifted back to the pattern seen during the previous period of low abundance in the mid-

1970s, when cod densities tended to be highest in shallow inshore waters. This provides further support for the hypothesis that cod distribution is density-dependent during the summer feeding season in the southern Gulf, with distribution shifting from warm (high cost) shallow waters at low abundance to colder (low cost) deeper water at high abundance (Swain 1993).

For both cod and plaice, the percent of the biomass occupying eastern strata has been high in recent years. For cod, the percent of the biomass in the east has tended to increase over the history of the survey. For plaice, no sustained trend is evident, though the values for 1995 and 1994 are the highest and third highest in the time series. A number of hypotheses can be suggested to explain variation in the distribution of biomass between eastern and western strata:

- A high proportion of the biomass in eastern strata could reflect an early migration out of the southern Gulf. However, analyses of fisheries timing suggests that the timing of the fall cod migration is remarkably constant and occurs well after the September survey (Sinclair and Currie 1994). Commercial fisheries data are not available to track the fall migration in 1994 and 1995, but sentinel fisheries data indicate a movement of cod out of the western Gulf in mid to late October in both these years (J. M. Hanson and G. A. Chouinard, pers. comm.), consistent with fall fisheries timing in earlier years and again well after the September survey.
- Unlike the fall migration out of the Gulf, timing of the spring migration into the Gulf appears to be variable and related to the disappearance of ice from the Gulf (Sinclair and Currie 1994). A delay in the spring migration may reduce westward penetration into the Gulf and affect the distribution of spawning between western and eastern sites. If fish tend to return each year to the same feeding grounds (e.g., Powles 1965) or to their nursery areas, then changes in the distribution between western and eastern areas in one year may influence the distribution between these areas in future years.
- Changes in the distribution between western and eastern areas may reflect environmental changes, changes in the distribution or abundance of prey, competitors, or predators (including fisheries), changes in the relative abundance of genetically distinct stock components, or differences in exploitation rates between the two areas.

Further work is required to understand the mechanisms underlying variation in the distribution of cod and plaice between western and eastern grounds in the southern Gulf.

The recent changes in the distributions of cod and plaice in the southern Gulf are consistent with anecdotal reports from fishers. Fishers view cod abundance as relatively high in inshore areas, particularly off PEI and Cape Breton, and cod and plaice abundance as relatively high in eastern areas compared to western areas (Anon. 1996).

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Table 1. Poisson regression results for the effect of depth on catch rates of age-5 cod in the southern Gulf of St. Lawrence in September during 5 yr of low abundance, 5 yr of high abundance, 1994 and 1995. *N* is the number of tows. *%D* is the percent of the deviance of the null model accounted for by linear or quadratic depth terms (or both), and *P* is the significance level associated with these terms.

Depth Term	Statistic	Low	High	1994	1995
	N	333	368	156	175
Both	*%D*	9.1	22.5	12.0	6.1
	P	<0.0001	<0.0001	<0.0001	0.004
Linear	*%D*	8.5	3.5	11.7	5.0
	P	<0.0001	0.0003	<0.0001	0.003
Quadratic	*%D*	0.6	19.0	0.2	1.1
	P	0.14	<0.0001	0.53	0.15

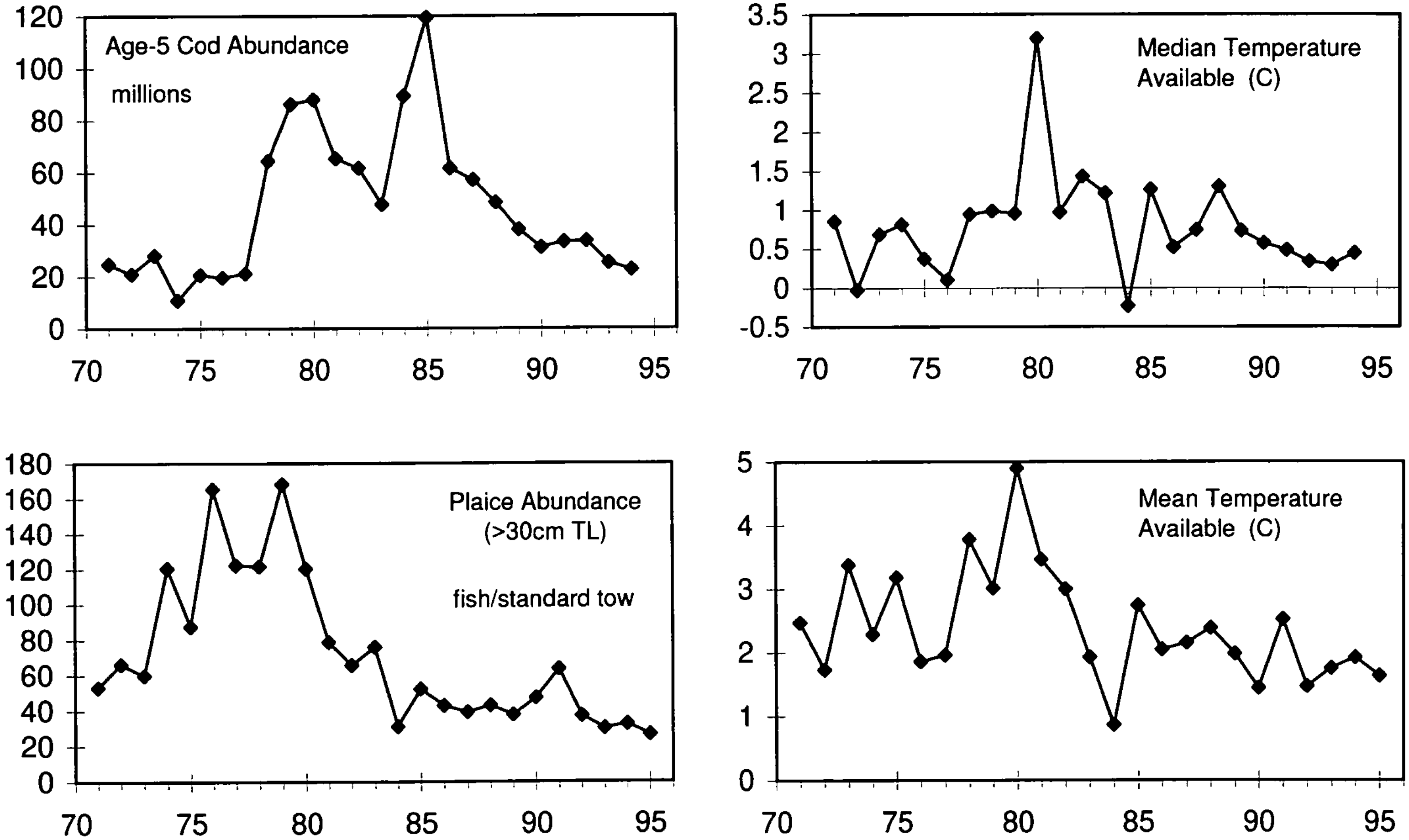

Fig. 1. Variation in bottom temperature and in the abundance of cod and plaice in the southern Gulf of St. Lawrence. Cod abundance is midyear abundance of cod aged 5 yr, calculated from data given in Sinclair et al. (1995). Plaice abundance is the stratified mean catch per tow of commercial-sized plaice in the September survey.

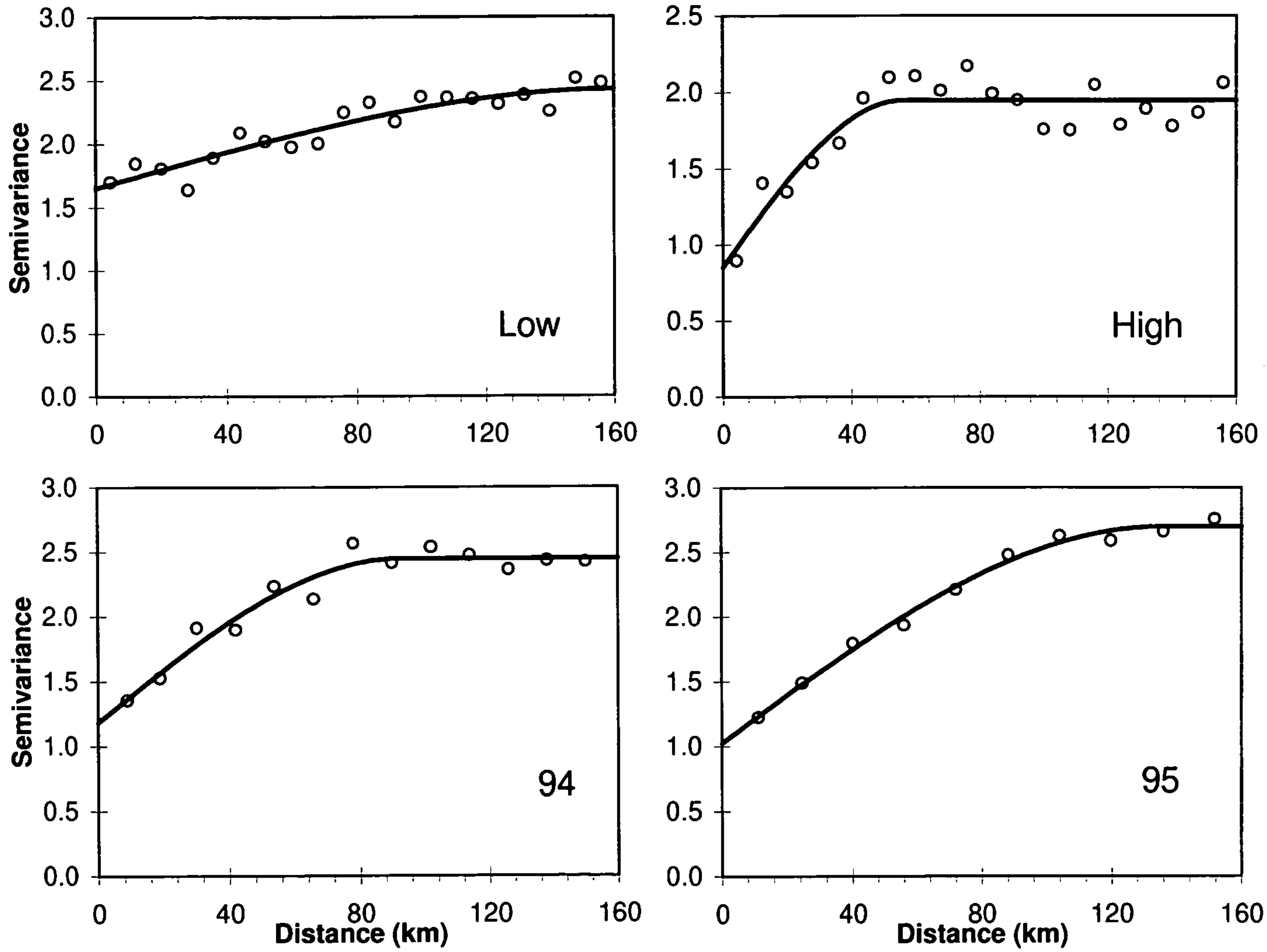

Fig. 2. Variograms for the log of abundance-adjusted local density of age-5 cod in periods of low and high abundance, and in 1994 and 1995.

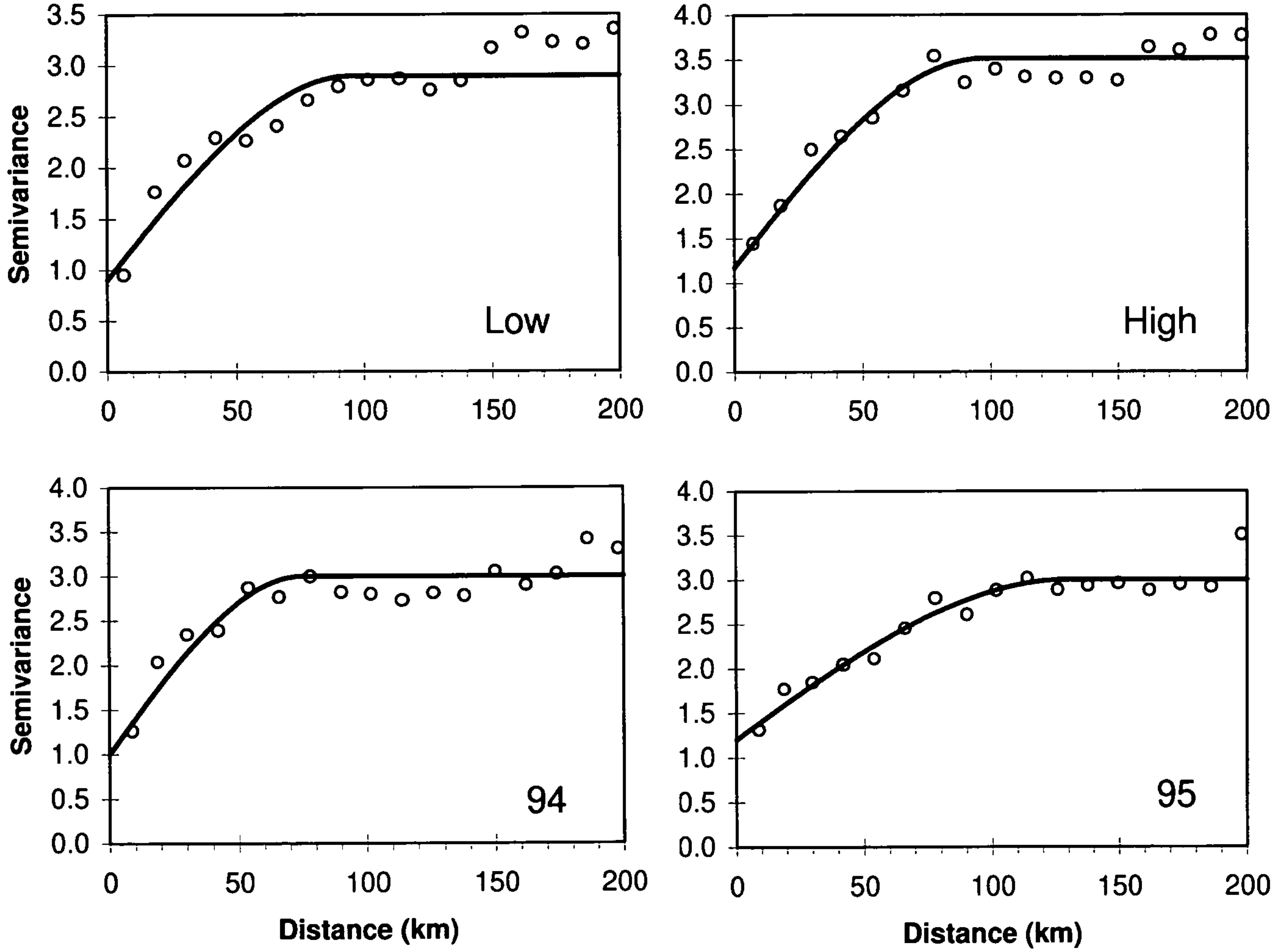

Fig. 3. Variograms for the log of abundance-adjusted local density of commercial-sized plaice (>30 cm TL) in periods of low and high abundance, and in 1994 and 1995.

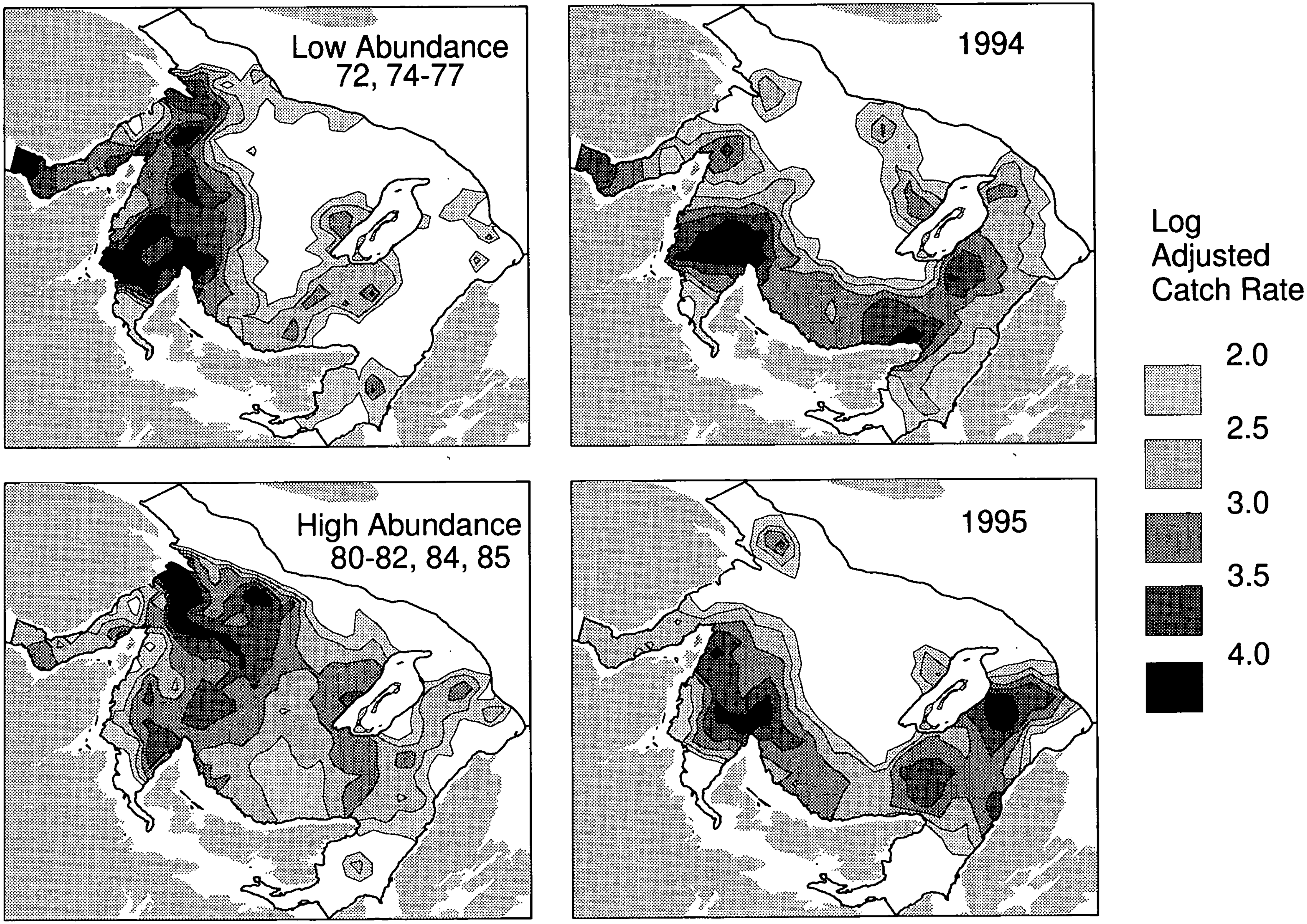

Figure 4. Distribution of age-5 Atlantic cod in the southern Gulf of St. Lawrence during five years of low abundance in the 1970s, five years of high abundance in the early to mid-1980s, and recent years. Catch rates are adjusted to the same average level (25 fish/tow) in all years.

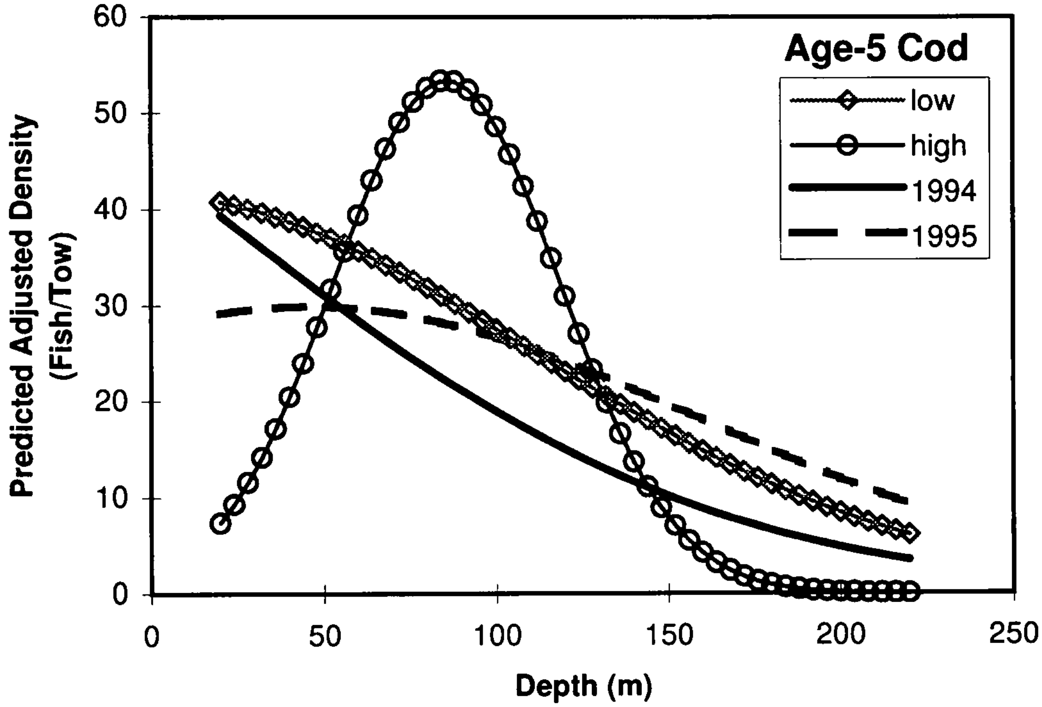

Fig. 5. Poisson regression lines predicting the density (fish/tow) of age-5 cod (adjusted to an average value of 25 fish/tow in each year) from depth, for five years of low abundance in the mid1970s, five years of high abundance in the early to mid1980s, and for recent (1994, 1995) years.

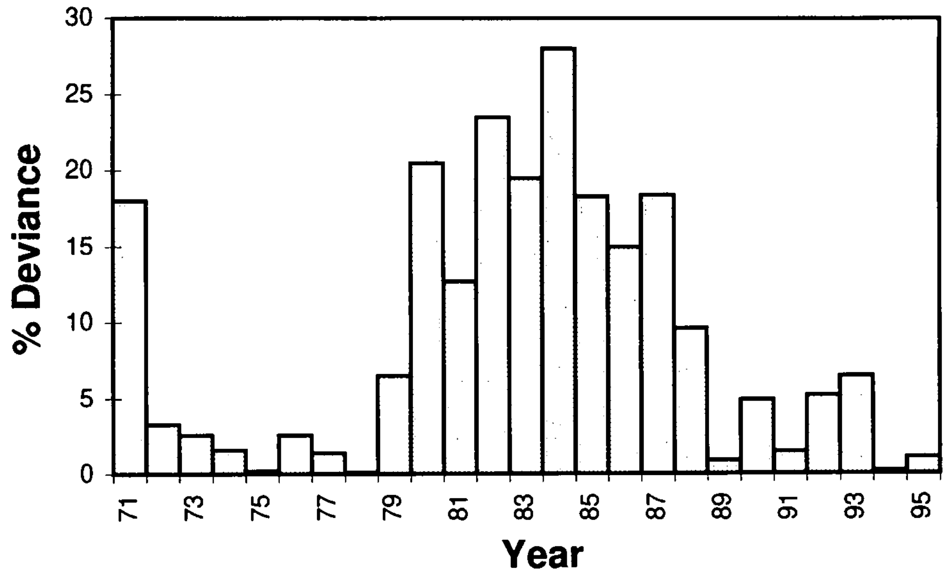

Fig. 6. Percent of the deviance in catch rates of age-5 cod explained by the quadratic depth term in a Poisson regression model with linear and quadratic depth terms.

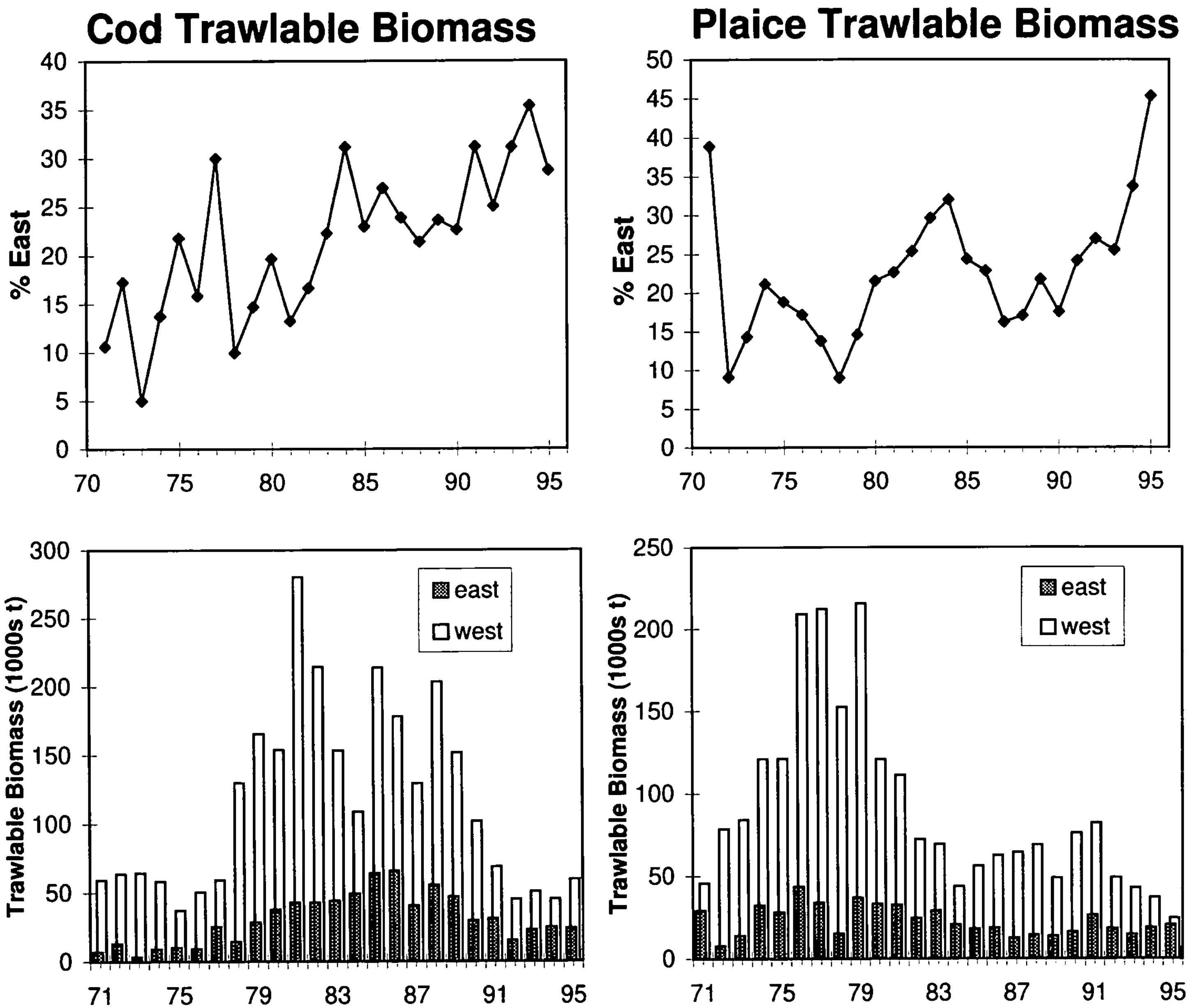

Fig. 7. Distribution of cod and plaice trawlable biomass between eastern (strata 431-439) and western (strata 415-429) regions of the southern Gulf of St. Lawrence.

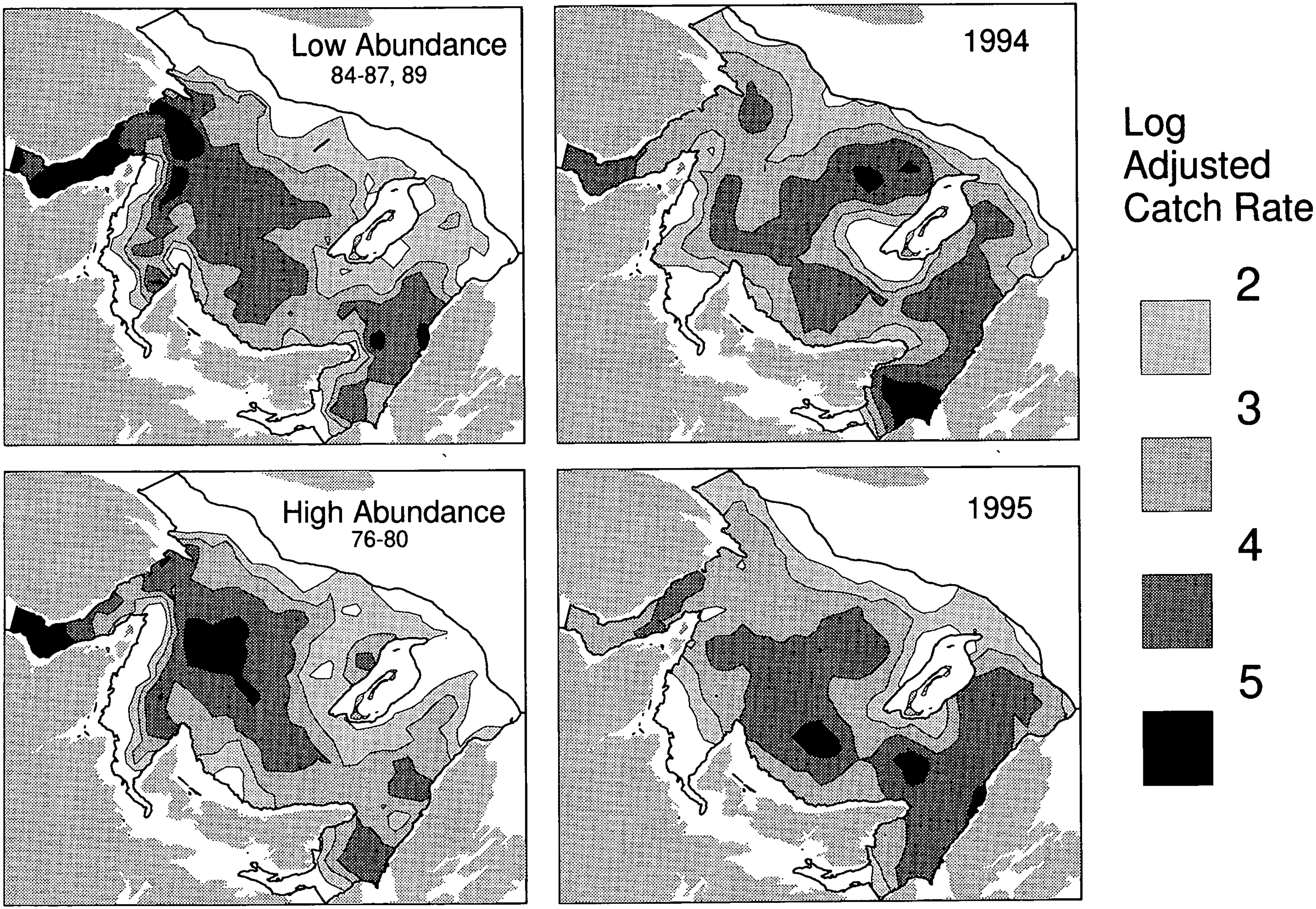

Figure 8. Distribution of commercial-sized American plaice (>30 cm total length) in the southern Gulf of St. Lawrence during five years of low abundance in the 1980s, five years of high abundance in the 1970s, and recent years. Catch rates are adjusted to the same average level in each year (70 fish per standard tow).