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Status of witch flounder in NAFO divisions 4RST, February 2006

L'état de la plie grise dans les divisions 4RST de l'OPANO, février 2006

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ABSTRACT

Landings of witch flounder in NAFO Divisions 4RST are mostly by seiners directing for witch flounder between May and October in St. George's Bay, Newfoundland (4Rd) and off the west coast of Cape Breton Island (4Tf and 4Tg). Landings declined in the 1990s, reaching historical lows between 1994 and 1997. The low landings in 1994-1997 reflected a sharp decline in effort in 4R during this period. Effort increased after 1997 and landings increased to the TAC (800-1000 t) in 1998-2000. Landings in 2005 were 928 t, near the TAC of 1000 t.

The research vessel (RV) survey biomass index for commercial sizes (30+ cm) over the entire 4RST area decreased to low values in the mid 1990s. This decline was mostly confined to the 4R, 4S and western 4T areas. The biomass index in eastern 4T has been at a relatively high level since the mid 1990s. Over the entire 4RST area, relative biomass increased sharply from a low level in 1998 to an intermediate level in 1999 and 2000, but has decreased since then. The index in 2005 was 80% of the 1987-2005 average. The abundance of large fish over 45 cm in length appears to be very low compared to the abundance in the 1970s and early 1980s. In contrast to the RV survey, catch rates in the July sentinel survey of the northern Gulf provide no indication of an increase in biomass since the mid 1990s.

Although a strong yearclass appeared in the survey catches in the mid to late 1990s, growth rate has been slow for this yearclass, and its eventual recruitment to commercial sizes has not resulted in the anticipated increase in biomass at these sizes. Little trend in fishing mortality is evident over the 1987 – 2005 period. Biomass changes over this period do not appear to be attributable to effects of fishing alone. Nonetheless, it appears that biomass has again started to decline following its partial recovery in the late 1990s, and landings near 1000 t may not be sustainable at this stock's current low level of productivity.

RÉSUMÉ

Les débarquements de plie grise dans les divisions de l'OPANO sont pour la plupart imputables aux senneurs qui ciblent l'espèce de mai à octobre dans la baie St. Georges, à Terre Neuve (4Rd), et sur la côte ouest de l'île du Cap Breton (4Tf et 4Tg). Les débarquements ont chuté dans les années 1990, atteignant des creux historiques entre 1994 et 1997. Ces creux correspondent à une baisse marquée de l'effort dans 4R pendant cette période. L'effort a augmenté après 1997 et les débarquements se sont élevés jusqu'au niveau du TAC (800 à 1000 t) entre 1998 et 2000. En 2005, ils se sont chiffrés à 928 t, soit près du TAC de 1 000 t.

L'indice de biomasse des plies grises de taille commerciale (30+ cm) pour l'ensemble de la zone de 4RST, d'après le relevé par navire de recherche (NR), était tombé bien bas au milieu des années 1990. Cette baisse s'est produite surtout dans 4R, dans 4S et dans l'ouest de 4T. L'indice de la biomasse dans l'est de 4T s'est maintenu à un niveau

relativement élevé depuis le milieu des années 1990. Dans l'ensemble de 4RST, la biomasse relative a augmenté en flèche à partir du creux de 1998, jusqu'à un niveau intermédiaire en 1999 et en 2000, mais elle a baissé depuis. En 2005, l'indice était de 80 % de la moyenne de 1987 à 2005. L'abondance des gros poissons de plus de 45 cm de longueur semble très faible comparativement à celle des années 1970 et du début des années 1980. Contrairement aux résultats du relevé du NR, le relevé par pêche sentinelle en juillet, dans le nord du Golfe, n'a donné aucune indication d'une hausse de la biomasse depuis le milieu des années 1990.

Même si une forte classe d'âge a fait son apparition dans les prises du relevé entre le milieu et la fin des années 1990, le taux de croissance de cette classe d'âge a été lent et son recrutement au sein de la population exploitable n'a pas donné l'augmentation anticipée de la biomasse à ces tailles. On n'observe à peu près aucune tendance de la mortalité par pêche entre 1987 et 2005. Les changements de la biomasse au cours de cette période ne semblent pas attribuables aux effets de la pêche seulement. Néanmoins, il semble qu'elle ait de nouveau commencé à diminuer après un rétablissement partiel à la fin des années 1990. Des débarquements à près de 1 000 t ne sont peut-être pas durables, vu le faible niveau actuel de productivité du stock.

INTRODUCTION

Witch flounder occur in the Northwest Atlantic from off southern Labrador to Cape Hatteras. They most commonly occur in deep holes and channels and along the shelf slope on muddy bottom. Juveniles tend to occupy deeper water than adults, especially during summer (e.g., Powles and Kohler 1970, Markle 1975, Morin and Hulbut 1994). Adults undertake seasonal migrations, moving into deeper water in winter and shallower water in summer (e.g., Powles and Kohler 1970). Powles and Kohler (1970) noted that the geographic extent of these migrations may be small, as little as 5-10 miles.

In the Gulf of St. Lawrence, witch flounder form dense concentrations in deep water in winter months and become more widely dispersed throughout the Gulf in summer (Bowering and Brodie 1984). In the early 1950s, a commercial fishery for witch flounder developed at the south side of St. George's Bay, Newfoundland, where boats with Danish seines fished during the summer months (Bowering and Brodie 1984). In the late 1970s, large quantities of witch flounder were landed by offshore otter trawlers fishing in the winter months in the Esquiman Channel southwest of St. George's Bay. This led to the first catch quota for this stock, set in 1977 at a precautionary level of 3500 t for NAFO divisions 4RS. An assessment at this time revealed large numbers of old, slow-growing fish which were frequently landed in a "jellied" condition (Bowering 1978). In 1979, the total allowable catch (TAC) was raised to 5000 t to reduce the numbers of these old fish and stimulate growth. The TAC was reduced back to 3500 t in 1982, once this objective appeared to have been met (Bowering and Brodie 1980, Bowering 1981).

From 1977 to 1994, the fishery for witch flounder in the Gulf of St. Lawrence was regulated within NAFO divisions 4RS. Landings in 4T were not subject to catch quotas, a concern given expected increases in effort for other groundfish species following the closure of the cod fisheries in the Gulf in 1993 (R. Morin, pers. comm.). Following an analysis of the distribution of witch flounder in the Gulf of St. Lawrence (Morin and Hurlbut 1994), the Fisheries Resource Conservation Council (FRCC) recommended that the management unit for witch flounder in the Gulf be redefined to include 4T (FRCC, 1994). This recommendation was implemented in 1995 and a 4RST stock unit was assumed in subsequent assessments of stock status.

The stock structure of witch flounder in NAFO Subarea 4 was reviewed in January 2001 (O'Boyle 2001). This review examined a proposal that the witch flounder moving into the Cape Breton Trough in eastern 4T each summer were more closely affiliated with witch flounder on the northeastern Scotian Shelf (NAFO Div. 4VW) than with those in other regions of the Gulf of St. Lawrence. The review acknowledged that the stock affiliations of witch flounder in eastern Div. 4T are uncertain but concluded that there is yet insufficient evidence to warrant a revision of the management units for witch flounder. Thus, this assessment of stock status is based on a 4RST management unit.

The last full assessment of this stock occurred in February 2001 (Swain and Poirier 2001). This document updates assessment analyses to 2005.

THE FISHERY

Landings

Landings of witch flounder in the Gulf of St. Lawrence averaged 3400 t from 1960 to 1975 (Fig. 1, Table 1). Fisheries in 4R and 4T contributed roughly equally to these landings, with relatively minor contributions from 4S (Fig. 1). Landings rose sharply in 1976 with the onset of a winter fishery by large otter trawlers exploiting winter concentrations of witch in the Esquiman Channel. Landings dropped sharply in 1981 when these large trawlers were excluded from the northern Gulf cod fishery. Landings increased from low levels near 1000 t in the early 1980s to levels near 2500 t by the late 1980s. However, landings declined throughout the early 1990s to a historical low of 320 t in 1995. Landings were near this low level from 1994 to 1997, when catches remained below the allocated quotas for all gear sectors. The decline in landings was particularly strong for 4R-based Danish seiners, whose landings reached only about one-quarter of their allocation during the 1994 to 1997 period. This decline in landings reflected a sharp decrease in fishing effort in 4R. In this period, a high incidence of crab gear interfered with the fishery for witch flounder in 4R in early summer, a period when fishing effort was traditionally high (Swain and Poirier 2001). The fishery during the 1994-1997 period was dominated by landings in 4T (Fig. 1). In 1996 and 1997, 4T-based vessels caught about 75-80% of the allocation. Restrictions on fishing practices may have contributed to landing shortfalls during this period. For example, delays in the opening of the fishery until June precluded traditional fisheries during spring movements of witch when catch rates tend to be high and may have contributed to the 1997 shortfall (R. Hébert, DFO Moncton, pers. comm.). Landings increased in the 1998-2000 period (Fig. 1) when quotas were caught or exceeded by the fleets directing for witch flounder in 4R and eastern 4T. Landings remained near the TAC until 2003 when they declined to 65% of the TAC. Total landings in 2004 were 750 t, 75% of the TAC. In 2004, seine fleets directing for witch flounder caught their quota in 4R but only 74% of their quota in 4T. In 2004, the late opening in the spring combined with bad weather in the fall prevented the 4T fleet from catching its quota. Landings were near the TAC in 2005, with the fleets directing for witch flounder in 4RST catching or exceeding their quota.

The fishery for witch flounder has been conducted almost entirely by mobile gears (Table 1). Danish seines have dominated the landings, except during the 1976-1980 period when winter catches by offshore trawlers contributed heavily to the landings. Since 1991, 87-100% of landings have been from unit areas 4Rd, 4Tf, 4Tg, 4Tk and 4Tnoq (Fig. 2 and 3). The proportion of landings was highest from 4Rd until 1994 when landings in this unit area declined sharply (Fig. 3). Landings in 4Rd remained low from 1994 to 1997, returning to their earlier levels in 1998-2005. Landings have remained fairly steady in 4Tf and 4Tg. These areas dominated the fishery in the 1994-1997 period (Fig 3). In the 1998-2005 period, 4Rd and 4Tfg contributed roughly equal portions of the landings. Contributions from 4Tk and 4Tnoq are now fairly minor.

The fishery for witch flounder is primarily a directed fishery (Fig. 4). Trawls directing for witch are largely restricted to 4T. From 1994-1999, directed effort by trawls has been at an intermediate level, well above the very low level in 1993 (when the cod fishery closed) but below the high levels of 1991and the early 2000s (Fig. 5). However, directed effort by trawls has been slight in all years compared to that by seines. In 4R, directed effort by seines decreased sharply in 1994 and remained low through 1997. Seine effort in 4R then increased, reaching the 1991-1993 levels by the early 2000s. Directed effort by seines remained high in 4T throughout the 1991-2005 period.

Catch-at-length

We attempted to estimate mobile gear catch-at-length for 1987-2005, the period when relative estimates of population numbers at length were available for the entire 4RST region from summer RV surveys (see below). Port sampling of witch landings has been sparse and limits how finely catches can be disaggregated by gear, fishing zone and season for the calculation of catch at length. Most samples were from seines (the gear which landed most of the catch), but several trawl samples were also available. A preliminary examination of length frequencies did not reveal any consistent differences between the two gears or between seasons (January-June versus July-December). Thus, samples and catches were pooled over gears and months. Lengths in the catch did however appear to differ among fishing zones (Fig. 6, see Swain and Poirier 2001 for additional years). Fish landed in 4R tended to be smaller than those landed in 4T since 1990, so where possible we applied 4T samples to 4T landings and 4R samples to 4R (and 4S) landings (4S landings were low and mostly unsampled - see Swain et al. 1998*b*). No samples were available from 4R in 1987, 2002 and 2004, so we used 4R samples from the preceding and following years to estimate catch at length in these years. Other details regarding methods and the samples available for 1988-1999 are given in Swain et al. (1998*b*) and Swain and Poirier (2001). The number of length frequency samples and the landings that they were applied to are given in Table 2 for 2000-2005.

Length composition of the landings are given in Table 3 and Figure 7. The large drop in the landings from 1989 to 1990 was not accompanied by any decrease in the size of the fish landed (Fig. 7). For example, the modal size in the landings was 36 cm in 1988 and 39 cm in 1992. Modal lengths in 2004-2005 were 34 cm. Although there have been only slight changes in the modal length of landings over the past 15 years, length distributions have become less skewed to the right, with a smaller proportion of large fish in recent years than in the late 1980s. The sizes of fish landed in recent years are considerably smaller than those landed in the mid 1970s and early 1980s (Fig. 8).

End-of-Season Telephone Survey

Fishers participating in the groundfishery in the southern Gulf have been surveyed by telephone following the fishing season in most years since 1996 using the same questionnaire (e.g., Hurlbut and Daigle 2000). (No survey was conducted in 2003.) Opinions on witch flounder abundance are summarized in Table 4 for the few (2-7, except 0 in 2002) fishers surveyed whose first priority was witch flounder. In most years, the majority of the 2-7 respondents considered witch flounder abundance to be the same or higher than in the previous year. The exceptions were 2001 and 2004, when respondents considered witch flounder abundance to be the same or lower than in the previous year. The most frequent response was that abundance was the same as in the previous year. Responses were scored from –2 (much lower) to 2 (much higher), with 0 indicating the same abundance as last year. The average score tended to be positive up to 2000 and negative since then. The cumulative average score indicates increasing abundance from 1995 to 2000 and a decline in abundance since then, in the average opinion of the respondents. On average, respondents also considered abundance to be higher than in the previous 5 years in most years up to 2000, but lower than in the previous 5 years in two of the three years surveyed since then. Compared to all previous years fished, respondents considered abundance to be somewhat lower in 1996-1997, higher in 1998-2000, and lower in 2001-2005.

RESEARCH SURVEY DATA

Background

Data are combined from two research vessel (RV) surveys in order to calculate abundance and biomass indices for witch flounder over the entire 4RST stock area. One survey has been conducted in the southern Gulf of St. Lawrence each September since 1971 (Fig. 9), the second has been conducted in the Estuary and the northern Gulf each August since 1984 (Fig. 10).

Fishing in the September survey was by the *E.E.Prince* from 1971-1985, by the *Lady Hammond* from 1985-1991, by the *Alfred Needler* from 1992 – 2002, by the *Wilfred Templeman* in 2003, and by both the *Alfred Needler* and the *Teleost* in 2004 and 2005. The *E.E.Prince* used a Yankee-36 trawl and subsequent vessels used a Western IIA trawl. In all years, the target fishing procedure was a 30-min tow at 3.5 knots, for a standard tow of 1.75 nautical miles. Further details of procedures for the southern Gulf survey are given by Hurlbut and Clay (1990).

In the August survey, fishing was by the *Lady Hammond* using a Western IIA trawl from 1984 to 1989 and by the *Alfred Needler* using a URI shrimp trawl from 1990 to 2003. In 2004, fishing was by the *Teleost* using a Campelen trawl. Comparative fishing between the *Needler* and the *Teleost* was conducted during the 2005 survey. Target fishing procedures in the August survey were a 30-min tow at 3.5 knots in 1984-1989 (standard tow = 1.75 nautical miles), a 20-min tow at 2.5 knots in 1990-1992 (standard tow = 0.83 nautical miles), a 24-min tow at 2.5 knots in 1993 (standard tow = 1.0 nautical mile), a 24-min tow at 3.0 knots since 1994 using the URI trawl (standard tow = 1.2 nautical miles), and a 15-min tow at 3.0 knots using the Campelen trawl (standard tow = 0.75 nautical miles).

Adjustments for differences in fishing practices, gears and vessels are needed in order to construct abundance indices that cover the entire stock area and are consistent over time. Catches of witch flounder in summer surveys tend to be higher at night than in day (Swain and Poirier 1998). In the September surveys, fishing was conducted only in daytime hours prior to 1985 but throughout the 24-h day since then. Even since 1985, the proportion of sets conducted at night has varied widely among years for the strata where witch are likely to be caught (Swain and Poirier 1998). Thus, for both the September and August surveys, we adjusted day catches to be equivalent to night catches as described by Swain and Poirier (1998). A comparative fishing experiment in 1985 failed to reveal significant differences in fishing efficiency for witch flounder between the *E.E.Prince*/Yankee-36 trawl and the *Lady Hammond*/Western IIA trawl. However, comparative fishing using the Western IIA trawl in the southern Gulf in 1992 indicated that fishing efficiency of the *Alfred Needler* for witch flounder was significantly greater than that of the *Lady Hammond* (Swain et al. 1998*a*). We adjusted September catches by the *Alfred Needler* since 1992 to be equivalent to *Lady Hammond* catches as described by Swain et al. (1998*a*). Comparative fishing between the *Alfred Needler* using a URI trawl and the *Lady Hammond* using a Western IIA trawl, conducted in August 1990 in the northern Gulf, indicated length-dependent differences in fishing efficiency for witch flounder between these two vessels and gears (Swain et al. 1998*a*, Swain 2001). At small sizes, fishing efficiency was greater for the URI trawl, whereas at large sizes, efficiency was greater for the Western IIA trawl. Swain et al. (1998*a*) estimated relative fishing efficiency between the Western IIA and URI trawls for witch flounder 24 cm or greater in length, a length range over which relative fishing efficiency changed little. This estimate was used to convert catches of witch in this size range in the August survey since 1990 to be equivalent to catches in a standard 1.75-nautical mile tow by the *Lady Hammond* using a Western IIA trawl. Using these conversion factors, consistent catch rate indices for witch flounder greater than 23 cm in length were calculated for the entire Gulf (Fig. 11). These indices are updated for 2001-2005 here. Swain (2001) estimated length-dependent relative fishing efficiencies between these two vessels and gears. These estimates are used here for analyses that include lengths below 24 cm.

Vessel changes in the September survey 2003-2005

Comparative fishing was conducted between the *Needler* and the *Teleos*t (both using a Western IIA trawl) during the 2004 (11 tows) and 2005 (90 tows) September surveys. No differences in fishing efficiency for witch flounder were detected between the two vessels. Additional comparative fishing during the July survey of the Scotian Shelf supported this conclusion. No diel effect on relative fishing efficiency was detected. See Benoît (2006) for details. Thus, witch flounder catches by the *Teleost* were considered equivalent to those by the *Needler*. Diel differences in fishing efficiency were also considered equivalent between the two vessels, and daytime catches by the *Teleost* were adjusted to nighttime catchability using the factor estimated previously for the *Needler* (Swain and Poirier 1998).

No comparative fishing has been conducted between the *Templeman* and either the *Needler* or the *Teleost* using a Western IIA trawl. Thus, no adjustments for the change in vessel in 2003 are possible in the analyses presented here. Daytime catches by the *Templeman* were adjusted to nighttime catchability using the factor estimated previously for the *Needler*.

Vessel and gear changes in the August survey 2004-2005

The primary survey vessel for the August surveys in 2004 and 2005 was the *Teleost* using a campelen trawl. Comparative fishing with the *Needler* and URI trawl was conducted during the 2004 (N=7) and 2005 (N=122) surveys (where N is the number of paired tows with witch caught by at least one vessel). Relative fishing efficiency was estimated, standardizing tows by the *Needler* to 1.75 nm and those by the *Teleost* to 0.8 nm. We used generalized linear models with a logit link and binomial error. Extra-binomial error was allowed, with the scale parameter ϕ estimated using Pearson's χ^2 statistic. When effects were nominally significant, statistical significance was assessed using randomization tests (with 999 random permutations of the data).

At all lengths, more witch flounder were captured by the Campelen trawl than by the URI trawl (Fig. 12). This difference was highly significant (Table 5), with the Campelen catching 2.9 times more witch per standard tow than the URI. However, a length-independent adjustment did not adequately correct for the difference in fishing efficiency between the two trawls, under-correcting at small lengths and over-correcting at large lengths (Fig. 12).

We estimated a length-dependent correction with the following binomial model:

$$\log\left(\frac{p_C}{1-p_C}\right)=\beta_0+\beta_1 L$$

where p_C is the probability that a fish caught in a set of paired tows was caught by the Campelen trawl, *L* is fish length (cm), and β_0 and β_1 are intercept and slope parameters. The length term was highly significant (Table 5), and corresponded to a fourfold difference in efficiency at 10 cm declining to a twofold difference at 50 cm. Application of this length-dependent adjustment adequately corrected for the difference in fishing efficiency between the two trawls (Fig. 12).

We tested for a diel difference in relative fishing efficiency using the model:

$$\log\left(\frac{p_C}{1-p_C}\right)=\beta_0+\beta_1$$

where β_1 is a parameter for time of day. This term was not significant. Thus, diel differences in catchability were assumed to be similar between the two trawls, and the correction factor previously estimated for the URI was used to convert day catches by the Campelen to night catchability.

Incomplete survey coverage

Survey indices were calculated using a set of strata sampled in most years (415-439 in the September survey and 401-414, 801-824, 827-832 in the August survey). For years up to 2000, estimated values for missed strata were obtained as described by Swain and Poirier (2001). Stratum 828 was unsampled in the August 2002 survey. Witch density in this stratum in 2002 was assumed to be the average of that in neighboring strata in the same depth zone (827 and 832). No tows were made in strata 438 and 439 in the September 2003 survey, nor in strata 402, 807, 808, 819, 829 and 830 in the August 2004 survey. In these cases, predicted values for the missed strata were obtained using a statistical model with terms for year and stratum. Generalized linear models with a log link and Poisson error were used. Overdispersion was allowed, with the scale parameter ϕ estimated using Pearson's χ^2 statistic. Analyses were restricted to the year with missed strata and the preceding and following years in order to reduce the likelihood of a change in distribution between years. Analyses were conducted with lengths ≥24 cm combined, and by 2-cm length interval. The assumption that geographic distribution did not change between years was tested in the analyses with lengths combined by including a stratum × year interaction term in the model. This interaction was significant in neither case (nominal $P > 0.9$ for September 2003, and P=0.14 based on a randomization test for August 2004).

In cases where less than two tows were made in a stratum, approximate standard errors for the stratified mean catch rate were obtained by using a predicted SD for the missed stratum, based on the stratum mean and the CV of the stratum means.

Geographic distribution

Small witch flounder (<30 cm in length) tend to be restricted to the deep waters of the St. Lawrence Estuary and the Laurentian, Anticosti and Esquiman Channels (Fig. 13). They were widespread throughout this area in 1987-1990. In the 1991-1995 period, they became more sparsely distributed in the deep channels of the northern Gulf, particularly in eastern regions. They again became widespread in the 1996-2000 and 2001-2005 periods, with relatively high catch rates throughout the deep channels of the northern Gulf in both these periods.

Large witch flounder (≥30 cm) tend to move into less deep waters during the summer feeding season, with concentrations occurring in the Cape Breton Trough west of Cape Breton Island, the

Chaleur Trough and Shediac Valley east of the Gaspé Peninsula and the St. George's Bay area off western Newfoundland. In the 1987-1990 period, large witch flounder penetrated deeply into the western Magdalen Shallows along the Chaleur Trough and Shediac Valley, a pattern also typical of earlier years in the 1970s and 1980s (Swain et al. 1998*b*). Penetration of large witch flounder into the western Magdalen Shallows was less strong in the 1991-1995 period and has been absent since then. Concentrations of large witch flounder also declined in the deep channels of the northern Gulf after 1990. Relatively high densities occurred on the shelf off western Newfoundland in the 1996-2000 period but not in the 2001-2005 period. Strong concentrations of large witch flounder occurred in the Cape Breton Trough in all time periods between 1987 and 2005.

The geographic distribution of witch flounder in the 2005 summer RV surveys was typical of the pattern seen in recent years (Fig. 14). The highest catch rates occurred in the Cape Breton Trough off northwestern Cape Breton. Relatively high catch rates also occurred in the St. Lawrence Estuary, along the southern slope of the Laurentian Channel, and on the shelf off western Newfoundland.

Abundance Indices

Abundance indices for witch flounder 24 cm and greater in length are shown in Figure 15. In the southern Gulf survey, abundance of this size class increased to record high levels in the late 1990s and early 2000s (Fig. 15*a*). These high mean catch rates reflected several large catches in the Cape Breton Trough area in each of these years. Mean catch rates in this survey have tended to be lower in recent years, though the smooth fit to the time trend in this survey remains slightly above the longterm average.

Catch rates in the August survey generally declined from the late 1980s to the mid 1990s and remained at relatively low level through the mid to late 1990s (Fig. 15*b*). Catch rates in this survey have fluctuated widely since 2000. The smooth fit to these data suggests that abundance in the northern Gulf has been at an intermediate level in recent years.

Combining data from both the southern and northern Gulf, the abundance index tended to decline from the late 1980s to the mid 1990s, increasing in the late 1990s to an intermediate level (Fig. 15*c*). Although mean catch rates have fluctuated widely in recent years, the smooth fit to the data remained at this intermediate level from 2000 to 2005.

Size Composition

Catches from both the August and September surveys are combined into a single length frequency distribution for the entire Gulf in Figure 16. Catches by the URI and Campelen trawls are adjusted to be comparable to those by the Western IIA in this figure using length-dependent adjustments. Estimated abundance of fish over 30 cm declined sharply from 1990 to 1993. Abundance in the 30-40 cm length interval recovered in the late 1990s, though catch rates in this length interval have fluctuated quite widely since 2000. Abundance over 40 cm has been low since 1990. Abundance of fish under 25 cm has been generally greater in the 1990-2005 period than in the 1987-1989 period. This may reflect ineffective adjustment for the change in trawl in the northern Gulf survey in 1990 and/or improved recruitment (see below).

Figure 17 shows changes in relative abundance by size class for the entire Gulf. No trends over time are evident for the smallest size class (≤15 cm). The abundance of pre-recruits (the 16-29 cm size class) shows a slight increasing trend over the 1987-2005 period, but this is entirely due to the low values in the 1986-1989 period (and may reflect ineffective adjustment for the change in gear in 1990). Catch rates of the 30-39 cm size class tended to be high from 1987-1990 and then declined to a low level in 1993. Catch rates of this size class remained relatively low from 1994 to 1998 but increased in 1999 and 2000 to a high level. Catch rates of this size class have fluctuated around an intermediate level since 2001. Catch rates of large witch flounder (≥ 40 cm) were high from 1987 to 1990 and then declined sharply from 1990 to 1993. Catch rates at these large sizes remained low from 1993 to 1998, increased somewhat in the 1999 – 2002 period, and returned to a low level in recent years.

A longer term perspective on changes in witch flounder size distribution can be obtained for the southern Gulf from the September survey (Fig. 18). Although overall abundance has been high in the southern Gulf since the mid 1990s, large fish over 45 cm in length have been rare in the 1990s compared to the 1970s and 1980s. In contrast, pre-recruit abundance (fish <30 cm in length) has been much higher since the mid-1990s than in earlier periods.

Biomass Trends

Biomass trends for commercial-sized witch flounder (30 cm and longer) were obtained for the entire Gulf from the length distribution of the survey catches and estimates of the length-weight relationship for witch. There was no indication of sexual dimorphism in the length-weight relationship, so data for both sexes were pooled to estimate the length-weight parameters. Estimates were obtained using the NLIN procedure of SAS. Where possible, parameters estimated from a particular survey were applied to the length distributions of that survey. No length-weight data were available for the 1987-1992 August surveys, so parameters estimated from September survey data were applied to the northern Gulf length distributions in these years.

Biomass declined sharply from the 1987-1990 period to the 1993-1998 period (Fig. 19). The decline occurred after 1990 and thus cannot be attributed to the change in gear in 1990. Relative biomass reached a minimum in 1993, reflecting the very low abundance estimate in that year. Biomass remained stable at a low level from 1994 to 1998. Biomass increased sharply to an intermediate level in 1999 and 2000, but has decreased since then. The index in 2005 was 80% of the 1987-2005 average. The increase in biomass in the late 1990s and early 2000s was primarily due to increased abundance of fish under 40 cm. Biomass of fish 40 cm and longer was at a low level in 2004 and 2005.

Changes in biomass have not occurred uniformly throughout the 4RST area (Fig. 20). The decline in biomass in the early 1990s was restricted to the 4R and 4S/western 4T areas. No clear decline in biomass occurred in the eastern 4T area during this period. In recent years, biomass has been relatively high in eastern 4T, though the index tended to be lower in 2003-2005 than the very high 1999-2002 level. In contrast, biomass has remained low in the 4STw area since 1993, except for somewhat higher values in 2000 and 2003. In 4R, biomass of commercial sizes slowly but steadily increased from the very low 1993 level to moderate levels since about 2000.

Recruitment

Pre-recruit abundance in the RV survey fluctuated without trend between 1990 and 2003, with particularly high values in 2000 and 2003 (Fig. 17, fish 16-29 cm in length). Pre-recruit abundance has tended to be high since 1990 relative to the late 1980s. However, the trawl used in the August survey changed in 1990 to one that is more efficient at catching small witch flounder. Although adjustments for this change in efficiency have been included in these analyses, based on the results of comparative fishing experiments, it is possible that these adjustments have not been entirely effective. Moreover, the time series of pre-recruit abundance is short, and it is unknown how recent values compare to the longterm average.

Catches in the August RV survey suggest the appearance of a strong year-class in the late 1990s (Fig. 21). A mode, interpreted as this year-class, appeared at progressively larger sizes in the length frequency distribution from this survey in most years from 1997 to 2003. In 2003, this year-class appeared to be recruiting to commercial sizes. This implies considerably slower growth than reported by Bowering and Brodie (1984) for this stock in the early 1980s (recruitment to commercial sizes at age 8 yr, as opposed to 6 yr in the early 1980s). The sizes that would represent this year-class did not appear to be particularly abundant in 2004 and 2005, though interpretation of these data is confounded by the year-effects evident in this survey in recent years.

Modes in the length frequencies from the August RV survey suggest the progression of a second strong year-class from a modal length near 10 cm in 2001 to a length near 25 cm in 2005 (Fig. 21).

SENTINEL SURVEY DATA

Background

Two mobile-gear sentinel surveys have been conducted in the northern Gulf of St. Lawrence beginning in 1995, one in early summer (usually mostly in July) and one in fall (late September and October). Each survey is conducted by 9 otter-trawlers, each equipped with the same trawl and rockhopper gear. Since 1997, a restrictor cable has been used to standardize the horizontal opening of the trawl. The survey follows a stratified random design using the same strata as the August research vessel survey. Additional discretionary tows conducted on observed fish concentrations were not included in this analysis. The target fishing procedure is a 30-min tow at 2.5 knots, giving a standard tow of 1.25 nautical miles. Tows in the 3Pn strata were omitted for these analyses. The fall survey was discontinued after 2002; results presented here are for the July survey only.

A similar sentinel survey, using the same gear and fishing procedures (except for the restrictor cable), has been conducted in August in the southern Gulf of St. Lawrence since 2003. This survey uses the same strata as the September RV survey.

Geographic distribution

The geographic distribution of witch flounder catches in the mobile-gear sentinel surveys is summarized for 1995 - 2004 in Figure 22. In the 1995 – 2002 period when only the northern Gulf was surveyed, catch rates tended to be highest along the shelf off the west coast of Newfoundland, particularly in the St. George’s Bay area. Relatively high catches also tended to occur along the southern slope of the Laurentian Channel and in the Estuary along the Gaspé Peninsula. Distribution appeared to be somewhat more concentrated in the 1999-2002 period than in the 1995-1998 period

In 2003 and 2004, both the southern and northern Gulf were monitored by the sentinel surveys. The distribution of catches in the northern Gulf was similar to that in earlier years, with highest catches along the shelf off the west coast of Newfoundland and along the southern slope of the Laurentian Channel. In the southern Gulf, catches were exceptionally high in the Cape Breton Trough along the west coast of Cape Breton. Relatively high catches also occurred in the southern Gulf survey along the slope of the Laurentian Channel. Witch flounder also penetrated into the western Magdalen Shallows in August, particularly in 2004, though at low densities.

Distribution in the 2005 sentinel surveys was similar to that seen in earlier years (Fig. 23). The highest catch rates occurred in the Cape Breton Trough and along the southern slope of the Laurentian Channel north of the Magdalen Islands. Catch rates were also relatively high on the shelf along the west coast of Newfoundland.

The distribution of witch flounder catches in the sentinel surveys is generally consistent with the distribution in the August RV surveys given the relatively large size of the witch caught by the trawl used in the sentinel surveys.

Size composition

As in the RV surveys, juveniles comprise a higher proportion of catches in the northern Gulf sentinel survey than in the southern Gulf survey (Fig. 24), reflecting its greater coverage of juvenile habitats. However, vulnerability of small fish is lower to the sentinel survey gear than to the RV survey gears (see Swain and Poirier 2001 for details), and few fish smaller than 20 cm are caught in the sentinel surveys. In the southern Gulf sentinel survey, strong modes occurred each year in the length frequency distribution between 32 and 35 cm. Modes in the length frequency distribution of catches in the northern Gulf survey were less sharp and occurred at smaller sizes (26-32 cm). Few fish longer than 45 cm were caught in either survey.

Biomass Trends

Catch rates in the July sentinel survey reveal no clear trends in witch flounder biomass in the northern Gulf between 1995 and 2005 (Fig. 25). The high catch rate in the 1997 survey is due to a single tow. The increase in biomass suggested by including this tow in the index is not supported by the mean catch rates in subsequent years. In contrast to the August RV survey, catch rates in the July sentinel survey provide no indication of an increase in biomass since the mid 1990s, though this may reflect differences in the area covered or in the lengths included in the index.

The time series is still too short for the August survey to provide much information on trends in biomass. No trend is suggested by the 2003 – 2005 values (Fig. 25).

Catch rates in the October sentinel survey of the northern Gulf also fluctuated without trend between 1995 and 2002 (DFO, 2003). The mean catch rate in this survey was relatively high in 2000 and low in 2002. This survey was discontinued after 2002.

ANALYSIS

Relative Fishing Mortality

We looked for trends in fishing mortality (*F*) by calculating relative F (*R*) at length, the ratio of catch at length divided by the RV index of population abundance at length (Sinclair 1998). *R* was very low for witch below the commercial size, though it tended to be higher in the late 1980s than since then (Fig. 26, <30 cm). Among commercial-sized witch, *R* tended to be higher for larger (≥40 cm) witch (Fig. 26). No strong trends in *R* over time are evident for commercial sizes. For the 30-39 cm length class, *R* tended to be relatively high in the late 1980s and low in the 1990s. For the 40+ cm length class, there was a weak tendency for *R* to be relatively low in the 2000s. The very high value for *R* in 1993 may reflect a year effect in the survey rather than an increase in *F*; the survey abundance index was unusually low in this year (Fig. 15).

The value of *R* and its relationship with *F* will depend on the relative timing of the survey and fishery (Sinclair 1998). For a given value of *F*, *R* will decrease as survey timing becomes earlier. The proportion of the 4RST witch catch that has been made prior to the August and September surveys has varied substantially over the 1988-2005 period. The proportion of the landings made before August in the 1994-2005 period averaged about half the level in the 1988-1993 period. Thus, values of *R* late in the time series are biased downward relative to those early in the time series. A slight increase in *F* might be obscured by the earlier timing of the surveys relative to the fishery since 1994.

Surplus Production Models

We fit a surplus production model to the time series of survey biomass (30+ cm) and fishery catch. We fit this model as a Bayesian state-space model, implemented using WinBUGS. These models consist of two coupled components, a state process model and an observation model. The first model represents the unobservable stochastic processes governing the population's dynamics. The second model describes the observation errors. The Schaefer surplus production model comprised the process model:

$$B_t = B_{t-1} + rB_{t-1}\left(1 - \frac{B_{t-1}}{K}\right) - C_{t-1}$$

where B_t is biomass in year *t*, C_t is catch in year *t*, *r* is the intrinsic rate of population growth, and *K* is carrying capacity.

The observation component related the survey biomass index I_t to population biomass:

$$I_t = qB_t$$

where *q* is catchability to the survey. We assumed lognormal error for both the process and observation models.

We used uninformative priors for *K*, process and observation error (σ^2, τ^2), and *q*, though *q* was restricted to the range 0.01-1.2. We used a moderately informative prior for *r*, a normal distribution with a high variance (dnorm(0.2,0.258)) but restricted to the range 0.05-0.35. In our view, this range spans the plausible values of *r* for a slow-growing long-lived demersal fish like witch flounder. Biomass at time 0 (1986) was also a parameter in the model. We used an informative prior for B_0 based on the average biomass index in 1987-1990 and an assumed value for *q*. Estimates of length-specific catchability of flatfish to research trawl surveys by Harley and Myers (2001) suggested a value near 0.3 for *q* at commercial sizes of witch flounder. For our initial run, we assumed a value of 0.3 for *q*, yielding the following prior for B_0:

$$B_0 \sim \text{dnorm}(30{,}4)$$

We checked the sensitivity of our results to this prior by also using priors with means of 20 and 40.

Results from the initial run (prior mean of 30 for B_0) are shown in Figures 27-30. The model fit the observed biomass index well (Fig. 27). There was little information in the data on *r*, and the posterior for *r* was fairly flat over the range of the prior (Fig. 28). *q* seemed to be well estimated and had a posterior median near 40% (Fig. 28). The posterior for *K* was sharply peaked, with a median near 20 thousand tones. However, the posterior was strongly skewed to the right (Fig. 28).

According to this model, Exploitation rate (catch/biomass) has varied without trend at a level near 0.1 over the 1987-2005 period (Fig. 29). Posteriors for biomass in 2006 (B_2006), catch at maximum surplus production (C_MSP), and biomass at maximum surplus production (B_MSP) are shown in Figure 30. Like the posterior for *K*, they were sharply peaked but strongly skewed to the right. The posterior median for C_MSP was about 1000 t.

The prior for B_0 affected the model estimate for *q* but not the median estimate for *r* or *K* (Table 6). As B_0 increased, *q* decreased. We also fit the model with the prior for B_0 uniform over the range 10 – 50 thousand tonnes. This yielded a posterior for *q* similar to that produced by a normal prior for B_0 with a mean of 30 thousand tonnes. The posterior median for catch at maximum surplus production was similar (1000 – 1100 t) regardless of the prior on B_0 (Table 6).

Stage-structured Population Models

We also modeled the population using a length-based stage-structured model, again fit as a Bayesian state-space model. The model consisted of a juvenile stage (16-29 cm length class) and an adult stage (lengths $\geq$ 30 cm). Based on growth models in Bowering and Brodie (1984), witch were assumed to recruit to the juvenile stage at age 3 yr. The number of individuals recruiting to the juvenile stage equaled the number of adults at time *t-3* yr times a recruitment rate *r*/2 (half the adults were assumed to be female). Individuals moved from the juvenile stage to the adult stage based on a transition probability, θ. The annual cycle was scheduled to match the observation period, set at September 1 (the mid-point of the August – September survey period). First, recruitment to each stage occurred. Then, 1) the September – December catch was removed, 2) natural mortality occurred, 3) the January – August catch was removed, and 4) the population was observed by the survey. Demographic and environmental stochasticity was introduced via independent and identically distributed log-normal errors with mean 0 and variance σ^2_i. The observation series was provided by the survey catch rates, grouped into stages based on length. These were related to the unobserved abundances of each stage *i* by catchability *q* and log-normal observation error τ^2_i.

The value of θ will depend on juvenile growth rate. Juveniles would take about 3 yr to grow from a length of 16 cm to 30 cm according to the growth models in Bowering and Brodie (1984). This corresponds to a θ of 0.33. The progression of modes across this length interval in Figure 21 suggests a slower growth rate, requiring 5 or more years to grow from 16 to 30 cm in length. This corresponds to a θ of 0.2 or less. We tried three different priors for θ: 1) a beta distribution centered on 0.33, beta(33,67); 2) a beta distribution centered on 0.2, beta(20,80); and 3) a uniform distribution over the range 0.1-0.35.

We used uninformative uniform priors for juvenile and adult natural mortality (0-5 for M_J and 0-5 for M_A). For process and observation error, we set uniform priors (0-2) on the SD. Both errors were assumed to be lognormal. For recruitment rate *R*, we tried three different priors: 1) a normal distribution centered on 35, 2) a normal distribution centered on 17.5, and 3) a uniform prior over the range 2-50.

We attempted to adjust the survey abundance indices for catchability prior to use as data inputs. First, the stratified mean survey catch-at-length was scaled to “trawlable” abundance, based on the number of trawlable units in the survey area. Next, abundance at length was adjusted for size-selectivity of the survey trawl using the summer-fall curve reported by Harley and Myers (2001) for flatfish. For flatfish, Harley and Myers (2001) reported a value of 0.831 for maximum catchability, γ. This corresponded to an average catchability of 32% for adult witch flounder. For illustrative purposes, we also tried values of 1.2, 1.5 and 2.0 for γ, corresponding to average adult catchability of 47%, 59%, and 78%. Because data were “Q-corrected” before use as model inputs, the prior for *q* in our models was a normal distribution centered on 1.

Priors for pre-1987 abundance were normal distributions centered on the average abundance in 1987-1990.

Figures 31 and 32 show the priors and posteriors for selected model parameters for two representative cases. In the case in Figure 31, informative priors are used for θ (beta centered on 0.2) and for *R* (normal centered on 17.5). For the parameters with informative priors (*q*, θ, *R*) posterior distributions change little from the prior distributions. However, both natural mortality parameters, which had uninformative priors, are well estimated. In the case in Figure 32, uninformative priors are used for θ and *R*, as well as for M_J and M_A. M_A remains quite well estimated. In contrast, M_J is not well estimated, though its posterior distribution is more restricted than its prior distribution. For θ and *R*, posterior distributions are less uniform than their priors, but they are highly skewed with sharp peaks near the lower limits of their prior range (and near or beyond the lower limits of plausibility).

Table 7 summarizes the data inputs and priors for the different model runs and Table 8 gives the posterior medians for selected parameters for each of these runs. The parameters θ and M_A are correlated. If juvenile growth is high (high θ), M_A is required to be high. In run 2a, where a strong prior on θ constrains juvenile growth to be at the relatively high level reported for the early 1980s, M_A is estimated to be near 0.6, an unexpectedly high value. When juvenile growth is constrained (or allowed) to be lower (runs 2b – 2d), M_A is estimated to be near 0.4, a more plausible though still high value. When an uninformative prior is used for θ (run 2d), the data suggest a low value near 0.2, consistent with the slow juvenile growth indicated by the survey length frequencies and indicating M_A near 0.4. Similarly, *R* and M_J are correlated. When an uninformative prior is used for *R* (run 2d), the data suggest a relatively low value, but M_J is not well estimated in this case (Fig. 32). When an informative prior is used for *R* centered near the relatively low value suggested by run 2d, M_J is estimated to be near 1.3 (run 2c). These results suggest that this population is currently at a low level of productivity, with slow juvenile growth and high adult natural mortality.

The model with high juvenile growth (θ near 0.33) does not fit the data well (Fig. 33a). It fails to predict the decline in adult abundance in the early 1990s and subsequent partial recovery in the late 1990s. Models with slower juvenile growth (θ near 0.2) do better (Fig. 33b), though they still underestimate the decline in abundance in the early 1990s, with residuals mostly positive in 1987 to 1990 and negative from 1993-1998.

We explored the consequences of assuming higher catchability to the survey. Results for runs 3 and 4 (adult *q* averaging 47% or 59%, respectively) were very similar to those for run 2 (adult *q* averaging 32%). In both cases, M_A was estimated to be near 0.4 (Table 8). An extreme assumption (adult *q* averaging 78%) produced a somewhat lower estimate of 0.33 for M_A (run 5, Table 8). A higher *q* produced a marginally better fit to the data, though the decline in abundance in the early 1990s remained underestimated even given the most extreme assumption for *q* (run 5, Fig. 34).

The trends in adult *F* predicted by these models are shown in Figure 35. (Predicted juvenile *F* was very low, <0.003 in all cases.) Predicted *F* was highest in 1987-1989 and then declined to a low level for the remainder of the time series. The level predicted for *F* depends on the assumption for *q*. Using the selectivity curve estimated by Harley and Myers (2001) for flatfish elsewhere (run 2), the level of *F* is near 0.1 in 1987-1989 and 0.03-0.05 thereafter. Even assuming very high values for *q* (run 5), estimated *F* remains relatively low, with the median estimate averaging 0.08 for the 1991-2005 period.

The failure of these models to fit the decline in abundance in the early 1990s indicates that they do not adequately account for some important component of the population's dynamics. One possibility is that the assumption of constant *M* is incorrect. The decline in abundance in the early 1990s could reflect even higher adult *M* during this period. Alternatively, it could reflect high unreported catch during this period (when effort in the cod fishery rose to very high levels). Density-dependent recruitment processes (i.e., compensatory recruitment rates), which are not incorporated in the model, could also be involved.

UNCERTAINTY

This assessment contains many uncertainties. Unfortunately, most of these uncertainties are not currently quantifiable. Fishing efficiency for witch flounder varies substantially between day and night and among the vessels and gears used to conduct the summer research surveys. We have attempted to adjust for these variations in catchability, but the uncertainty associated with these adjustments is not incorporated in the error bars around the survey abundance indices. A substantial increase in the catch rates of small fish occurred in the 1990 survey when the gear used in August changed to the URI trawl. It is unclear whether this increase reflects improved recruitment in 1990 or ineffective adjustment for the change in gear. However, declines in survey catch rates, biomass and mean length all occurred after 1990, and so cannot be attributed to the gear change in 1990.

Stock structure has been considered a major uncertainty. In contrast to the 4R and 4STw areas, survey catch rates of witch flounder in eastern 4T were at record-high levels in the late 1990s and early 2000s. The interpretation of these high catch rates depends on stock structure. If witch flounder in the entire 4RST area comprise a single stock, then these high survey catch rates in eastern 4T reflect a distribution change in a stock that appears to have been at a low level throughout much of the 1990s and at an intermediate level in recent years. An alternate hypothesis is that witch flounder in eastern 4T are more closely affiliated with those in the 4VW area (e.g., Swain and McRuer 2001). Abundance of pre-recruit witch appears to have been exceptionally high in 4VW in the mid to late 1990s (McRuer et al. 1997, Swain and McRuer 2001). Prospects for witch in eastern 4T may depend on whether they are more closely affiliated with witch in 4R, 4S and western 4T or with those in 4VW. However, a review of stock structure of witch flounder in NAFO Subarea 4 concluded that the evidence did not support a revision of the current management units (O'Boyle 2001).

Abundance and biomass indices for this stock have fluctuated very widely since the late 1990s. This increases uncertainty about current status.

The cause of the stock decline in the early 1990s is unknown. According to the stage-structured population model, *F* is relatively low and cannot account for the decline. This suggests that the decline may be due to high levels of unreported catch in the early 1990s, or due to a decrease in productivity (e.g., an increase in adult *M*).

CONCLUSIONS

The survey biomass index for commercial sizes of witch flounder in 4RST declined sharply in the early 1990s. This decline was mostly confined to the 4R, 4S and western 4T areas. The biomass index in eastern 4T has been at a relatively high level since the mid 1990s. Over the entire 4RST area, relative biomass increased sharply from a low level in 1998 to an intermediate level in 1999 and 2000, but has decreased since then. The index in 2005 was 80% of the 1987-2005 average. The increase in biomass in the late 1990s and early 2000s was primarily due to increased abundance of fish under 40 cm. Biomass of fish 40 cm and longer was at a low level in 2004 and 2005. In contrast to the RV survey, catch rates in the July sentinel survey of the northern Gulf provide no indication of an increase in biomass since the mid 1990s.

Large fish over 45 cm appear to remain rare relative to their abundance in the 1970s and 1980s, judging from length distributions in the September research surveys. The sizes of witch flounder in the landings in both 4R and 4T remain much smaller than those landed in the mid 1970s and the early 1980s.

Although a strong yearclass appeared in the survey catches in the mid to late 1990s, growth rate has been slow for this yearclass, and its eventual recruitment to commercial sizes has not resulted in the anticipated increase in biomass at these sizes. This stock appears to be experiencing a period of low productivity, with slow juvenile growth and high adult natural mortality. Fishing mortality appears to be at a relatively low level, but this low level appears to be near the maximum sustainable by the population in its current state of low productivity.

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Table 1. Landings (t) of witch flounder in NAFO divisions 4RST by gear type. OTB=otter trawl, OTB1=side otter trawl, OTB2=stern otter trawl, SNU=seine, GNS=gillnet, LLS=longline.

YEAR	OTB	OTB1	OTB2	SNU	GNS	LLS	OTHER	TOTAL	TAC
1960	1912	0	0	1309	0	72	45	3338	
1961	1428	0	0	1907	7	19	135	3496	
1962	1342	0	0	2012	0	28	5	3387	
1963	1561	0	0	2612	37	25	15	4250	
1964	1377	0	0	1657	0	86	230	3350	
1965	1137	0	0	2389	1	67	14	3608	
1966	0	1620	39	1845	93	5	110	3712	
1967	1	964	33	1647	36	23	10	2714	
1968	0	1227	102	1995	46	13	7	3390	
1969	3	1286	294	3179	0	1	0	4763	
1970	12	1203	504	3078	8	0	0	4805	
1971	17	1108	183	2352	11	137	13	3821	
1972	30	968	329	636	2	7	29	2001	
1973	68	613	56	1330	39	12	106	2224	
1974	0	707	946	1569	15	0	10	3247	
1975	82	771	371	1449	25	4	20	2722	
1976	111	1606	4303	730	9	0	116	6875	
1977	99	962	1248	715	4	0	8	3036	3500
1978	3	616	2767	938	69	3	114	4510	3500
1979	62	1065	1970	1309	120	14	21	4561	3500
1980	106	548	1618	1100	98	30	27	3527	3500
1981	108	446	267	1032	24	33	2	1912	3500
1982	93	105	122	934	24	4	0	1282	3500
1983	137	116	52	829	27	10	6	1177	3500
1984	75	110	314	536	51	19	2	1107	3500
1985	27	89	161	1127	28	7	221	1660	3500
1986	49	63	79	1216	6	2	408	1823	3500
1987	58	157	212	1671	7	0	504	2609	3500
1988	56	177	177	1835	34	1	250	2530	3500
1989	45	199	358	1698	47	0	0	2347	3500
1990	12	120	236	873	16	8	7	1272	3500
1991	0	5	180	752	37	2	17	993	3500
1992	11	3	129	825	16	2	3	989	3500
1993	0	0	103	691	11	0	96	901	3500
1994	0	0	31	384	4	0	28	448	1000
1995	0	2	18	292	4	0	4	320	1000
1996	0	1	12	479	0	0	1	493	1000
1997	0	0	73	494	3	0	0	571	1000
1998	0	0	48	816	1	0	0	865	800
1999	0	0	14	713	3	0	0	730	800
2000	0	0	81	914	1	0	0	996	1000
2001	0	0	111	705	0	0	0	816	1000
2002	0	0	176	847	1	0	0	1024	1000
2003	0	0	36	622	0	0	0	659	1000
2004	0	0	66	666	0	0	0	733	1000
2005	0	0	103	825	0	0	0	928	1000
MEAN	218	366	390	1251	21	14	56	2316	

Table 2. Numbers of witch flounder sampled for length from mobile-gear landings in NAFO Divisions 4RST, 2000-2005 (4R samples were applied to 4RS landings). Catch-at-age for 4R in 2002 and 2004 was determined from sampling conducted in adjoining years (one year before and one year after).

				Observer trips		
Year	Area	Landings (t)	Port samples	Commercial	Sentinel	Number measured
2000	4R	435.6	7	4		3453
	4T	558.9	8	16	18	7592
2001	4R	445.2	6			2403
	4T	370.8	10	12	8	6730
2002	4R	439.9				
	4T	582.7	16	13	8	8976
2003	4R	273.7	4			1040
	4T	384.4	7	21	1	11401
2004	4R	423.4				
	4T	325.3	10	20		9000
2005	4R	479.7	2			517
	4T	448.1	11	20		12061

Table 3. Estimated catch-at-length (thousands) for mobile-gear witch flounder landings in NAFO divisions 4RST, 1987-2005.

Length	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.2	0.0	0.1	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.4	0.3	0.1	0.1	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.1	0.0	0.2	0.1
24	0.0	0.0	6.6	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.3	0.2	0.1	0.0	0.1
25	0.0	0.0	0.0	0.0	0.0	0.2	1.8	0.0	0.0	0.0	0.0	0.3	0.2	3.2	0.6	0.2	0.8	0.2	0.1
26	0.0	22.3	0.0	0.0	0.0	3.5	3.2	0.0	0.0	0.6	0.0	2.9	1.9	0.5	2.6	2.0	2.0	3.1	0.3
27	7.1	19.2	0.0	0.0	0.0	6.2	5.1	0.1	1.4	0.5	0.2	10.2	2.9	1.7	3.3	4.0	4.3	4.2	0.1
28	10.1	42.4	25.5	0.0	1.6	7.7	11.9	2.4	1.9	6.4	2.1	24.6	4.8	2.3	5.7	4.4	4.0	10.8	19.9
29	34.1	81.4	0.0	0.2	11.5	17.7	21.1	4.3	2.8	9.6	6.7	30.5	6.1	9.1	4.5	13.2	19.7	21.1	22.9
30	43.1	73.3	38.9	18.5	4.8	20.2	36.3	8.5	7.9	20.7	17.8	49.5	20.2	24.8	17.8	35.2	42.2	49.4	69.5
31	56.0	191.9	116.4	32.6	19.0	56.8	48.0	17.1	15.8	23.4	24.6	78.5	30.6	45.0	55.6	66.1	80.6	75.6	91.3
32	138.4	314.2	244.2	98.8	30.7	58.6	48.1	19.8	19.0	34.8	39.5	116.7	59.5	77.0	89.4	111.0	116.1	122.7	154.4
33	225.0	343.9	276.5	115.5	61.2	90.1	75.6	31.0	27.6	51.3	42.8	146.8	89.0	114.5	138.8	182.5	173.5	207.9	276.0
34	298.1	407.5	305.8	162.5	79.8	126.1	118.9	50.3	35.8	73.3	70.5	173.9	126.4	180.8	205.4	251.5	193.1	254.5	322.3
35	411.3	497.7	412.1	190.2	131.8	150.0	132.1	53.1	63.7	117.9	84.7	209.7	163.7	222.6	220.7	257.6	203.1	240.4	320.7
36	564.3	592.5	429.6	189.5	126.0	143.3	167.0	71.5	68.3	140.3	118.1	246.9	188.8	258.4	234.8	301.0	235.6	251.8	310.3
37	504.0	512.9	516.2	200.9	151.7	178.2	181.4	77.5	66.7	144.2	100.4	262.7	213.0	282.4	265.1	285.1	214.4	201.0	232.0
38	628.5	476.0	409.2	159.8	148.7	172.2	170.7	94.9	68.6	141.3	132.5	216.1	211.5	302.7	245.8	275.9	176.7	199.6	269.2
39	514.5	355.2	416.0	151.4	138.2	223.7	159.1	78.6	82.4	104.6	129.4	205.6	180.2	265.6	205.5	238.5	137.5	180.0	270.8
40	528.3	352.1	303.9	183.9	102.9	195.8	138.2	69.6	85.4	97.6	108.7	155.4	150.9	213.6	174.0	220.9	110.7	104.4	114.8
41	391.5	252.6	306.1	155.6	116.6	142.4	140.3	66.6	45.1	80.2	96.6	132.0	129.0	171.2	131.8	164.2	93.7	93.0	97.0
42	363.9	208.1	262.8	170.0	137.0	121.2	127.9	65.9	29.0	53.0	74.4	97.2	97.8	123.8	99.3	133.4	64.5	73.3	81.5
43	317.7	203.1	188.3	134.2	84.2	108.8	119.5	45.5	45.9	44.1	51.4	68.9	75.5	99.7	76.4	93.3	43.8	52.4	56.4
44	289.2	216.7	193.4	114.0	94.4	86.6	92.6	46.0	16.6	43.3	38.8	54.5	49.0	70.1	45.4	71.1	34.5	43.2	42.3
45	241.1	170.0	150.6	96.5	52.7	76.8	69.8	25.2	14.5	22.6	23.8	34.5	32.7	48.7	35.2	44.6	15.4	21.2	23.2
46	186.9	160.3	209.8	80.5	57.3	51.1	49.6	26.6	17.9	25.2	39.1	31.6	29.5	31.7	19.6	21.9	7.2	13.9	22.1
47	107.9	104.0	94.4	82.3	44.1	41.1	47.7	18.3	16.3	14.0	22.9	17.5	12.7	18.3	8.4	15.3	6.7	10.7	9.6
48	154.9	115.6	59.9	54.5	26.0	36.2	31.2	15.5	19.2	12.2	17.6	11.4	8.6	10.3	5.2	15.3	7.6	10.0	9.4
49	77.3	71.6	63.4	51.6	21.0	17.9	18.2	13.7	5.5	10.5	4.9	12.5	6.0	8.7	3.5	7.8	0.8	1.8	3.6
50	83.7	58.4	52.1	31.4	17.5	11.0	24.2	6.9	13.1	3.2	7.9	7.1	6.3	5.0	1.2	6.7	2.5	4.3	1.1
51	59.8	36.4	43.2	18.2	52.6	20.3	16.1	7.1	5.1	2.3	3.0	5.1	3.1	2.9	3.0	2.2	0.2	0.7	2.2
52	26.5	28.6	17.0	14.8	13.4	5.6	8.4	8.6	1.1	2.5	0.5	3.0	1.1	2.9	0.4	0.4	0.2	0.9	2.1
53	29.6	19.5	28.3	5.9	18.9	9.4	7.6	4.2	0.8	2.1	2.9	2.5	0.9	2.1	0.3	0.3	0.1	0.1	0.3
54	25.7	22.9	7.4	4.4	28.2	8.7	4.2	3.2	0.2	3.3	0.5	1.3	1.5	3.3	0.1	0.7	0.2	0.2	0.7
55	28.5	15.4	5.9	14.0	19.8	2.0	3.9	2.7	0.3	0.8	0.4	2.1	1.1	0.3	0.1	0.2	0.0	0.2	0.7
56	21.9	25.6	1.6	13.4	13.3	1.3	6.9	1.9	0.5	1.8	0.5	1.0	0.1	2.2	0.1	0.2	0.1	0.0	0.3
57	11.7	10.7	0.0	7.7	7.2	1.1	0.7	2.7	0.2	1.1	0.0	0.5	0.6	0.8	0.1	0.0	0.0	0.0	0.2
58	14.2	2.9	11.8	2.2	3.3	1.5	1.7	3.8	0.0	1.0	2.8	0.5	0.2	0.2	0.1	0.0	0.1	0.0	0.0
59	1.4	0.3	1.6	4.4	3.3	1.0	0.7	3.2	0.2	0.1	0.0	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0
60	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0
61	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0
62	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0
63	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
64	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
65	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 4. Opinions on witch flounder abundance of respondents in the end-of-season telephone survey of participants in the groundfishery in the southern Gulf of St. Lawrence. Opinions are tabulated for respondents who gave witch flounder as their first priority.

Score: Year	-2 Much Lower	-1 Lower	0 Same	1 Higher	2 Much Higher	N/A	Average Score	Cumulative Average Score
Relative to previous year								
1996	0	0	4	3	0	0	0.43	0.43
1997	0	1	3	1	0	0	0.00	0.43
1998	0	1	1	2	0	0	0.25	0.68
1999	0	0	4	2	0	1	0.33	1.01
2000	0	0	2	1	1	0	0.75	1.76
2001	0	2	2	0	0	0	-0.50	1.26
2004	0	1	1	0	0	0	-0.50	0.76
2005	0	1	2	1	0	0	0.00	0.76
Relative to previous five years								
1996	1	0	3	1	1	1	0.17	
1997	1	1	1	2	0	0	-0.20	
1998	0	0	0	2	0	1	1.00	
1999	0	1	2	2	2	0	0.71	
2000	0	0	1	2	1	0	1.00	
2001	0	1	3	0	0	0	-0.25	
2004	1	1	0	0	0	0	-1.50	
2005	0	0	3	1	0	0	0.25	
Relative to all years fished								
1996	0	2	3	1	0	1	-0.17	
1997	1	1	1	2	0	0	-0.20	
1998	0	1	0	1	0	1	1.00	
1999	0	2	1	2	2	0	0.57	
2000	0	0	0	4	0	0	1.00	
2001	0	3	1	0	0	0	-0.75	
2004	0	2	0	0	0	0	-1.00	
2005	0	1	3	0	0	0	-0.25	

Table 5. Tests for differences in fishing efficiency between the URI and Campelen trawls during the August survey of the northern Gulf. Significance (*P*) is based on a randomization test when the nominal level was less than 0.05.

Model	Effect	Estimate	SE	*t*	*P*
Vessel only	Vessel	1.0792	0.0755	14.287	0.001
Length-dependent	Vessel	1.4902	0.1565	9.520	
	Length	-0.0163	0.0058	-2.829	0.007
Diel effect	Vessel	1.0927	0.1081	10.111	
	Diel	-0.0281	0.1555	-0.181	0.886[1]

[1]Nominal significance level.

Table 6. Posterior medians from three runs of the surplus production model. Each run was identical except for the prior on B_0. Units for *K*, *B* and *C* are thousands of tonnes,

	Prior for B_0 (mean or range)			
Parameter	20	30	40	10-50
q	0.52	0.40	0.33	0.43
r	0.18	0.18	0.18	0.18
K	22.59	20.29	20.53	20.47
B_{MSP}	11.30	10.15	10.27	10.23
B_{2006}	7.00	9.19	11.19	8.60
C_{MSP}	1.11	0.98	1.03	1.00
F_{MSP}	0.09	0.09	0.09	0.09

Table 7. Naming of runs of the stage-structured population model. Runs are named with a number and letter. The number refers to the value for γ used to q-correct the survey catch rates prior to input as data:

run	γ	Adult q
2	0.831	32%
3	1.2	47%
4	1.5	59%
5	2.0	78%

The letter refers to the priors used:

Parameter	a	b	c	d
θ	Beta(33,67)	Beta(20,80)	Beta(20,80)	Uniform(0.1,0.35)
R	Normal(35,5)	Normal(35,5)	Normal(17.5,5)|(2,)	Uniform(2,50)
M_J	Uniform(0,5)	Uniform(0,5)	Uniform(0,5)	Uniform(0,5)
M_A	Uniform(0,3)	Uniform(0,3)	Uniform(0,3)	Uniform(0,3)
q	Normal(1,0.14)	Normal(1,0.14)	Normal(1,0.14)	Normal(1,0.14)
SD_{OBS}	Uniform(0,2)	Uniform(0,2)	Uniform(0,2)	Uniform(0,2)
$SD_{PROCESS}$	Uniform(0,2)	Uniform(0,2)	Uniform(0,2)	Uniform(0,2)
$N_{pre1987}$ [1]	Normal(X,2)	Normal(X,2)	Normal(X,2)	Normal(X,2)

[1] X is the mean abundance in 1987-1990

Table 8. Posterior medians for selected parameters in different runs of the stage-structured population model. See Table 7 for details on the different runs.

run	M_A	M_J	θ	R
2a	0.62	1.89	0.32	33.4
2b	0.42	1.87	0.19	33.0
2c	0.42	1.29	0.19	16.4
2d	0.42	1.17	0.18	14.2
3b	0.40	1.87	0.19	33.4
3c	0.41	1.26	0.19	16.0
4d	0.39	1.27	0.18	15.9
5d	0.33	1.17	0.18	12.6

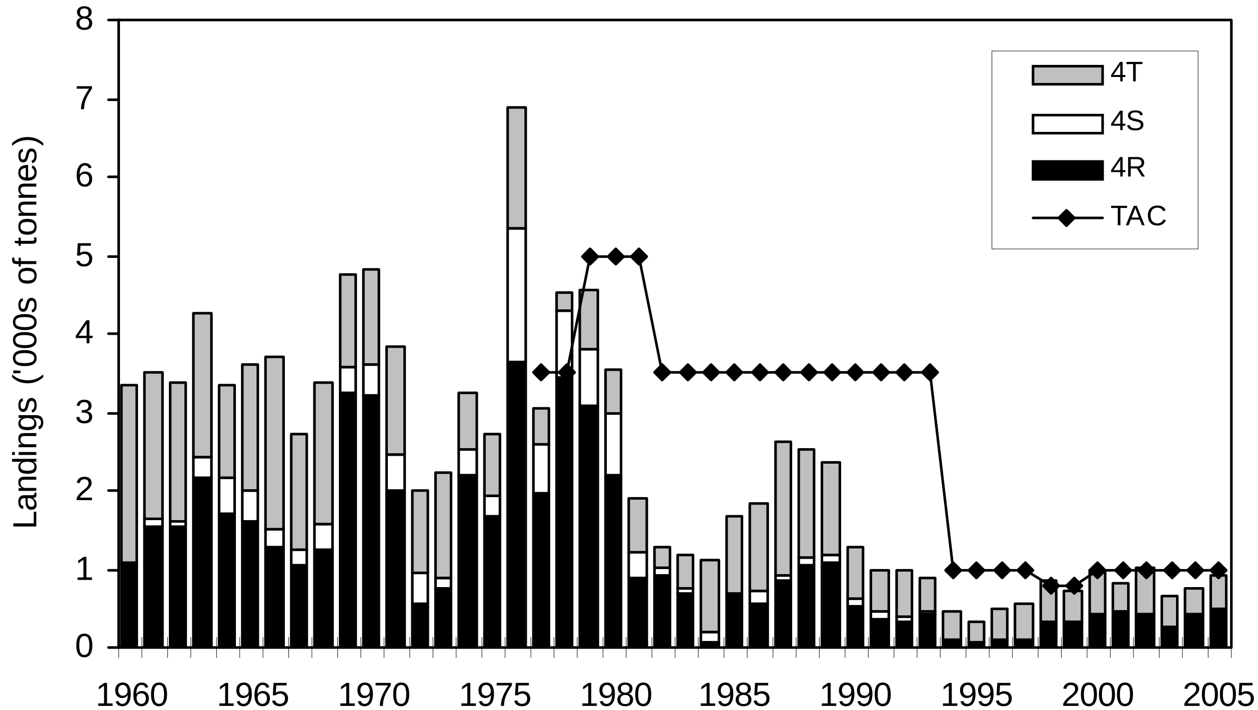

Figure 1. Landings of witch flounder in NAFO divisions 4RST.

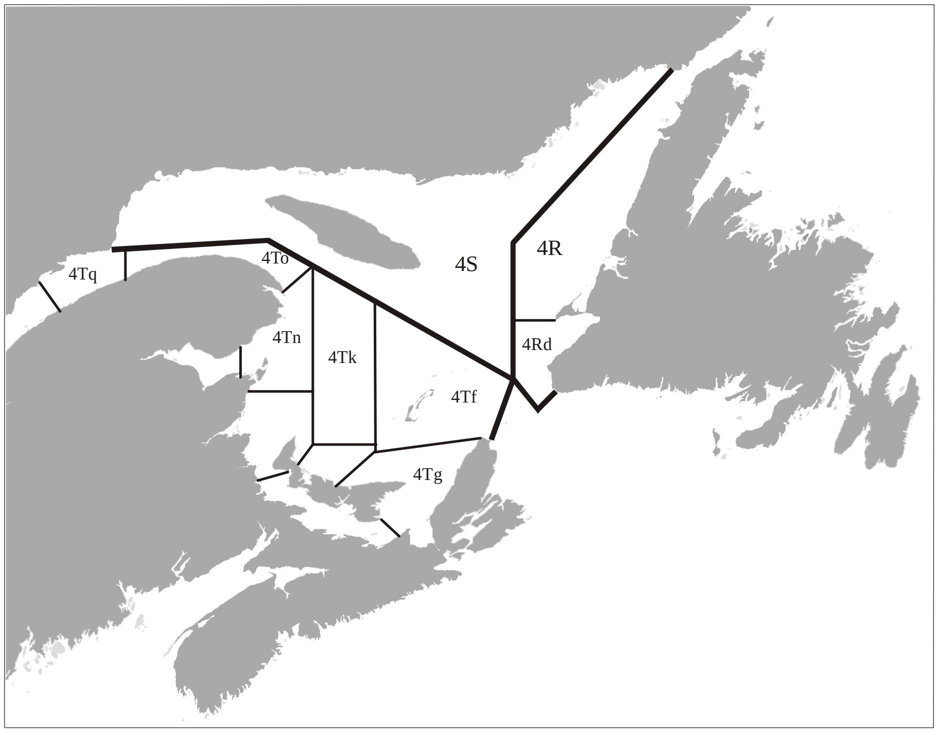

Figure 2. NAFO divisions 4R, 4S and 4T (bordered by heavy lines). Unit areas where most witch flounder are caught in commercial fisheries are labelled in lower case.

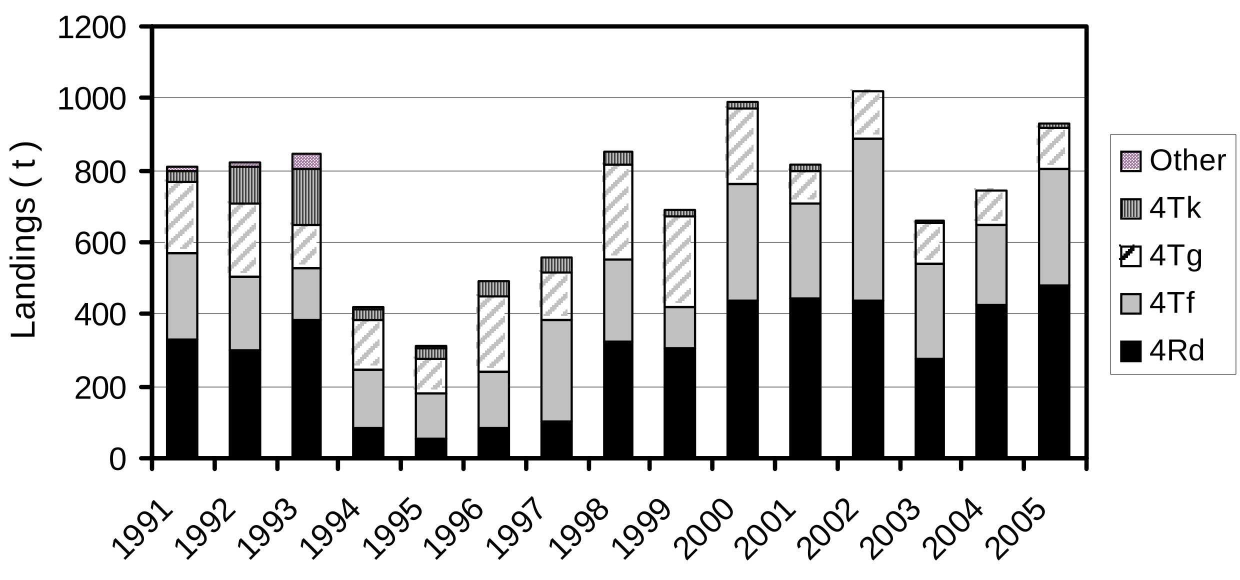

Figure 3. Landings of 4RST witch flounder by NAFO unit area.

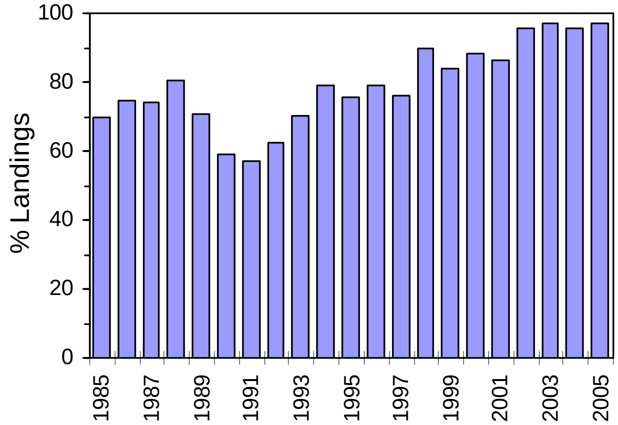

Figure 4. Percent of mobile-gear landings of 4RST witch flounder with witch as the main species caught.

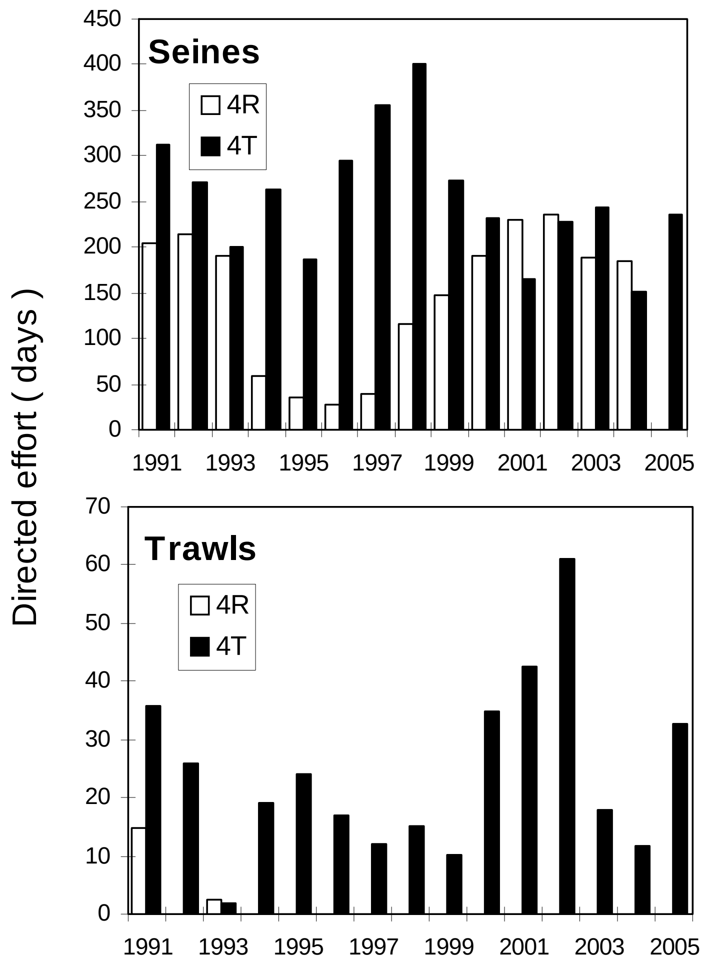

Figure 5. Fishing effort by seines and trawls directing for witch flounder in NAFO divisions 4R and 4T. Effort data are not available for 4R in 2005.

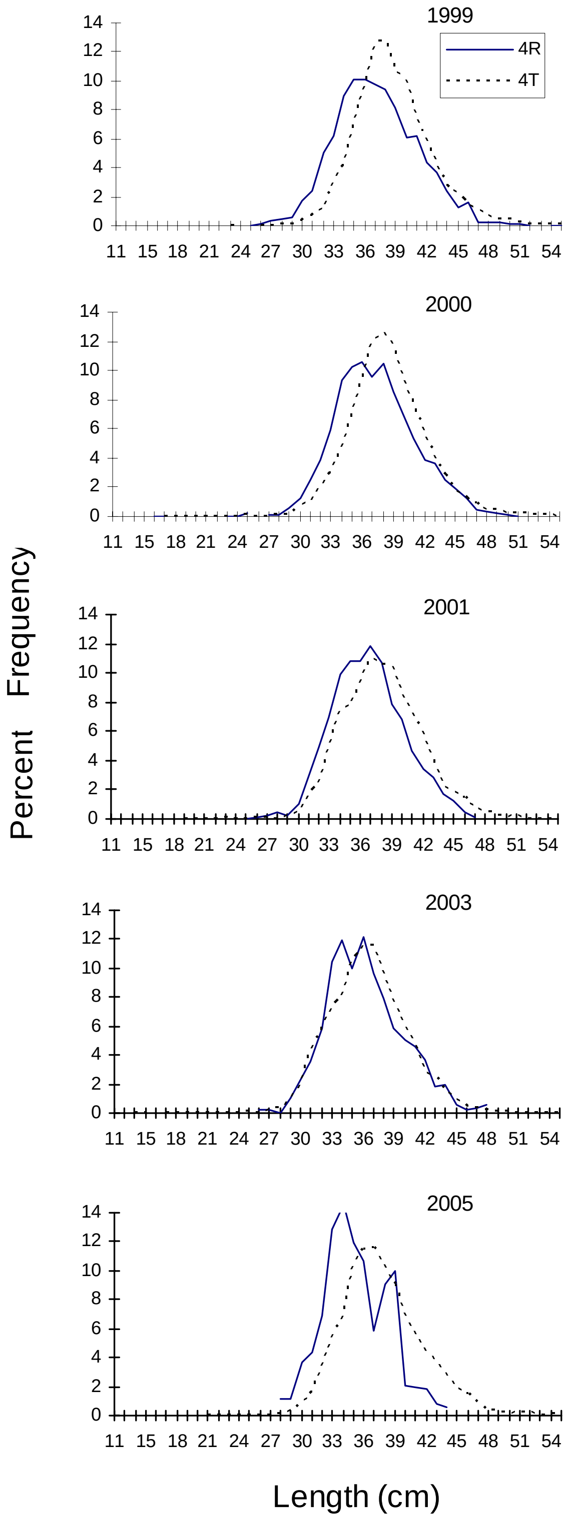

Figure 6. Average length frequencies (%) of witch flounder caught by mobile gear in NAFO divisions 4RST, 2001-2005. Averages were weighted by the landings associated with each length frequency sample.

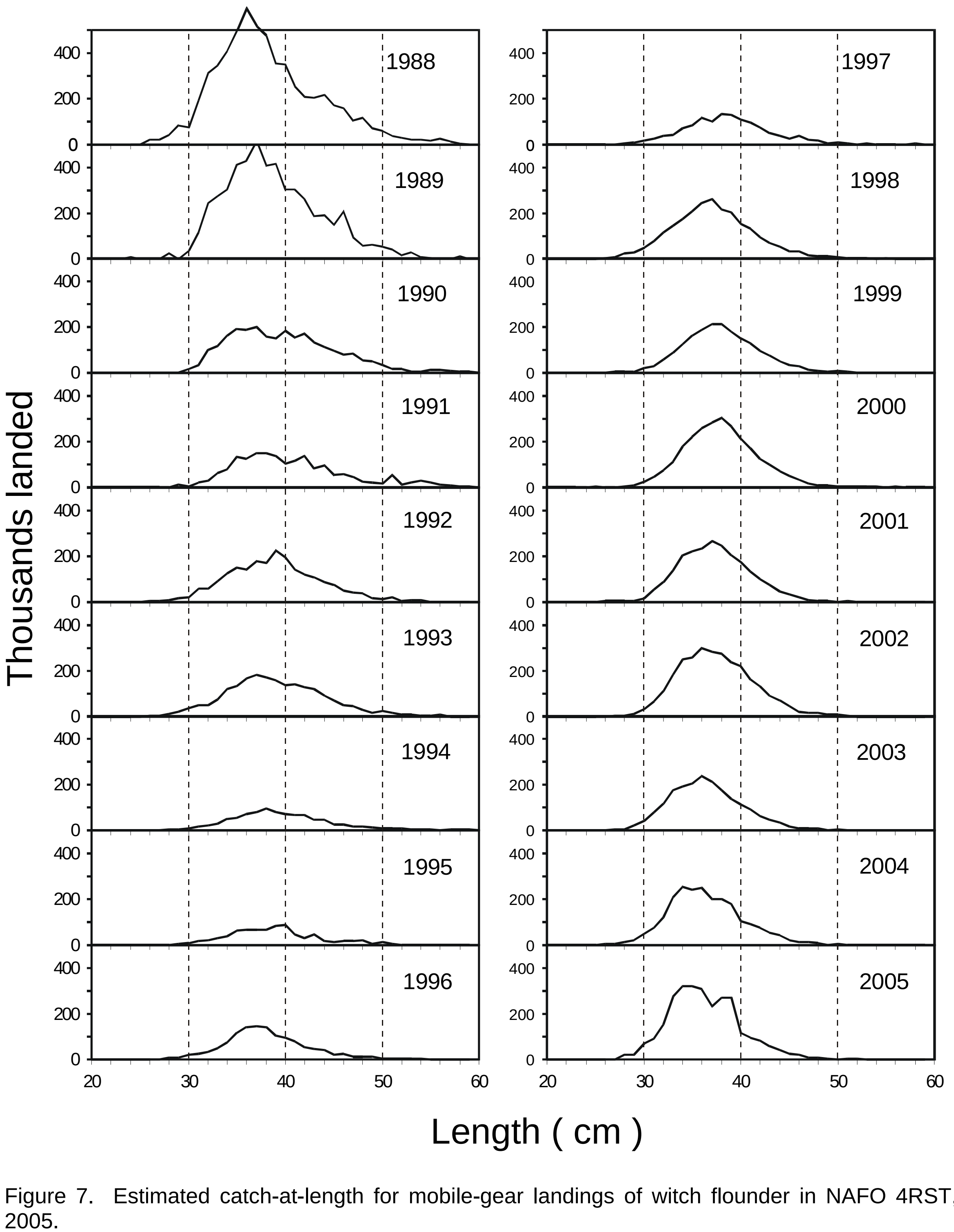

Figure 7. Estimated catch-at-length for mobile-gear landings of witch flounder in NAFO 4RST, 1988-2005.

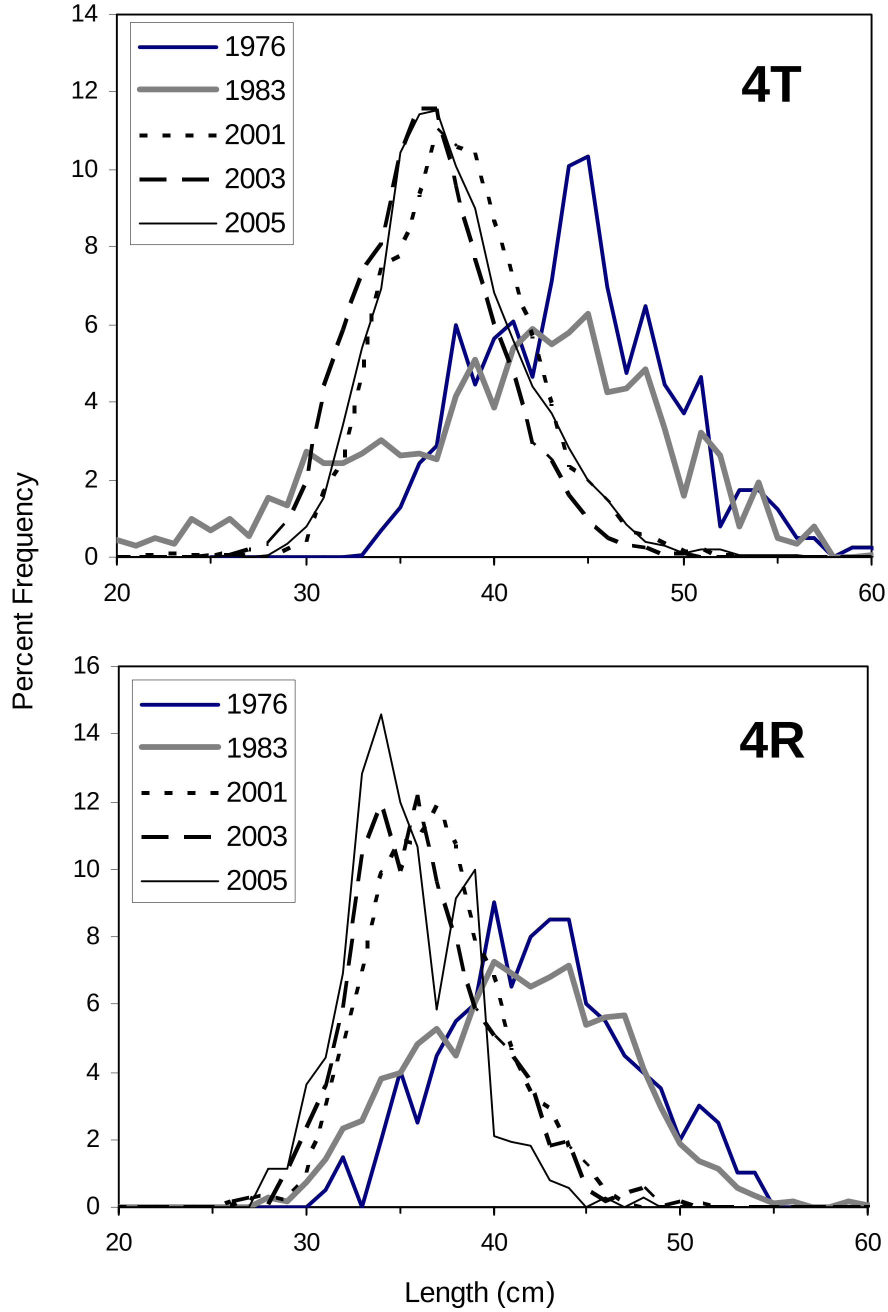

Figure 8. Comparison of length frequencies of witch flounder landed in 4T and 4R in 1976, 1983, 2001, 2003 and 2005.

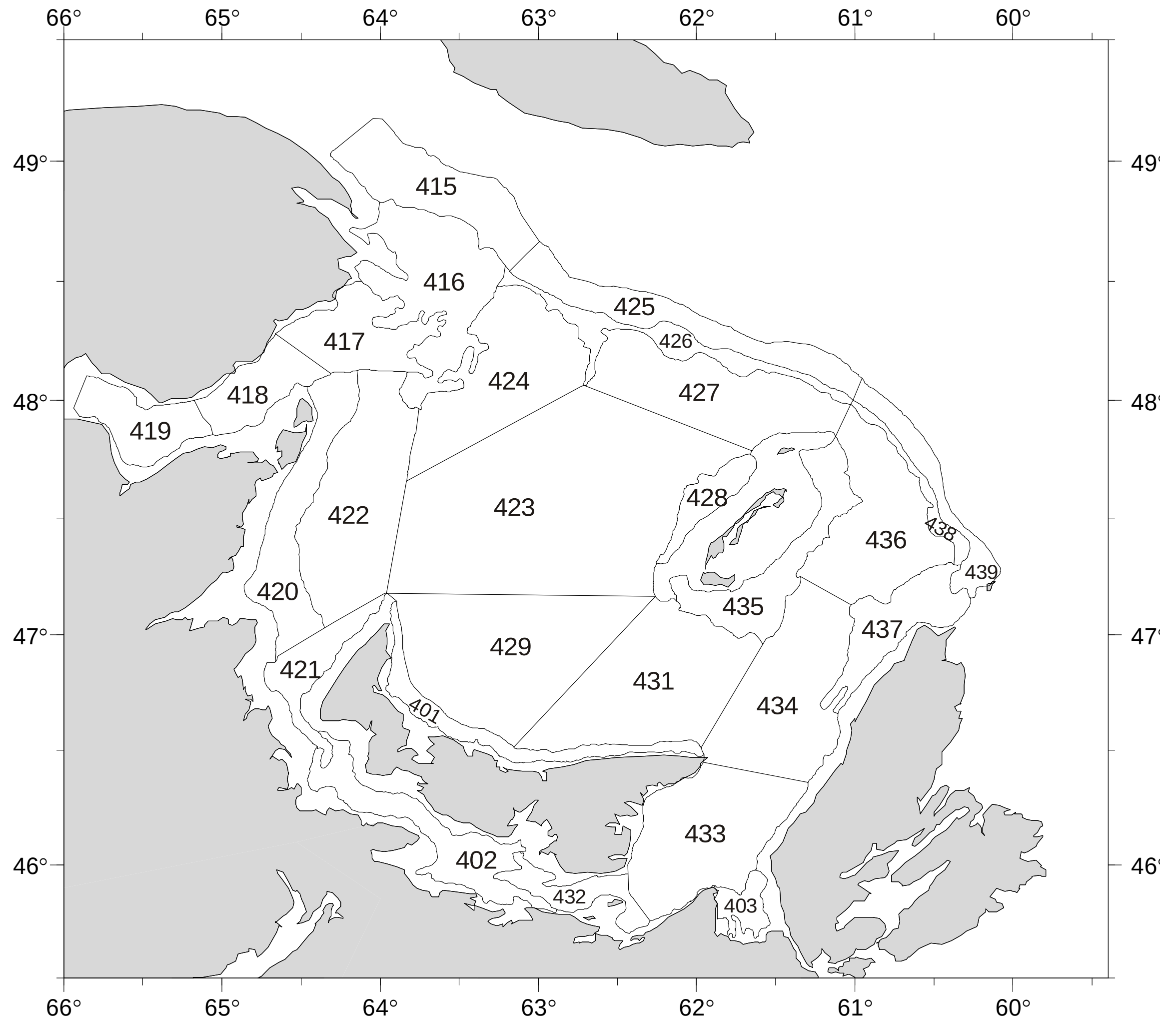

Figure 9. Stratum boundaries for the September bottom-trawl survey of the southern Gulf of St. Lawrence.

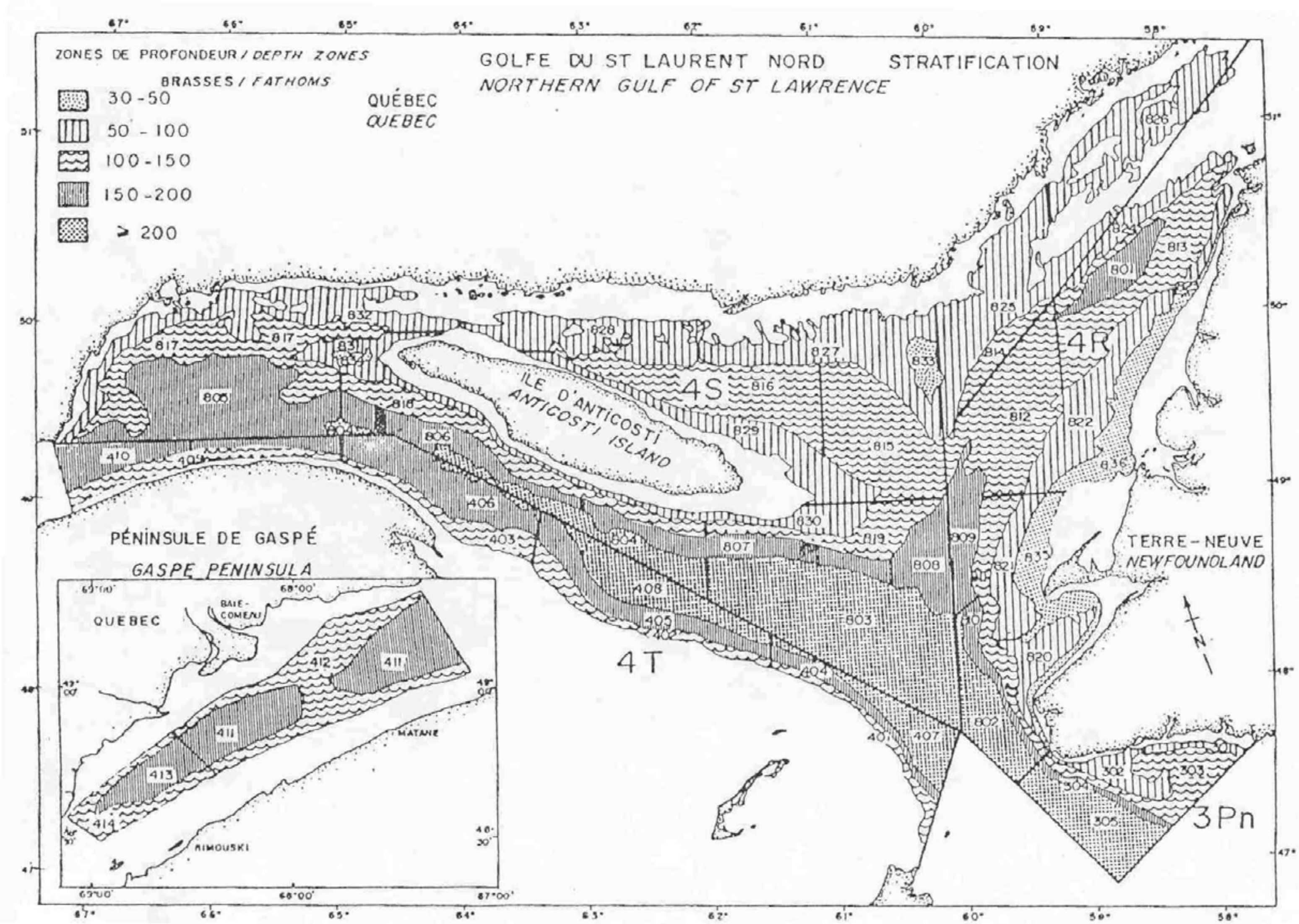

Figure 10. Stratum boundaries for the August bottom-trawl survey of the northern Gulf of St. Lawrence.

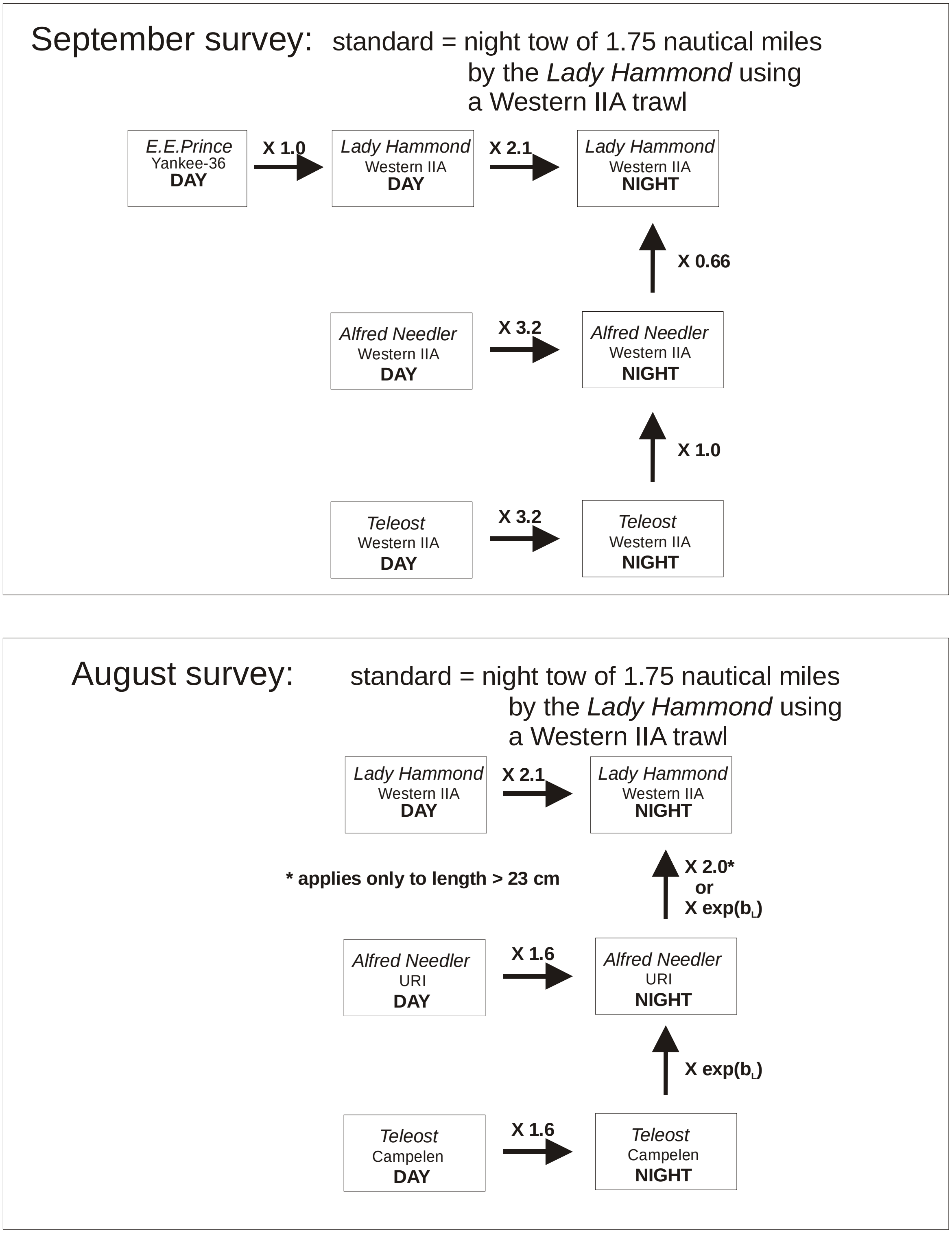

Figure 11. Construction of a consistent series of witch flounder catch rates in the summer surveys of the Gulf of St. Lawrence. All catches are standardized to a tow of 1.75 nautical miles before applying conversion factors. $\exp(b_L)$ is a length-dependent conversion factor.

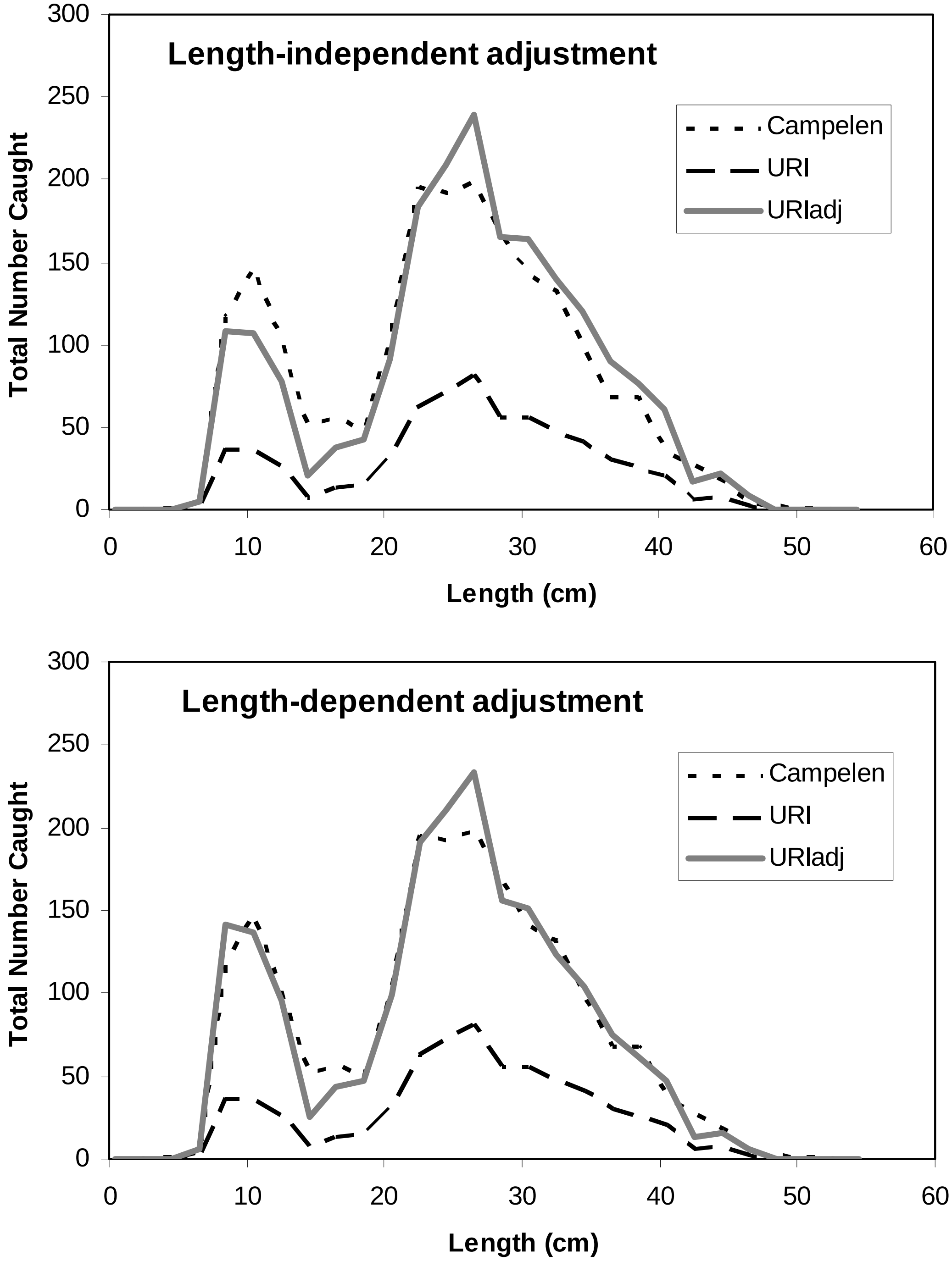

Figure 12. Catch of witch flounder in paired tows by the Campelen and URI trawls during the 2004 and 2005 August surveys of the northern Gulf of St. Lawrence.

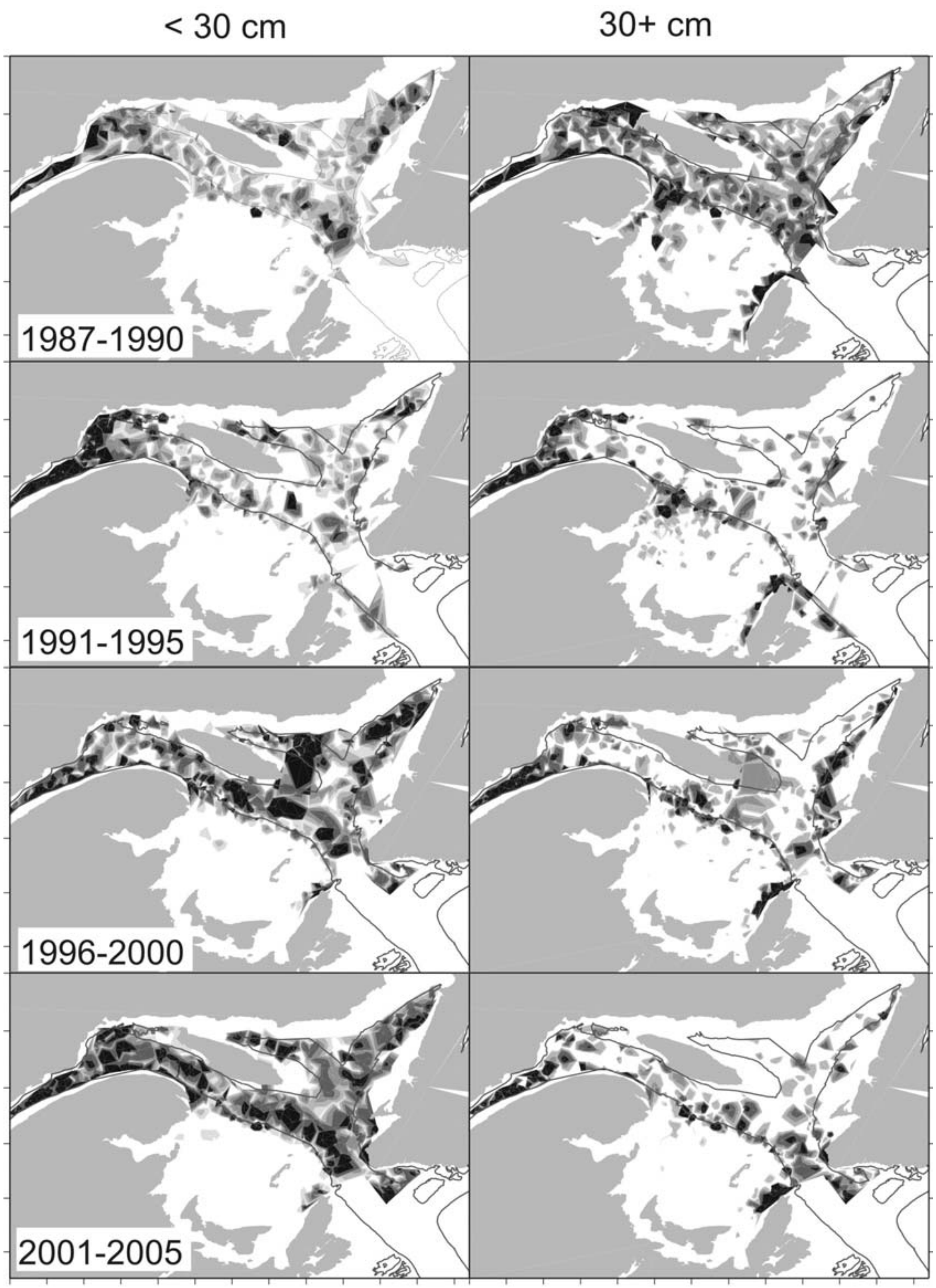

Figure 13. Distribution of two size classes of witch flounder in summer surveys of the Gulf of St. Lawrence. Darker shading indicates higher local density. Contour intervals are the 1st, 10th, 25th, 50th, and 75th percentiles of non-zero catches within each size class. Strata >833 omitted for consistency over time.

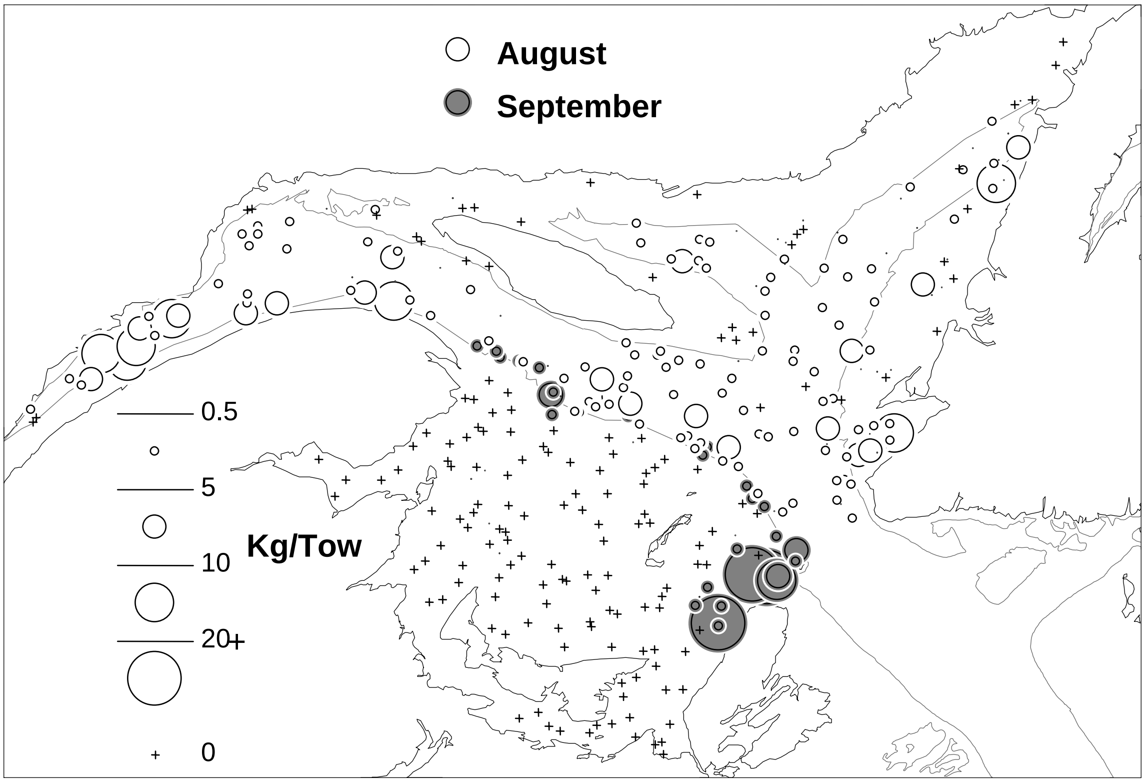

Figure 14. Catch rates (kg/tow) of witch flounder in the 2005 summer surveys of the Gulf of St. Lawrence. Catches have been adjusted to a 1.75-nm night tow by the *Lady Hammond* using a Western IIa trawl.

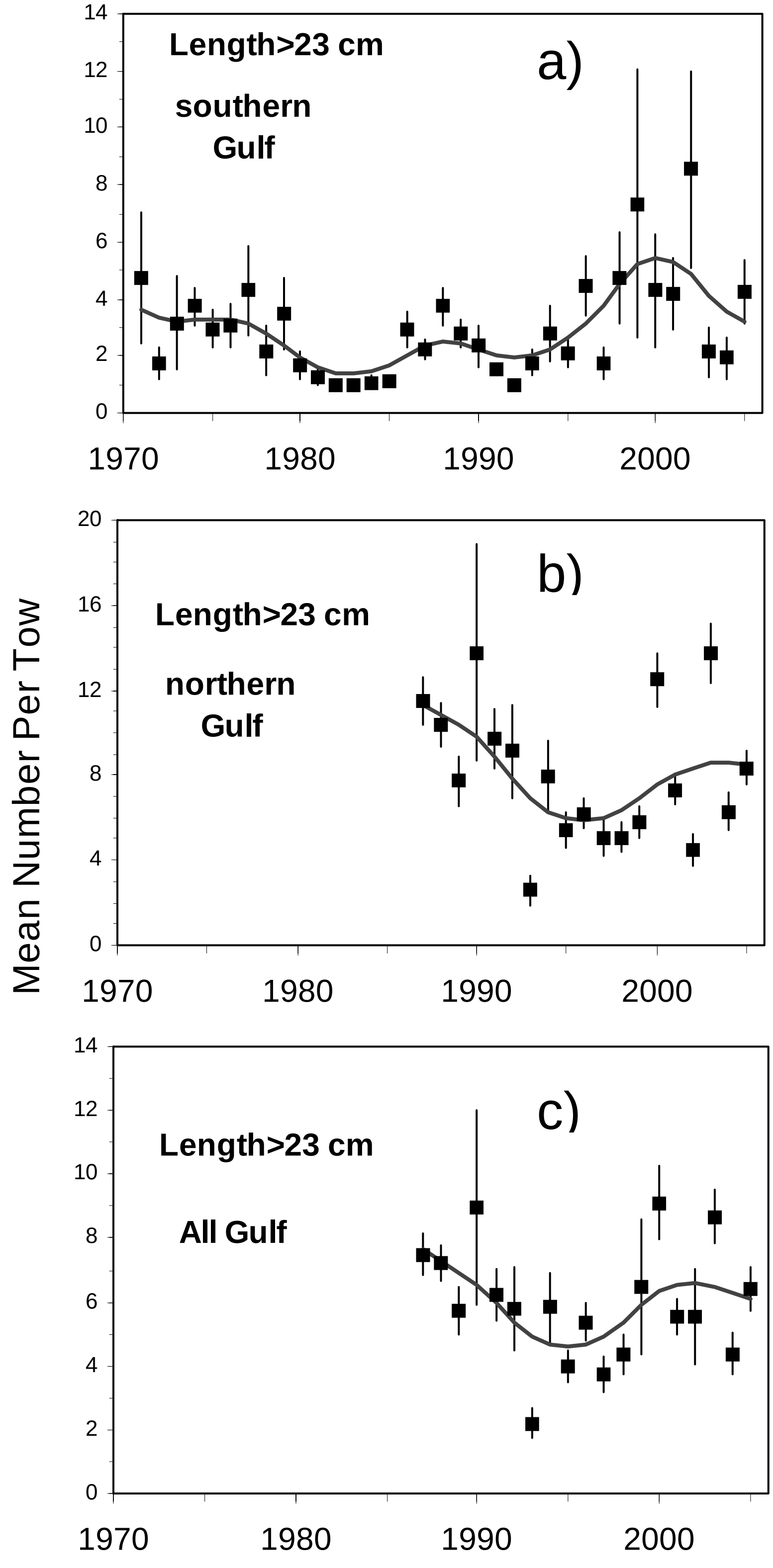

Figure 15. Mean catch rate of witch flounder 24 cm or greater in length in the summer RV surveys of the Gulf of St. Lawrence. Vertical lines are ±1SE. Grey lines are a smoothed fit to the time trend. Catches are adjusted to a 1.75-nm night tow by the *Lady Hammond* using a Western IIa trawl

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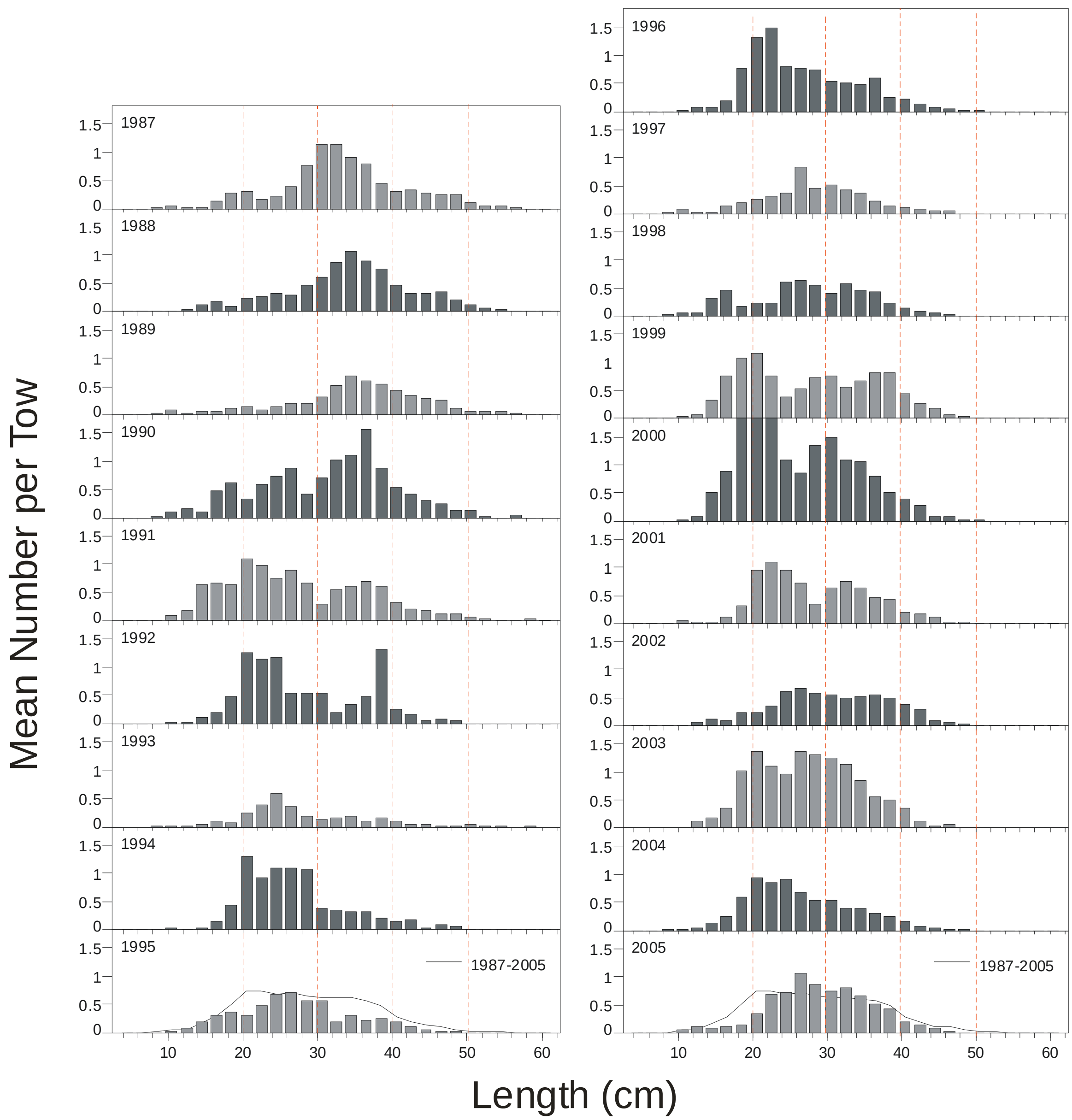


Figure 16. Length composition of witch flounder caught in the August/September surveys of the Gulf of St. Lawrence. Catches are adjusted to a night tow of 1.75 nm by the *Lady Hammond* using a Western IIA trawl. Lines show the average length composition for 1987-2000.

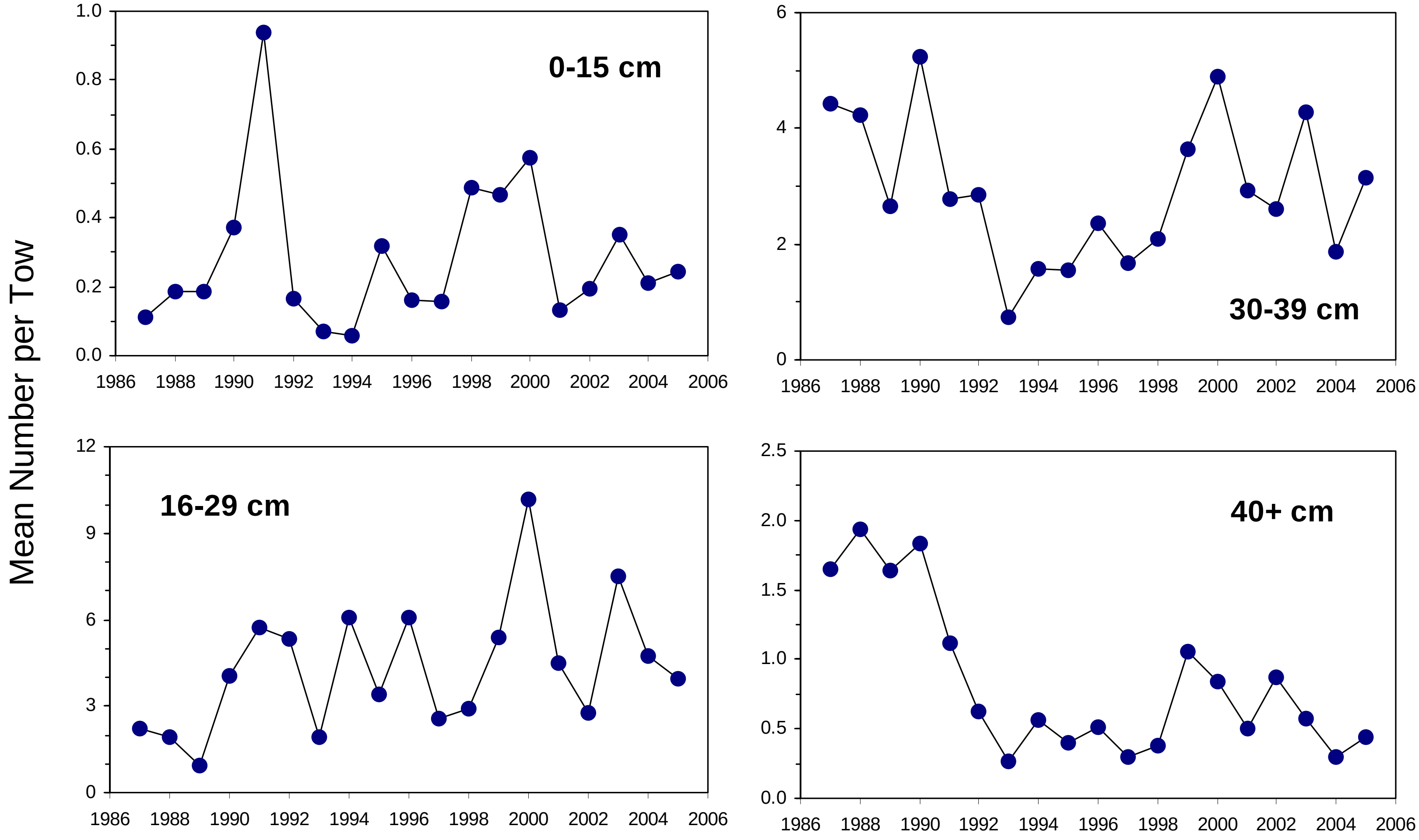


Figure 17. Relative abundance of witch flounder in the Gulf of St. Lawrence by length class.

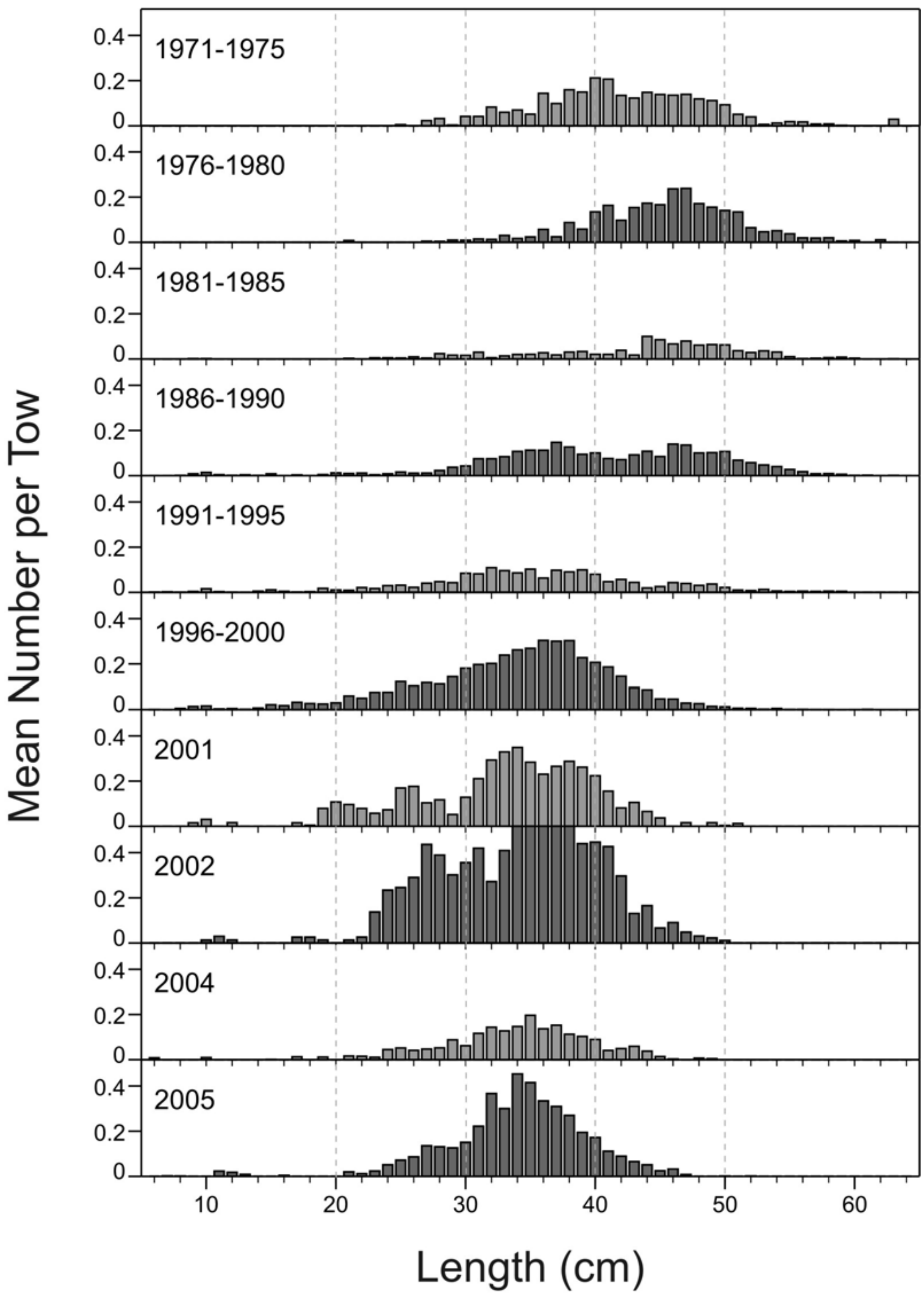


Figure 18. Length frequency distributions of witch flounder caught in the September surveys of the southern Gulf of St. Lawrence.

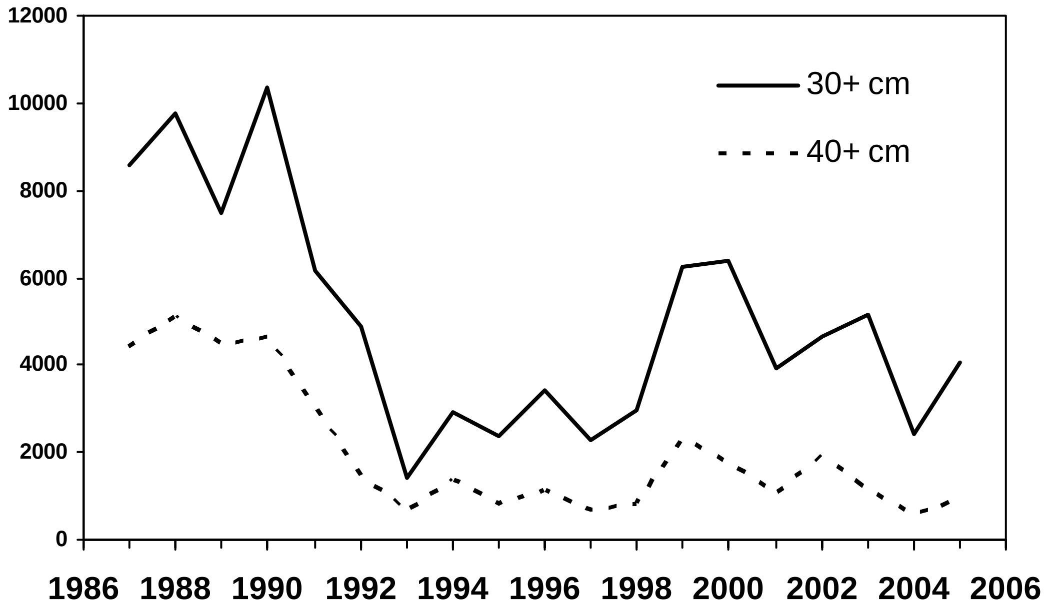


Figure 19. Biomass trends for witch flounder ≥30 cm and ≥40 cm in length in the August and September surveys of the Gulf of St. Lawrence.

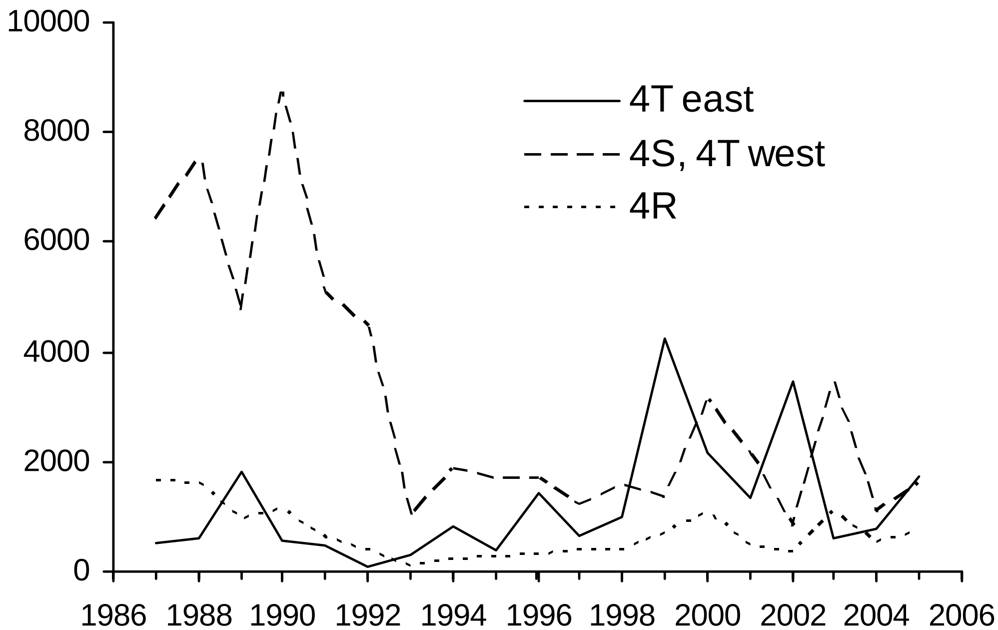


Figure 20. RV survey biomass indices by subregion of the Gulf of St. Lawrence for witch flounder ≥30 cm in length.

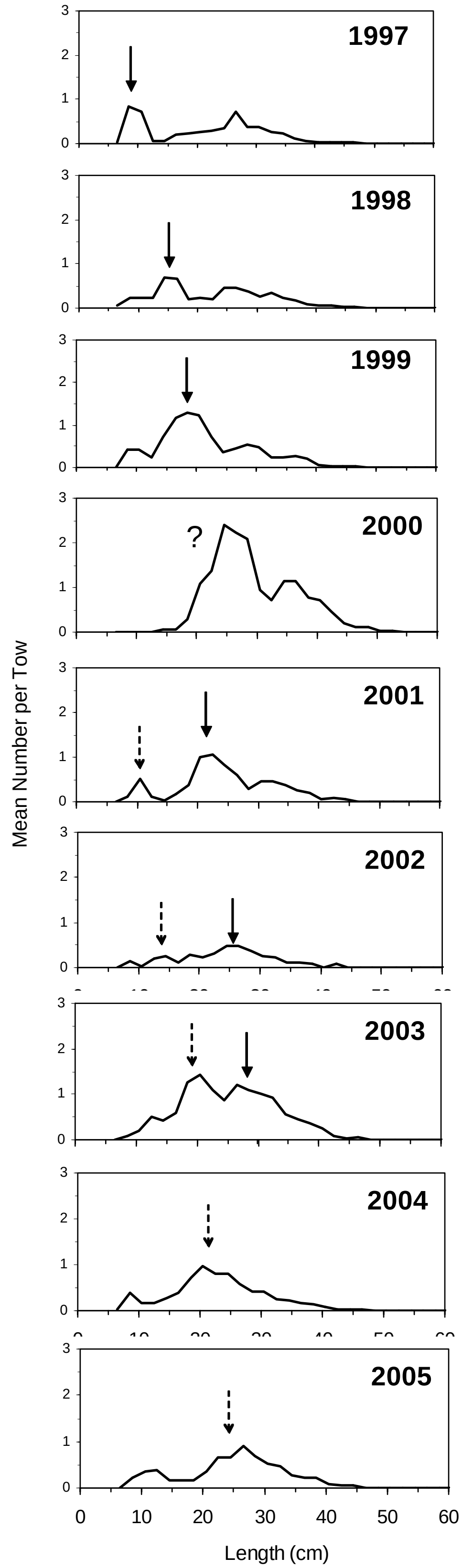


Figure 21. Length frequency distributions of witch flounder caught in the August RV survey of the northern Gulf of St. Lawrence. Catches are adjusted to a 1.75-nm night tow by the *Alfred Needler* using a URI trawl. Arrows indicate the possible progression of strong year-classes.

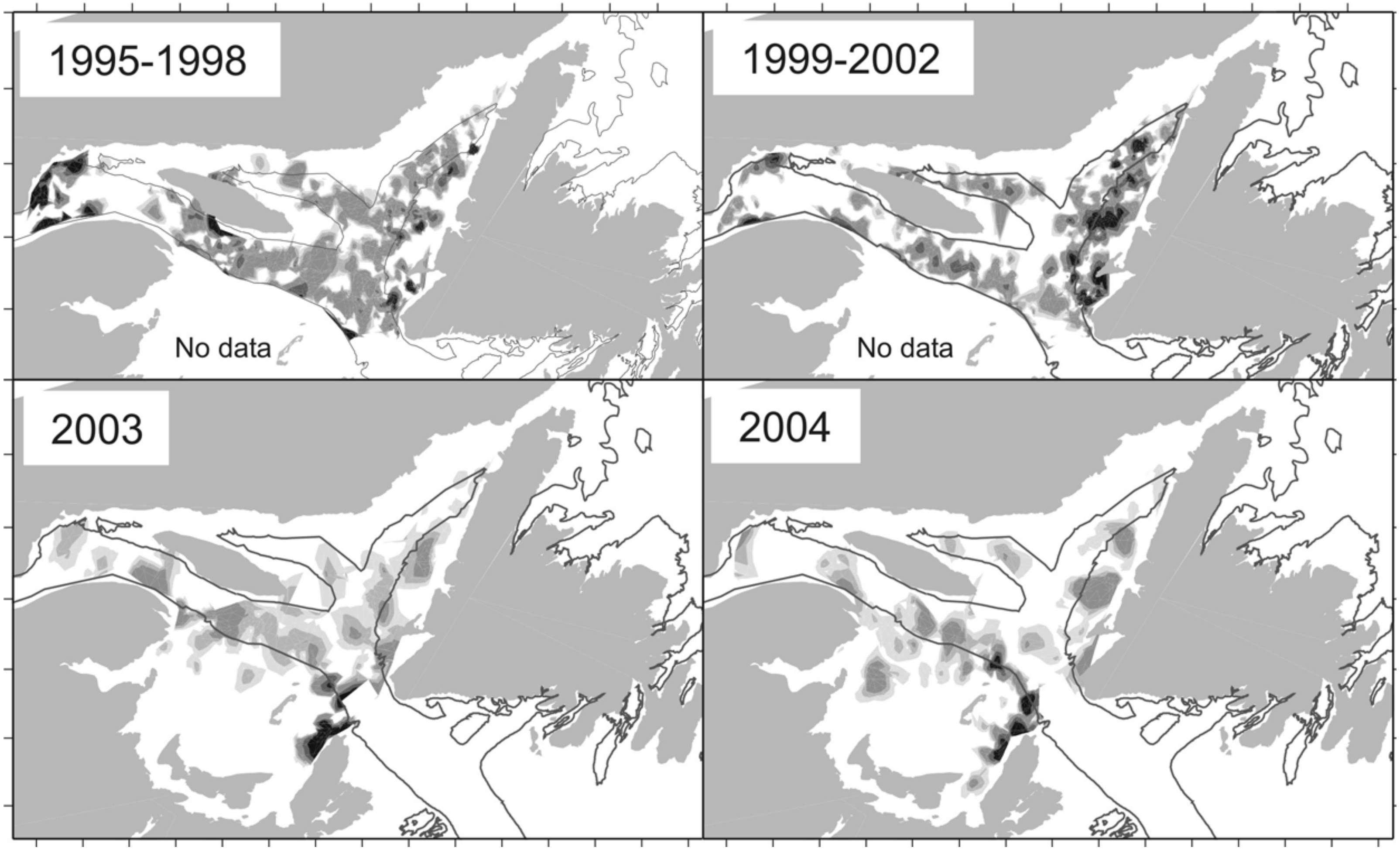


Figure 22. Distribution of witch flounder catches (kg/tow) in the mobile-gear sentinel surveys of the northern (July 1995-2004) and southern (August 2003-2004) Gulf of St. Lawrence. Darker shading indicates a higher catch rate. Contour intervals are 0.1, 0.5, 1, 5, and 10 kg/tow.

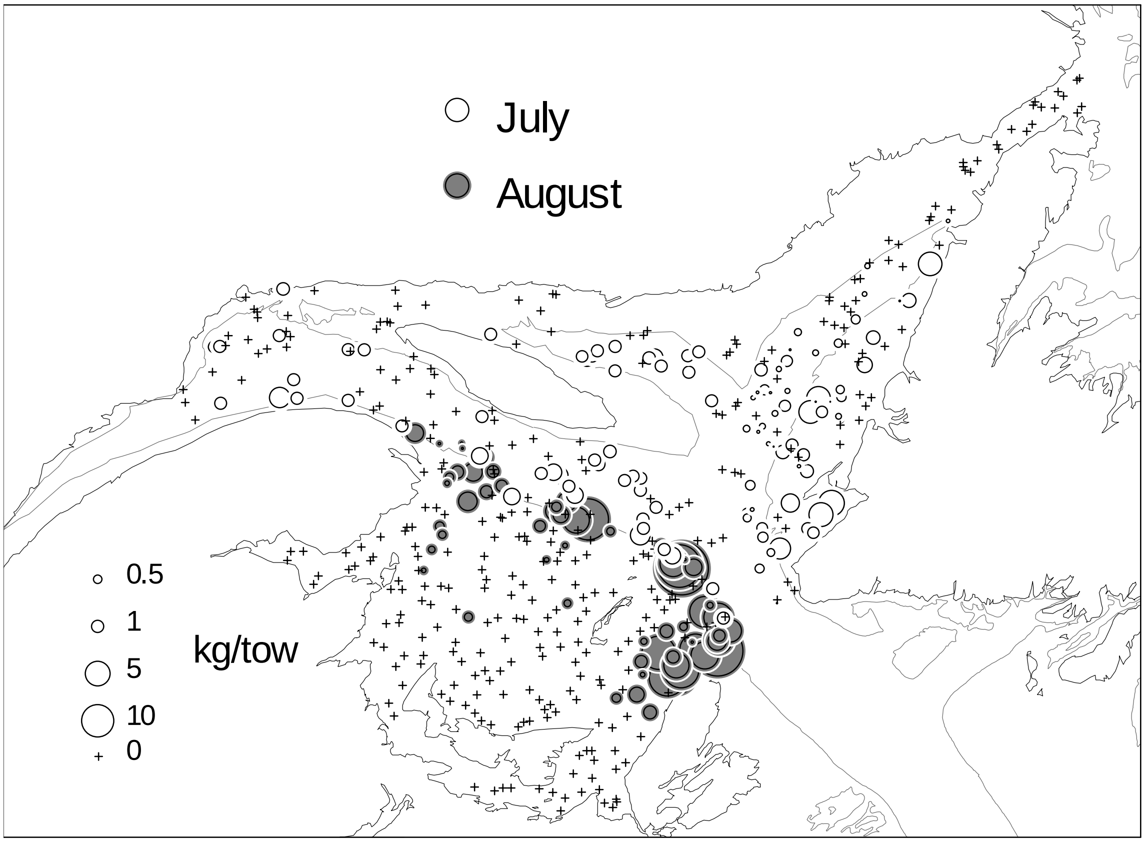


Figure 23. Distribution of witch flounder catches (kg/tow) in the 2005 mobile-gear sentinel surveys of the northern (July) and southern (August) Gulf of St. Lawrence.

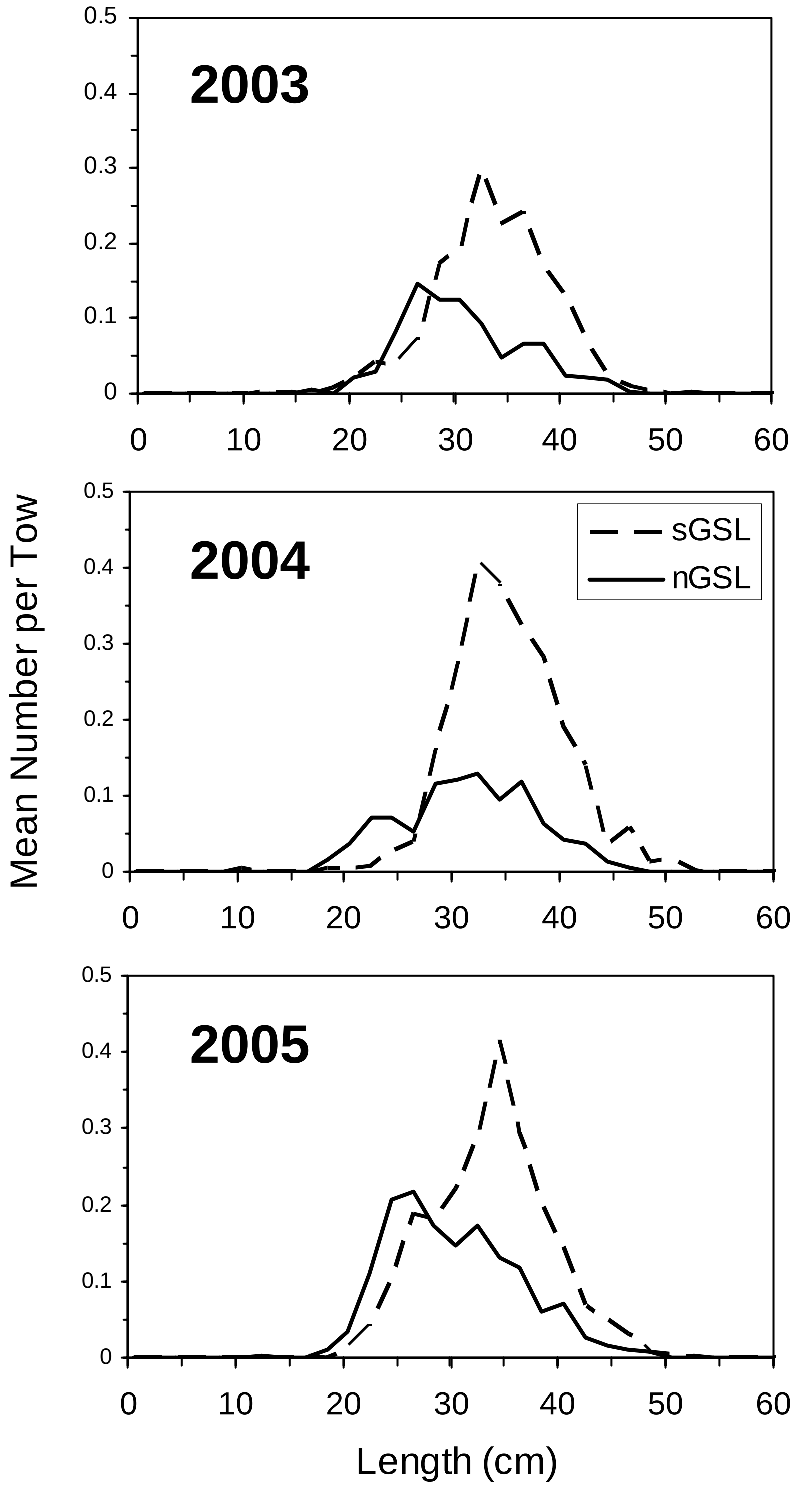


Figure 24. Stratified mean length frequency distributions of witch flounder caught in the July sentinel survey of the northern Gulf of St. Lawrence (nGSL) and the August sentinel survey of the southern Gulf of St. Lawrence (sGSL).

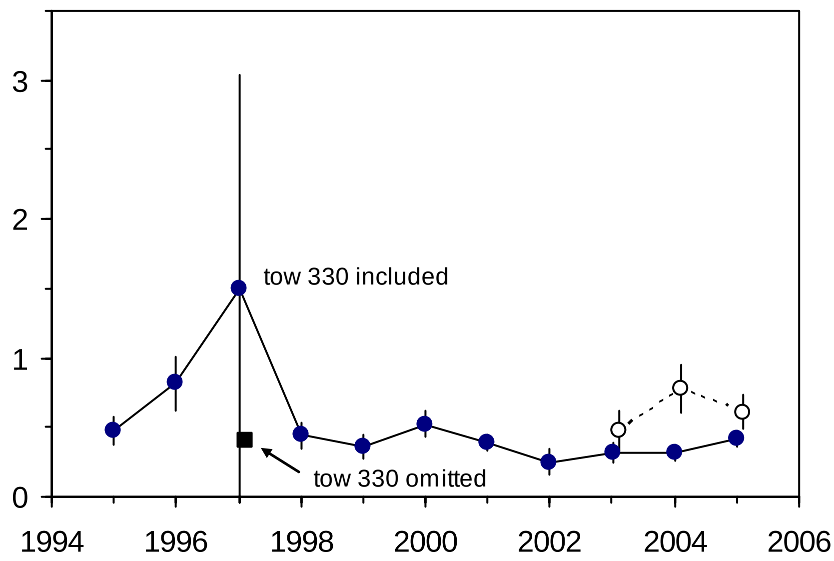


Figure 25. Stratified mean catch rates (kg/tow) in the July sentinel survey of the northern Gulf (solid symbols) and the August survey of the southern Gulf (open circles). Vertical lines are ±1SE. The high 1997 value in July survey is due to a single tow. The square shows the mean catch rate omitting this tow.

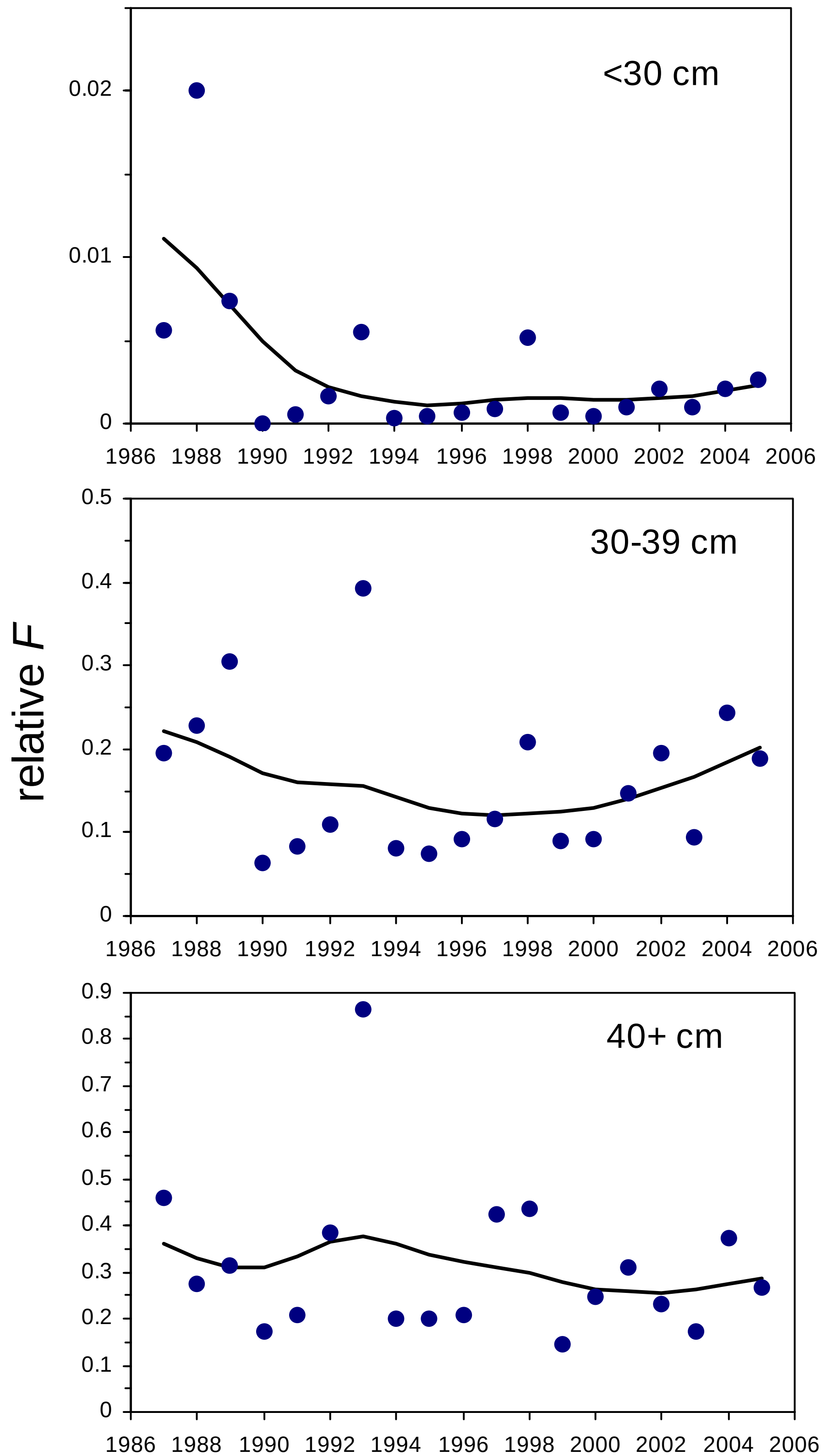


Figure 26. Relative fishing mortality of 4RST witch flounder, estimated as the ratio of catch in a length class divided by the RV survey estimate of population abundance in that length class. Line is a smoothed fit to the annual estimates (a Generalized Additive Model with *df* set to 4).

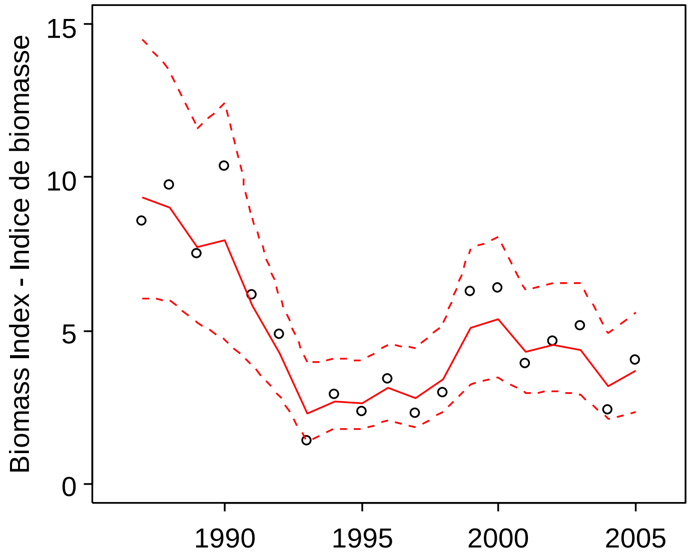


Figure 27. Observed survey biomass index (circles) and the median and 95% credible limits of the posterior of the indices predicted by the surplus production model (lines)

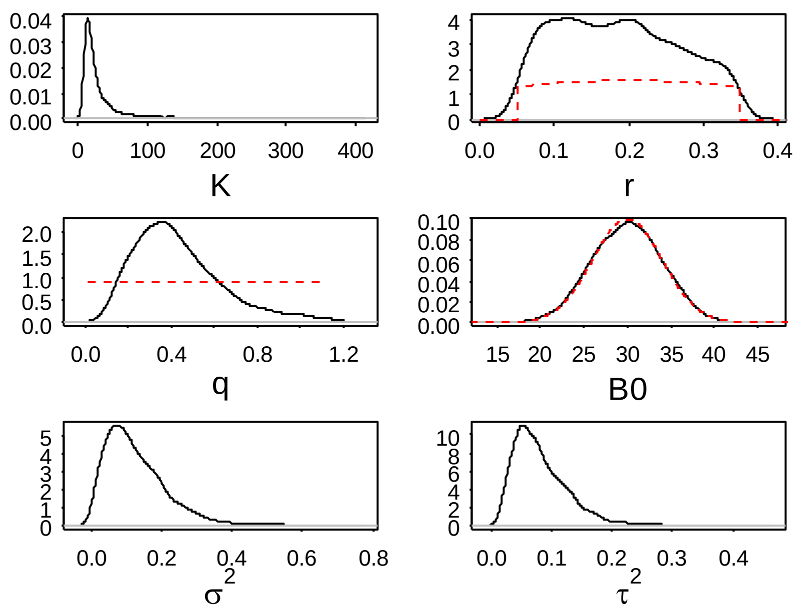


Figure 28. Posteriors for parameters of the surplus production model. Dashed lines show priors.

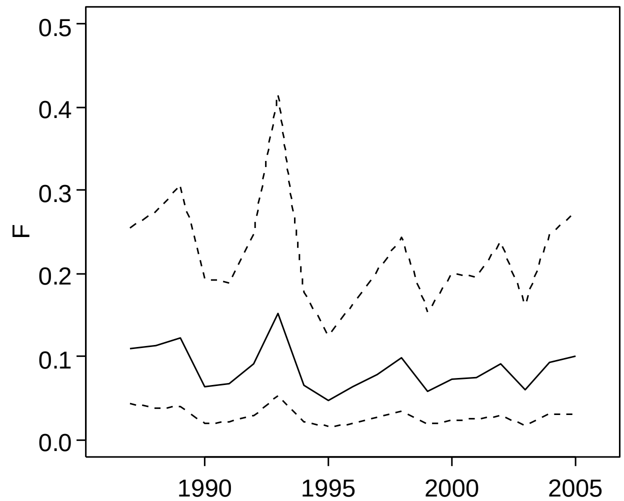


Figure 29. Posteriot median and 95% credible limits for exploitation rate based on the surplus production model.

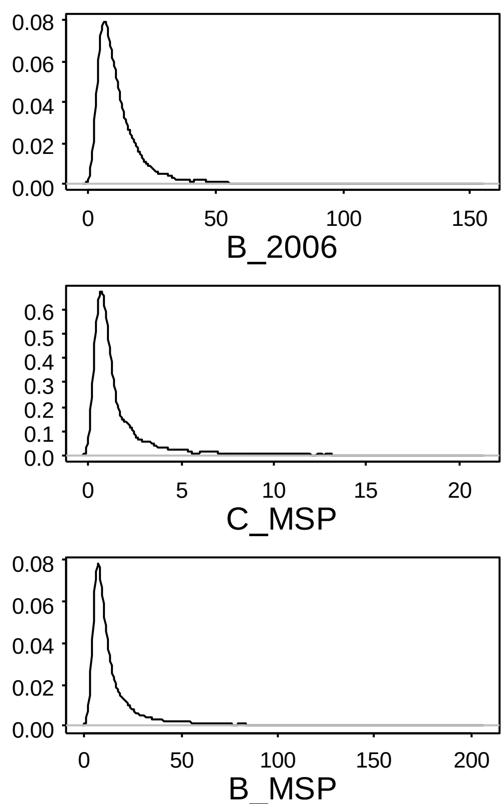


Figure 30. Posteriors from the surplus production model (run 1) for biomass in 2006 (B_2006), catch at maximum surplus production (C_MSP), and biomass at maximum surplus production (B_MSP). Units are thousands of tonnes.

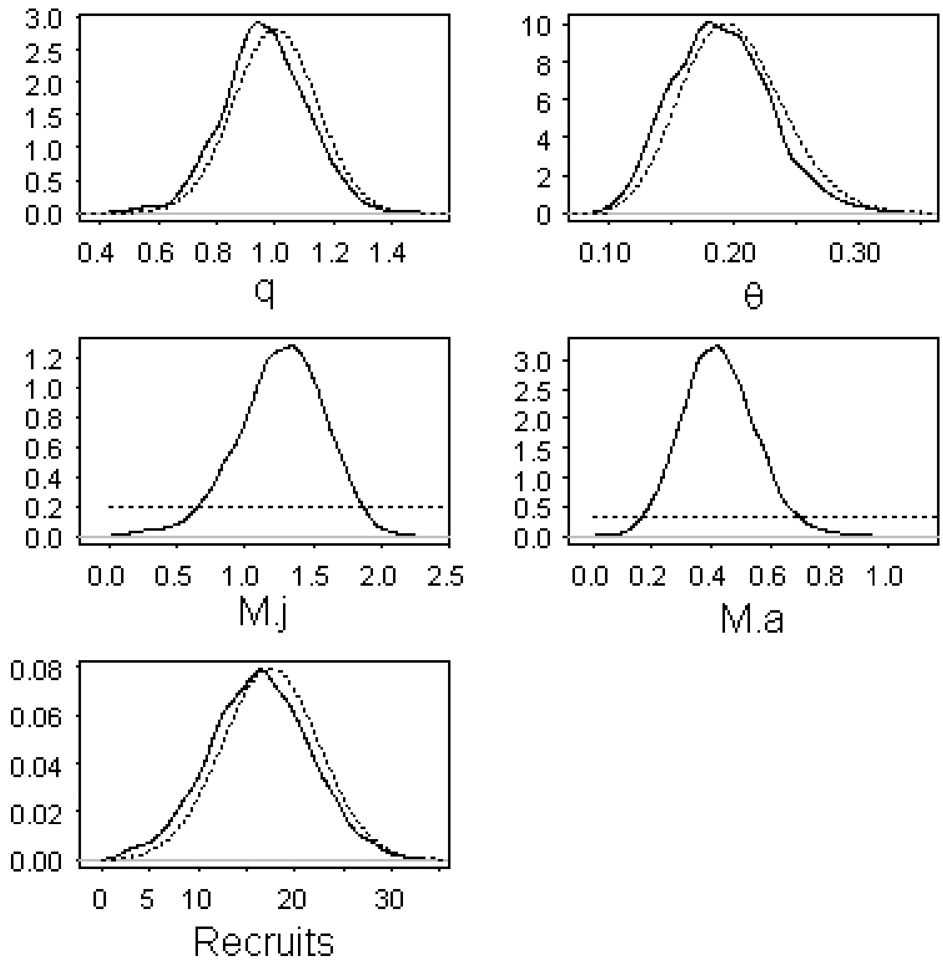


Figure 31. Prior (dotted line) and posterior (solid line) distributions for selected parameters in run 2c of the stage-structured population model. See Table 7 for a description of the inputs to this run.

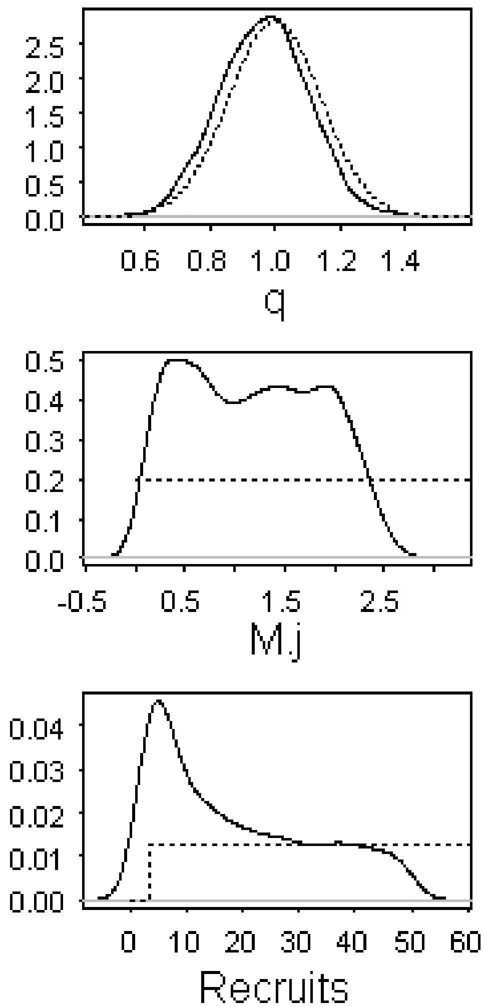
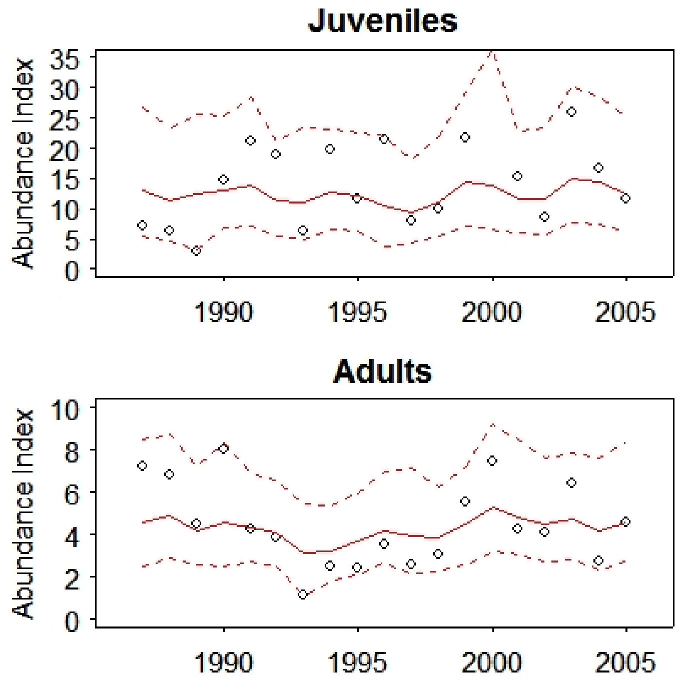


Figure 32. Prior (dotted line) and posterior (solid line) distributions for selected parameters in run 2d of the stage-structured population model. See Table 7 for a description of the inputs to this run.

a) run 2a: θ 0.32, *R* 33



b) run 2c: θ 0.19, *R* 16

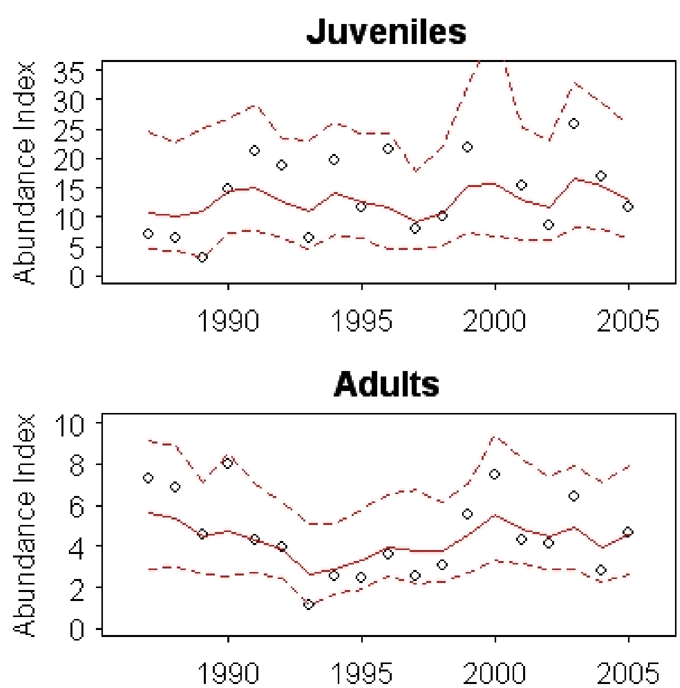


Figure 33. Fits of stage-structured population models with different priors on θ and *R*. Posterior medians for these parameters are given in the figure.

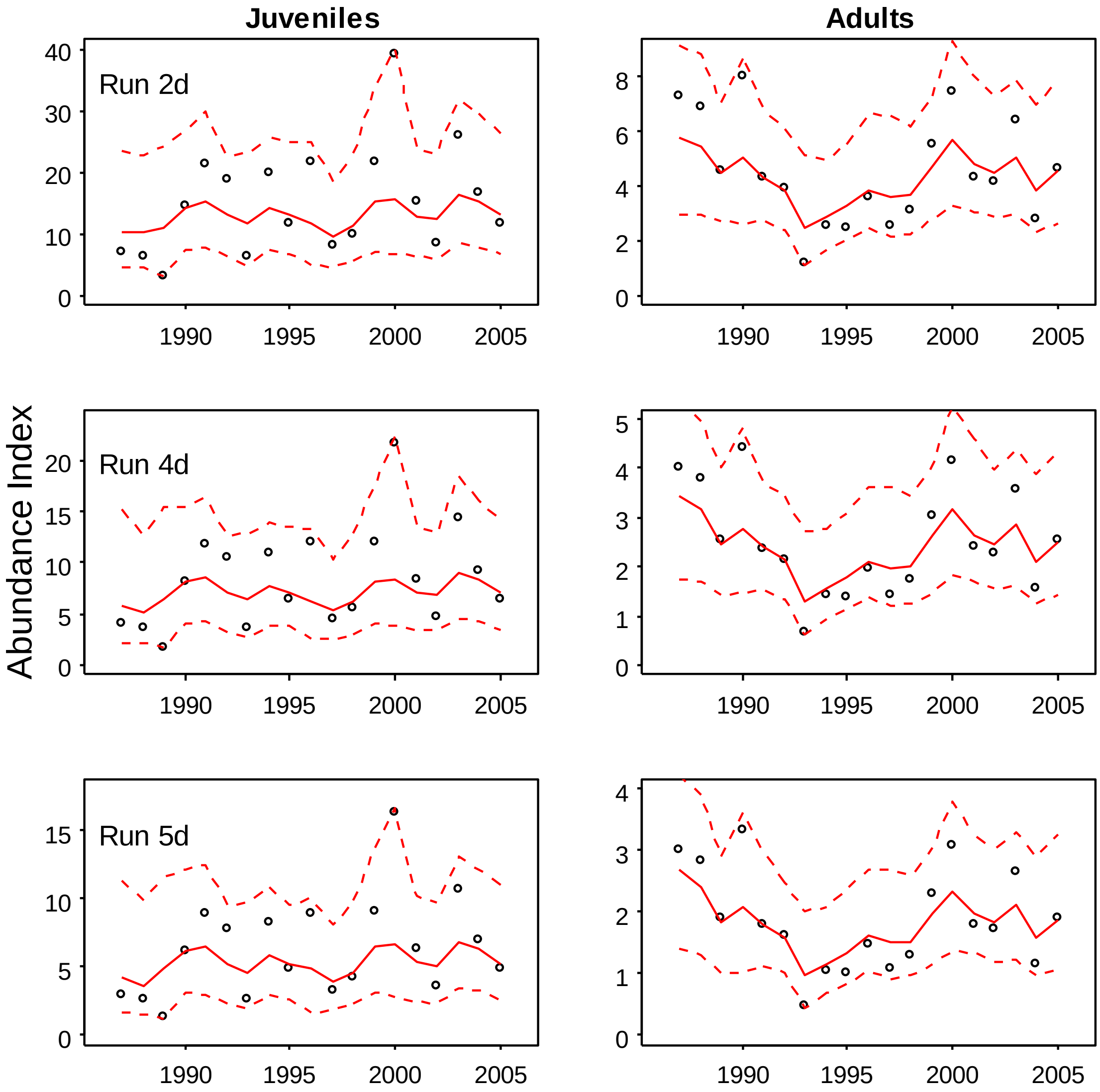


Figure 34. Fit of the stage-structured population model to the abundance indices, given three different Q-corrections. Circles are the observed indices and lines the posterior median and 95% credible limits. See Table 7 for details on the model runs.

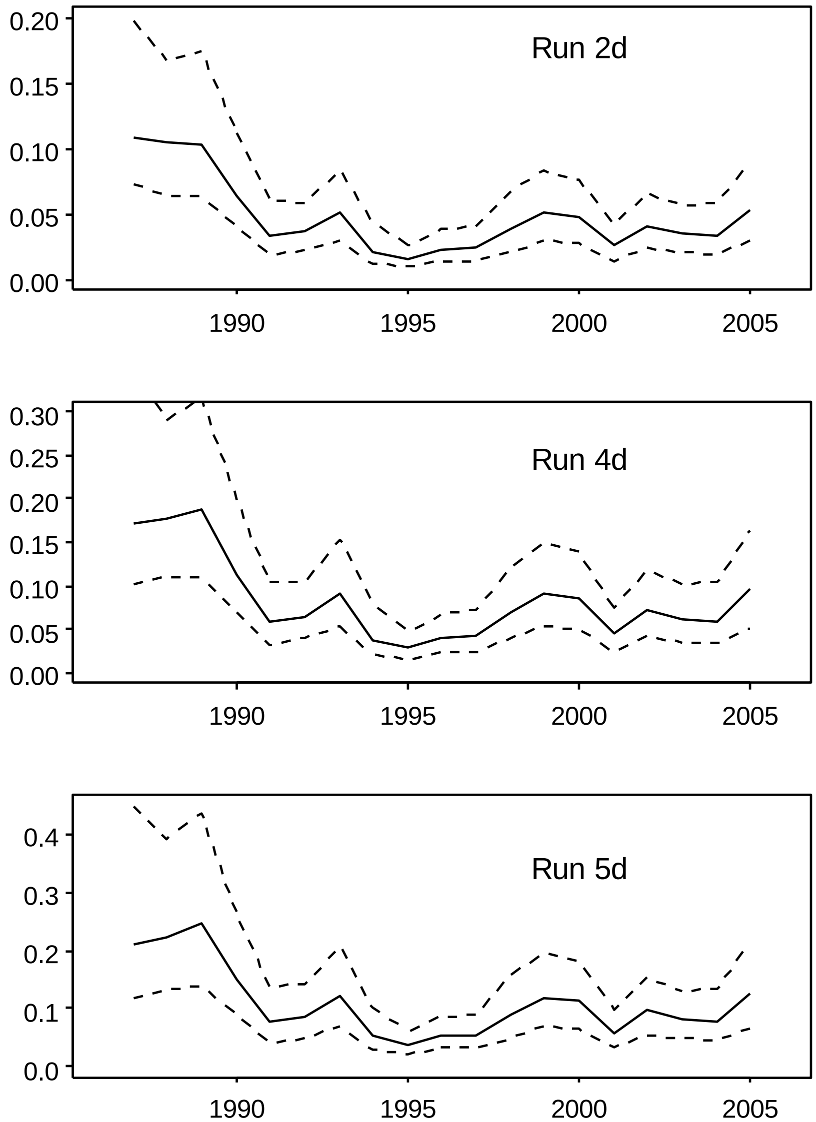


Figure 35. Trends in *F* on adults based on stage-structured population models given three different Q-corrections. Lines are the posterior median and 95% credible limits. See Table 7 for details on the model runs. (Posterior medians for *F* on juveniles were <0.003 in all cases.)