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Assessment of witch flounder (*Glyptocephalus cynoglossus*) in the Gulf of St. Lawrence (NAFO Divisions 4RST), February 2012

Evaluation de la plie grise (*Glyptocephalus cynoglossus*) dans le golfe du Saint-Laurent, (Divisions 4RST de l'OPANO), février 2012

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ABSTRACT

Witch flounder (*Glyptocephalus cynoglossus*) are slow growing and late maturing. In the 1970s, the mean length of a 12-year-old female in the southern Gulf of St. Lawrence was only 41 cm, and the age at 50% maturity of females was 10 years. Because of these life-history characteristics, this species is particularly vulnerable to overexploitation. A fishery for witch flounder developed in the Gulf of St. Lawrence (NAFO Divisions 4RST) in the 1950s. Annual landings averaged over 3,500 t in the 1960s and 1970s, declining to an average of 1,800 t in the 1980s. Landings declined further in the early 1990s to a low of 320 t in 1995. Landings then increased to an average of 850 t annually in 1998-2008 but again declined recently. In the 2011-2012 fishing season, the total allowable catch remained at 1,000 t. Landings in 2011 were 442 t (318 t in 4R and 124 t in 4T). The proportion of large fish (40 cm or greater in length) in the landings declined from 67-80% in the 1970s to 10% in 2011. A research vessel (RV) survey index of commercial biomass (fish 30 cm or longer) was constructed for 4RST based on the August RV survey of the northern Gulf and the September RV survey of the southern Gulf. This index, available since 1987, declined sharply in the early 1990s, increased to an intermediate level in 1999 and 2000, but then declined again, fluctuating around 40% of the 1987-1990 level since 2001. A sentinel survey index of fish 30 cm or longer, based on the July sentinel survey of the northern Gulf and the August sentinel survey of the southern Gulf, is available since 2003. This index declined after 2006 and was at its lowest level in 2011. The proportion of large fish in the RV survey catches has declined sharply. In catches by the September RV survey, the proportion of fish 40 cm or longer declined from 86% in the late 1970s to 8% in 2006-2011. Recruitment has been relatively strong in the 1990s and 2000s but has not resulted in improved abundance of 40+ cm fish. RV survey catches indicate that a strong year-class is again approaching commercial sizes. Population models indicate a 90% decline in commercial biomass since 1961. The limit reference point (LRP) for this stock, set at 40% of the biomass producing the maximum sustainable yield (B_{MSY}), is estimated to be 10,700 t of commercial-sized fish (30 cm or longer). The estimate of the biomass of fish 30 cm and longer in 2011 is 5,000 t, less than half the LRP. Based on the uncertainties in the estimates of both the 2011 biomass and the LRP, the probability that biomass is below the LRP in 2011 is 93%. The maximum removal reference in the healthy zone (the exploitation rate at MSY) is estimated to be 0.07 for this stock. The estimated exploitation rate in 2011 was 0.09. Projections of the population model indicate that biomass is expected to increase with annual catches of 300 t and decrease with catches of 850 t (the average level in 1998-2008). However, even with no catch, there is a 62% probability that biomass will remain below the LRP in five years.

RÉSUMÉ

La plie grise (*Glyptocephalus cynoglossus*) se caractérise par une croissance lente et elle atteint une maturation tardive. Dans les années 1970, la longueur moyenne d'une plie grise femelle de 12 ans dans le sud du golfe du Saint-Laurent était seulement de 41 cm et l'âge auquel 50% des femelles atteignent la maturité était de 10 ans. À cause de ces caractéristiques biologiques, cette espèce est particulièrement vulnérable à la surexploitation. Une pêche de la plie grise a été développée dans le golfe du Saint-Laurent (OPANO Divisions 4RST) dans les années 1950. Les débarquements annuels était, en moyenne, de plus de 3500 t dans les années 1960 et 1970, diminuant à une moyenne de 1800 t dans les années 1980. Les débarquements ont davantage diminué au début des années 1990 atteignant un très bas niveau à 320 t en 1995. Les débarquements ont ensuite augmenté à une moyenne de 850 t annuellement, de 1998 à 2008, mais ils ont de nouveau diminué récemment. Dans la saison de pêche de 2011-2012, les prises totales allouées sont demeurées à 1000 t. Les débarquements en 2011 ont été de 442 t (318 t dans 4R et 124 t dans 4T). La proportion des poissons de grandes tailles (40 cm et plus de longueur) dans les débarquements a diminué de 67-80% dans les années 1970 à 10% en 2011. L'indice des relevés annuels par navires de recherche de la biomasse commerciale (poisson de 30 cm ou plus) a été construit pour 4RST à partir du relevé annuel d'août du nord du Golfe et du relevé annuel de septembre du sud du Golfe. Cet indice, disponible depuis 1987, a chuté au début des années 1990 pour ensuite augmenter à un niveau moyen en 1999 et 2000, mais a chuté de nouveau. Il fluctue à environ 40% du niveau de 1987-1990 depuis 2001. L'indice du relevé sentinelle pour les poissons de 30 cm et plus, construit à partir du relevé sentinelle de juillet pour le nord du Golfe et le relevé sentinelle d'août pour le sud du Golfe, est disponible depuis 2003. Cet indice a diminué après 2006 et a été à son plus bas niveau en 2011. La proportion des poissons de grandes tailles dans les prises des relevés annuels par navire de recherche a chuté considérablement. La proportion de poissons de 40 cm et plus dans les prises du relevé de septembre a diminué de 86% à la fin des années 1970 à 8% en 2006-2011. Le recrutement a été relativement fort dans les années 1990 et 2000, mais aucune amélioration n'en a résulté quant à l'abondance des poissons de 40 cm et plus. Les prises des relevés annuels par navire de recherche indiquent de nouveau qu'une forte classe d'âge approche les tailles commerciales. Les modèles de population indiquent une diminution de 90% de la biomasse depuis 1961. Le point de référence limite (PRL) pour ce stock, fixé à 40% de la de la biomasse assurant le rendement maximal durable (BRMD), est estimé à 10 700 t pour les poissons de tailles commerciales (30 cm ou plus). L'estimation de poissons de 30 cm et plus en 2011 est de 5000 t, moins de la moitié du PRL. En tenant compte des incertitudes dans les estimations de la biomasse de 2011 et du PRL, la probabilité que la biomasse soit en-dessous du PRL en 2011 est de 93%. La référence quant au retrait maximum dans la zone saine (le taux d'exploitation à RMD) est estimée à 0,07 pour ce stock. L'estimation du taux d'exploitation en 2011 était de 0,09. En s'appuyant sur des projections, faites à partir du modèle de population, la biomasse devrait augmenter avec les prises annuelles de 300 t et diminuer avec les prises de 850 t (le niveau moyen de 1998-2008). Toutefois, même sans prise, la probabilité que la biomasse demeure en-dessous du PRL dans cinq ans est de 62%.

INTRODUCTION

Witch flounder (*Glyptocephalus cynoglossus)* 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 Hurlbut 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 3,500 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 5,000 t to reduce the numbers of these old fish and stimulate growth. The TAC was reduced back to 3,500 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 was 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 2006 (Swain and Morin 2006). This document updates assessment analyses to 2011.

THE FISHERY

LANDINGS

Landings of witch flounder in the Gulf of St. Lawrence averaged 3,400 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 flounder 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 1,000 t in the early 1980s to levels near 2,500 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 (see below). 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 their 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 flounder 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. Since 2000, the TAC has been set at 1,000 t. 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. Landings began to decline again in 2008, falling to a record low of 229 t in 2010, less than 25% of the TAC. In 2011, landings increased in 4R to about 75% of the quota allocated to the 4R fleet , but landings by the 4T fleet remained low at about 25% of their quota allocation.

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 (Figs. 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). Since 1998, 4Rd and 4Tfg have contributed roughly equal portions of the landings, though 4Rd dominated the landings in 2011. Contributions from 4Tk and 4Tnoq are now fairly minor.

The fishery for witch flounder is primarily a directed fishery (Fig. 4). In the 1990s and 2000s, trawls directing for witch flounder have fished primarily in 4T. In all years in this period, effort by trawls has been slight compared to effort by seines (Fig. 5). 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 1990s. In 4T, days fished declined from the late 1990s to the mid 2000s, and then increased sharply in 2006 and 2007. The increase in effort in 4T in 2006 and 2007 was less strong in terms of hours fished. Since 2007, effort has decreased sharply, reaching a very low level by 2010 in both 4R and 4T.

CATCH-AT-LENGTH

Swain and Morin (2006) present estimates of mobile gear catch-at-length for 1987-2005. Port sampling of witch landings has been sparse and consequently limited how finely catches could 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 (also see Swain and Poirier 2001). Fish landed in 4R tended to be smaller than those landed in 4T since 1990, so where possible 4T samples were applied to 4T landings and 4R samples to 4R (and 4S) landings (4S landings were low and mostly unsampled - see Swain et al. 1998*b*). Since the early 2000s, sampling has been very sparse in 4R; in years when no samples were available for 4R, samples from the preceding and following years were used to estimate catch at length. Other details regarding methods and the samples available for 1988-1999 are given in Swain et al. (1998*b*) and Swain and Poirier (2001). We extended these analyses from 2006 to 2011, and from 1971 to 1986. Sampling was very sparse in the 1970s and early 1980s, and samples from a number of years were usually grouped together to estimate the catch at length in a particular year. Frequently, the same group of samples was used for blocks of years in the 1970s. Thus, the estimates for the 1970s and early 1980s should be considered indicative of low-frequency decadal-scale differences rather than interannual variation. The samples used to estimate catch at length are listed in Table 2 for 1971-1986 and 2000-2011.

The length composition of samples from the commercial fishery differed dramatically between samples collected in the 1970s and early 1980s and those collected in the 2000s (Fig. 6). The proportion of fish 40 cm and longer was 67-80% in the 1970s samples, 52% in the 1980s samples and 20% in the 2006-2011 samples. The estimated length composition of the landings is given in Table 3 and Figure 7. The estimated proportion of fish 40 cm and longer in the landings was about 70-75% in the 1970s, declining to about 30% in the mid 1980s. This proportion averaged about 40% from 1987 to 1997, and then declined in the 2000s, falling to 10% by 2011.

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. Both surveys are stratified random bottom-trawl surveys. One survey has been conducted in the southern Gulf of St. Lawrence each September since 1971 (Fig. 8), the second has been conducted in the Estuary and the northern Gulf each August since 1984 (Fig. 9). However, witch flounder length frequency data (required for standardization between the two surveys) is available only since 1987 for the August survey.

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* in 1992 – 2002 and 2004-2005, by the *Wilfred*

Templeman in 2003, and by the *Teleost* since 2004. Comparative fishing occurred between the *E.E.Prince* and *Lady Hammond* during the 1985 survey, between the *Lady Hammond* and the *Alfred Needler* prior to the 1992 survey and between the *Alfred Needler* and *Teleost* during the 2004 and 2005 surveys. 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. Fishing was conducted in day only by the *E.E.Prince* and throughout the 24-h day by the other vessels. 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, by the *Alfred Needler* using a URI shrimp trawl from 1990 to 2003, and by the *Teleost* using a Campelen trawl since 2004. Comparative fishing occurred between the *Lady Hammond*/W2A and *Needler*/URI during the 1990 survey and between the *Needler* and the *Teleost* 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).

Based on analyses of the comparative fishing experiments, and additional analyses on diel variation in catchability of witch flounder, catches in the September and August surveys were standardized to a 1.75 nm night tow by the *Lady Hammond* using the Western IIA trawl for most analyses. Diel and vessel effects were independent of fish length, whereas differences in fishing efficiency were length-dependent between the Western IIA and URI trawls and between the URI and Campelen trawls. For some analyses restricted to lengths greater than 23 cm, adjustments between the Western IIA and URI trawls were independent of length because differences in fishing efficiency between these two gears varied little with length at these larger sizes. For analyses restricted to the August survey data since 1990, standardization was to the fishing efficiency of the URI trawl (D.P. Swain, unpublished analyses). Details on these adjustments are given by Swain and Poirier (1998), Swain et al. (1998*a*) and Swain and Morin (2006).

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). Estimated values for missed strata were obtained as described by Swain and Poirier (2001) and Swain and Morin (2006).

LIFE-HISTORY INFORMATION

Growth

Witch flounder otoliths collected during the 1974-1981 September surveys were aged (N = 301 males and 445 females). Growth was slow, with a mean length at age 12 years of 40 cm for males and 41 cm for females. Von Bertalanffy growth models were fit to these data and provided adequate fits for both males and females (Fig. 10, Table 4). Estimated asymptotic lengths (L_∞) were 69 cm for females and 54 cm for males. Size-at-age began to diverge between males and females at ages of 12-15 years, consistent with the earlier maturation of males (see below).

Bowering and Brodie (1984) reported growth rates for witch flounder collected from the northern Gulf during the same period (1975-1981). Their estimated growth rates were somewhat faster than those reported here, with their predicted lengths at age 12 years varying between 40 and

47 cm for males and 41 and 49 cm for females. However, the maximum ages in their data were considerably lower than those in the September data (26 versus 34 in 1976, declining to 16 versus 25 in 1980/1981), suggesting the possibility that ages may have been underestimated in their study.

Maturation

The main source of maturity data for witch flounder in the Gulf of St. Lawrence is the biological data collected during the September surveys. For late winter – early spring spawners such as witch flounder, there is concern about the reliability of maturity staging in September, mainly due to the difficulty in distinguishing between maturity stage 1 (immature) and maturity stages 7 and 8 (recovering/resting mature fish). Studies on other species (e.g., cod) have indicated that maturity staging of these species was reliable for September surveys prior to 1983, when the group conducting the survey changed (e.g., Swain 2011). Based on comparisons with samples collected in the spring, maturity staging of cod was unreliable in September surveys from 1983 to the early 1990s but appeared to be reliable in surveys conducted in the 2000s (Swain 2011, Supporting Information S3 and S4). To examine the reliability of the witch maturity data from the September survey, proportions at length were plotted for stage 1, stages 7-8 and stages 2-6 (unambiguously mature). Reliability is suspect if stages 7-8 begin to appear at considerably smaller sizes than stages 2-6. These plots suggest that the maturity staging was reliable in 1970-1982 but not in 1983-1999 (Fig. 11), consistent with results for cod (Swain 2011) and white hake (Swain et al. 2012). Plots for 2000-2009 also suggest reliability; however, during this period there was some confusion between the regular groundfish codes used for witch flounder and newly-introduced codes used for American plaice. (Code 2 represents a mature fish in the groundfish codes but an immature fish in the plaice codes.) The extent of this confusion in the 2000-2009 is uncertain, but it is known to be absent from the 2010-2011 data. Though data are sparse, plots for the 2010-2011 period are consistent with reliable staging.

Based on the 1971-1982 data, the estimated lengths and ages at 50% maturity (L_{50}, A_{50}) were 38.6 cm and 10.4 years for females and 33.2 cm and 7.5 years for males (Fig. 12). These values are similar to those reported by Bowering and Brodie (1984), based on witch flounder collected in January 1978-1981 in the northern Gulf: averages of 41.4 cm and 10.3 years for females and 31.5 cm and 6.9 years for males.

The data from surveys in the 2000s suggest that maturation is now earlier than in the 1970s and early 1980s, with L_{50} estimated to be 23.8 and 25.3 cm for males and females respectively based on the 2010-2011 data and 25.6 and 27.9 cm based on the 2000-2009 data (Fig. 13). While the reliability of the recent September data is uncertain, sampling in the Cape Breton Trough in late April and early May 2009-2011 also indicates earlier maturation: of 490 individuals sampled (lengths 26-54 cm) all but one fish were mature, including 30 males less than 31 cm in length and 32 females less than 35 cm in length. Earlier maturation is an expected evolutionary response to increased mortality at larger sizes, such as that imposed by fishing (Law and Grey 1989; Law 2000) or predation (Reznick and Ghalambor 2005; Swain 2011).

GEOGRAPHIC DISTRIBUTION

Small pre-commercial sizes of 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. 14). Densities of these small witch flounder tended to be high in the Estuary in all time periods since the start of the time series in 1987. Densities of these small fish in the channels were higher in the periods between 1996 and 2011 than in the earlier periods.

Larger commercial-sized witch flounder (≥30 cm) tend to move up onto the shelves 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 shelf off western Newfoundland, as well as in the Estuary. 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 (Fig. 15, see below). 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 sharply in the deep channels of the northern Gulf in the 1991-1995 period. Following the decline in the 1991-1995 period, densities along the shelf off western Newfoundland improved in the 1996-2000 period. Strong concentrations of large witch flounder occurred in the Cape Breton Trough in all time periods between 1987 and 2005.

A longer term perspective is provided by the September surveys of the southern Gulf (Fig. 15). Small witch flounder were rare in the southern Gulf in the 1970s and 1980s, mostly restricted to a narrow band along the southern slope of the Laurentian Channel, where they occurred at low densities. Densities of these small fish increased along the southern slope of the Channel in the 1990s, and again in the 2000s. Relatively high densities of these small fish appeared for the first time in the Cape Breton Trough in the 1990s and again in the 2000s.

Larger witch flounder occurred at relatively high densities on the western Magdalen Shallows in the 1970s and the 1980s. Beginning in the 1990s, densities in this area declined and distribution progressively contracted, with witch flounder in the western region of the southern Gulf now largely restricted to a narrow band along the southern slope of the Laurentian Channel. In the southeast, large witch flounder were widely distributed along the west coast of Cape Breton in the 1970s and 1980s, penetrating as far onto the Shallows as St. Georges Bay. In the 1990s and 2000s, large witch flounder in this area became increasingly concentrated in the Cape Breton Trough and along the slope of the Laurentian Channel.

Variation in the distribution of witch flounder in the summer RV surveys in recent years is shown on a finer temporal scale in Figure 16. Catches were highest in the Cape Breton Trough, along the southern slope of the Laurentian Channel and the in the St. George’s Bay area on the shelf off western Newfoundland. No significant interannual differences in distribution were evident in the 2006-2011 period.

LENGTH COMPOSITION

Population length distributions are available since only 1987 (Fig. 17). Abundance of commercial sizes (30+ cm) declined sharply in the early 1990s. Abundance of fish 30-40 cm in length recovered in the late 1990s and early 2000s, but abundance of larger (40+ cm) fish has shown no sign of recovery. Abundance of fish under 25 cm has been generally greater since 1990 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). Relatively high abundances in the 15-25 cm interval in the early 1990s, the late 1990s and early 2000s and in 2009-2010 suggest the appearance of a number of strong year-classes which may be responsible for the recovery and maintenance of abundance at the smaller commercial sizes (30-40 cm). However, survival of these strong year-classes does not appear to be sufficient to produce any recovery in biomass at larger sizes (40+ cm).

A longer term perspective is available for the portion of the stock occurring in the southern Gulf in September (Fig. 18). In the 1970s and early 1980s, 64-86% of the witch flounder caught in the September survey were 40 cm or greater in length, and 9-21% were 50 cm or greater. By 2006-2011, this had declined to 8% and 0.1%, respectively. In contrast, 1-7% of the witch flounder caught in the 1970s and early 1980s were less than 30 cm in length whereas 27% of those caught in 2006-2011 were in this size range.

BIOMASS TRENDS

Biomass trends for commercial-sized witch flounder (30 cm and longer, hereafter 30+ biomass) were obtained for the entire Gulf from the length distribution of the survey catches and estimates of the length-weight relationship. 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. 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 those 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 the August survey in 1990. Biomass reached a minimum in 1993 and remained at a low level from 1994 to 1998. Biomass increased sharply to an intermediate level in 1999 and 2000, but has decreased since then. Since 2001, biomass has fluctuated at a level about 40% of the 1987-1990 level. 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 has shown little recovery from the decline in the early 1990s. Since 2004, biomass of 40+ cm fish has fluctuated at a level less than 20% of the 1987-1990 level.

Changes in biomass have not occurred uniformly throughout the 4RST area (Fig. 20). The decline in biomass in the early 1990s occurred primarily in the 4R and 4S/western 4T areas. There has been little recovery of 30+ biomass in 4S and western 4T since the decline in the early 1990s. In 4R, 30+ biomass has recovered somewhat from the very low values of the early to mid 1990s, averaging 37% of the 1987-1990 levels in 2009-2011. In eastern 4T, 30+ biomass increased to a relatively high level in the late 1990s and early 2000s, but has since declined, averaging 64% of the 1987-1990 level in 2009-2011.

In the 4T portion of the stock area, biomass of small witch flounder (<30 cm in length) increased to relatively high levels in the late 1990s and the 2000s (Fig. 21). The biomass of larger witch (30+ cm) was relatively high in the 1970s, declining to a lower level in the early 1980s. Following a partial recovery in biomass in the late 1980s, 30+ biomass again declined to a low level in the early 1990s, where it remained except for a period of higher values in the late 1990s and early 2000s.

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 nine 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 (except that the sentinel surveys do not extend as far into the Estuary as does the RV 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 - 2011 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. High catches also occurred in the Laurentian Channel and the Estuary. Distribution appeared to be somewhat more concentrated in the 1999-2002 period than in the 1995-1998 period.

In 2003-2006, when both the southern and northern Gulf were monitored by the sentinel surveys, high catch rates were generally restricted to the shelf off western Newfoundland, the southern slope of the Laurentian Channel north of the Magdalen Islands and the Cape Breton Trough. In 2007-2009, catch rates tended to be highest in the Cape Breton Trough and in St. George's Bay off western Newfoundland. A similar distribution was observed in 2010 and 2011. Figure 23 illustrates the interannual variation in the distribution of witch flounder catches in the July and August sentinel surveys in recent years.

The distribution of witch flounder catches in the sentinel surveys is generally consistent with the distribution in the RV surveys given the lower efficiency of the sentinel gear at catching small fish (Swain and Poirier 2001).

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 generally occurred at smaller sizes (20-32 cm). Few fish longer than 45 cm were caught in either survey.

BIOMASS TRENDS

Catch rates in the July sentinel survey reveal little trend in witch flounder biomass in the northern Gulf between 1995 and 2011 (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. The biomass index from the August sentinel survey of the southern Gulf declined after 2006, with the 2011 value the lowest in the nine year time series (Fig. 25). Indices constructed by combining data from the two surveys show a temporal pattern similar to that from the August sentinel survey (Fig. 26).

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). Because trawlable abundance is typically expected to be less than actual abundance, *R* is expected to exceed the actual exploitation rate. Nonetheless, trends in *R* may indicate trends in *F*, with the caveats noted below.

For pre-commercial sizes (<30 cm), *R* was negligible in all years since the start of monitoring in 1987 (<0.023, mean 0.003). For the 30-39 cm length class, *R* tended to be relatively high in the late 1980s and low in the 1990s (Fig. 27). *R* of 40+ fish was about twice that of 30-39 cm fish. For both size classes. *R* increased somewhat in the mid 2000s and then declined to a low level with the sharp reduction in landings in 2010 and 2011. The 2011 estimate is biased low because it is based on preliminary catch statistics which accounted for only 296 of the 442 t landed in 2011.

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 made prior to the August and September surveys was relatively low from the mid 1990s to the mid 2000s (Fig. 28); thus, as an index of *F, R* during this period is biased low relative to earlier and later years.

POPULATION MODELLING – SCHAEFER SURPLUS PRODUCTION MODELS

Based on the preceding material, the following statements can be made:

1) Witch flounder is an unproductive species. Growth is very slow and maturation is at a late age. Such species are particularly vulnerable to overexploitation. An apparent decline in the age at maturation in the 4RST stock is consistent with the hypothesis that this stock has experienced unusually high adult mortality in recent decades.

2) Commercial (30+ cm) biomass of 4RST witch flounder declined sharply in the early 1990s. There appeared to be some recovery in biomass following a reduction in landings to 300-500 t. However, this partial recovery ceased and has been eroded following an increase in landings to the 700-900 t level. Thus, the stock appears to no longer be able to support landings under 1,000 t even though annual landings averaged over 3,500 t in the 1960s and 1970s.

3) There has been a dramatic contraction in the size composition of the stock since the 1970s and early 1980s. Fish 40 cm or longer comprised 70-80% of the landings and 86% of the September RV catch in the late 1970s but only 20% of the landings and 8% of the September RV catch in 2006-2011.

4). Pre-recruit abundance increased to a high level in 4T in the late 1990s and the 2000s. At the stock level, a number of strong year-classes have been evident in the 1990s and 2000s. Despite this strong recruitment there has not been any increase in the abundance of 40+ cm fish.

These observations suggest the following hypotheses (which are not mutually exclusive): a) the stock is severely depleted and even landings under 1,000 t exert a relatively high fishing mortality, and/or b) productivity of the stock has declined below its normal (already low) level.

These possibilities were explored using Schaefer surplus production models. Two types of models were examined, models assuming a constant productivity regime and models that allowed for changes in productivity regime.

Model Structure

Models were Bayesian state-space models, 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:

$$(1)\quad B_t = [B_{t-1} + rB_{t-1}\left(1 - \frac{B_{t-1}}{K}\right) - C_t]e^{\eta_t}$$

where B_t is biomass in late summer/early fall of year *t*, C_t is catch from September in year *t-1* to August in year *t*, *r* is the intrinsic rate of population growth, and *K* is carrying capacity. The parameter *r* was fixed at a constant level or allowed to vary decadally. The parameter η_t is an independent normal random variable with mean zero and variance σ^2, representing process stochasticity. Models incorporated as much as the catch history as possible, starting in 1961 or 1971.

The observation component related the biomass indices $I_{i,t}$ to population biomass B_t:

$$(2)\quad I_{i,t} = q_i B_t e^{\varepsilon_{i,t}}$$

where q_i is catchability for index *i* and the $\varepsilon_{i,t}$ are independent normal random variables with mean zero and variance τ^2_i, representing observation error in biomass index *i*. The model was fit to three indices of 30+ biomass. To estimate the joint posterior distribution of the model parameters, 275,000 samples were generated in each of two chains, the first 200,000 were discarded as a "burn-in", and every 30th sample thereafter was retained to reduce autocorrelation, yielding 5,000 samples from the joint posterior distribution. Contrasting values within the range specified by each of the prior distributions were used to initialize the two chains.

Biomass Indices

Index 1 was the trawlable biomass of witch flounder 30 cm and longer (hereafter 30+ trawlable biomass) in the September RV survey of 4T from 1971 to 1992. This index does not cover the entire stock area. Its use assumes that availability to the September survey (i.e., the proportion of the stock occurring within the September survey area) does not change over time. The index was used only for the 1971-1992 period because the proportion of the stock occurring in the September survey area changed as the stock declined in the early 1990s (Fig. 29). The 4T survey accounted for an average of 20% of the 4RST biomass from 1987-1992 and about 50% of this biomass from 1993-2002. The assumption of roughly constant availability to the September survey, so that changes in the September RV index track changes in stock biomass over the 1971-1992 period, is supported by the following observations. The increase in availability in 4T in the mid 1990s was accompanied by a shift in distribution, with a large drop in biomass in western regions of the Gulf, i.e. the western Magdalen Shallows, the estuary and the 4S area to the west of Anticosti Island (Fig 14). No shifts in distribution are evident in the 1970s and 1980s. In the southern Gulf, distribution was stable between the 1970s and 1980s, with the decline in the proportion of 30+ cm witch flounder occuring in western regions not evident until the 1990s (Fig. 15). Likewise, summer densities in the area to the west and southwest of Anticosti Island were relatively high in 1976-1981 (Bowering and Brodie 1984), as was the case in the 1987-1990 period (Fig. 14). Secondly, a January survey conducted from 1978 to 1994 provides information on abundance over most of the stock area during the late 1970s and 1980s. Although there are unresolved difficulties with the witch flounder data from this survey (poor survey coverage during heavy ice years and other inconsistencies in the data), a size-aggregated abundance index from this survey suggests that stock abundance was low in 1983 and 1984 relative to 1978-1980 and 1985-1987 (Fig. 20 in Swain et al. 1998b), consistent with the biomass trends in the September survey during this period (Fig. 21). While there is thus some support for the assumption that the 1971-1992 trends in the September RV survey track stock trends over this period, models were also fit omitting this index to examine the sensitivity of model results to this assumption.

Index 2, covering 1987-2011, was 30+ trawlable biomass in the combined August and September RV index for 4RST (Fig. 19). Index 3, covering 2003-2011, was 30+ trawlable biomass in the combined July and August sentinel surveys (Fig. 26).

Prior on *r*

Following McAllister et al. (2001), an informative prior for *r* was developed based on the life history characteristics of 4RST witch flounder. We approximated *r* using the Euler-Lotka method, which involved numerically solving the following equation for *r*:

$$(3) \quad \sum_{a=A_0}^{A_{\max}} e^{ar} w_a m_a \alpha l_a = 1$$

where a is age, w_a is the mean weight of females at age a, m_a is the proportion of females mature at age a, l_a is survival from age A_0 to a, and α is the slope of the stock-recruit relationship at the origin. To construct the prior distribution for *r*, we first developed distributions for the parameters needed to obtain the various quantities in equation 3. This was done as follows:

i) A Ricker stock – recruit relationship was fit in WinBUGS using the 1987-2011 4RST RV data. Recruits consisted of the 24-29 cm length group in 1992-2011, which was assumed to comprise 5-year-old fish. Spawning stock biomass consisted of 30+ trawlable biomass five years earlier (1987-2006). The posterior distribution of α was estimated based on a sample size of 10,000 MCMC draws.

ii) A Von Bertalanffy growth model was fit to the age and length data on females collected during the 1974-1981 September RV surveys. The model was fit using AD Model Builder and posterior distributions (N=10,000) for the growth parameters (t_0, k, $L\infty$) were obtained using MCMC sampling (saving every 20th iteration).

iii) Posterior distributions (N=10,000) for the parameters a and b of the length-weight relationship were obtained by fitting the model log(W) = log(a) + b log(L) in WinBUGS, using data from the 1971-1985 September RV surveys.

iv) Posterior distributions for parameters of the maturity ogive for females were obtained by fitting a logistic regression of maturity versus age in WinBUGS, using the 1974-1981 September RV data.

v) The instantaneous rate of natural mortality (*M*) was assumed to be 0.2 for 5 year olds, declining to 0.15 for fish aged 9-30 years. These values of M were consistent with the age composition of the population (e.g., ages up to 34 years).

vi) Sets of parameters were randomly selected from the distributions described above, and *M*-at-age was randomly selected from a lognormal distribution with a mean equal to the log of the assumed valued and SD=0.2. The quantities in equation 3 were calculated with these parameters and the equation was solved for *r*. This was repeated 10,000 times to obtain the distribution for *r* shown in Figure 30. This distribution was well approximated by a normal distribution with a mean of 0.1687 and a SD of 0.014.

McAllister et al (2001) indicate that all possible ages should be included in these calculations. A trial was conducting starting at age 1. *M* was assumed to be 0.7 at age 1 and 0.45 at age 2, declining to 0.145 for ages 11-30. Age-5 recruits were scaled to age-1 abundance based on these assumed values for *M* and the stock-recruit relationship was re-calculated. This trial led to estimates for *r* very similar to those described above (mean *r* = 0.17). These estimates for *r* seem appropriate for a slow-growling, late-maturing fish like witch flounder. However, we used a prior with lower precision (SD=0.05, see Fig. 30) to account for uncertainties not incorporated in this analysis.

Priors on *q*

An informative prior for catchability to the combined August and September RV surveys (index 2) was constructed based on the selectivity curve for catchability-at-length of flatfish to summer/fall RV surveys estimated by Harley and Myers (2001). The median *q* for index 2 was estimated by averaging the Harley-Myers estimates of median *q* for lengths 30-51 cm, weighting by average abundance at length in the 4RST survey population (1987-2011). This estimate was then adjusted from average 24-h catchability to night catchability by multiplying by 1.5 (night catchability for witch is about twice day catchability in RV surveys). This is done to match the RV survey indices used here which are adjusted to night catchability. A lognormal prior based on the resulting median (0.4776) and a SD of 0.325 (which matched the uncertainty around the Harley-Myers estimates) was used for q_2. (Fig. 31).

Uniform priors were used for catchability of indices 1 and 3. For index 1, the prior was uniform between 0.1 and 0.6; *q* for this index is expected to be about 20% of q_2. For index 3, the prior was uniform between 0.1 and 1.0; *q* for this index is expected to be lower than q_2 because of the lower catchability of the sentinel trawl for small fish.

Initial biomass

Bayesian surplus production models are often re-parameterized ($P_t=B_t/K$) by expressing annual biomass as a proportion of carrying capacity in order to speed up convergence (Meyer and Millar 1999). This was the approach initially taken here. Uniform priors between 0.2 and 1.0 or between 0.5 and 1.2 were used for P_0, biomass in year t_0 as a proportion of *K*. These represent hypotheses for the level of depletion in the stock at the start of the time series in 1960. The data contained little information on the initial level of biomass relative to *K*. Two other approaches were thus also taken: i) a somewhat more informative, but still broad, prior centered on 0.85

was used for P_0, i.e., lognormal(log(0.85), sd = 0.5); and ii) the model was re-cast from P_t back to B_t, and priors for B_0 were constructed as follows. For a model starting in 1971, the prior for B_0 was based on the *q*-corrected biomass index 1 at the end of year 1 (Aug/Sept. 1971) plus the catch in year 1 minus the expected production in year 1 (based on previous models), yielding the following prior: lognormal(log(43), sd = 0.35). For a model starting in 1961, the prior for B_0 was based on the *q*-corrected biomass index 1 at the end of year 11 (Aug/Sept. 1971) minus the expected total net production (production – catch) from 1961 to 1971 (expected based on the average of the results of previous models), yielding lognormal(log(62), sd = 0.35).

Other priors

Priors on the standard deviation (SD) of observation error were uniform, extending from the survey CV to about three times this level, i.e. unif(0.35,1), unif(0.35,1), and unif(0.25,0.75) for indices 1-3, respectively. Uniform priors were also placed on log(*K*) (unif(2,6)), and the SD of process error (unif(0.05,1)).

Limit Reference Point (LRP)

Following standard practice, 40% of the estimated biomass producing the maximum sustainable yield (B_{MSY}) was chosen as the LRP.

Results – single productivity regime

The models described here are summarized in Table 5; they differ in terms of i) starting year (1961 or 1971), ii) whether they are parameterized in terms of P_t or B_t, iii) the prior on initial biomass, and iv) whether index 1 was used in the modelling. All models produced essentially the same fit to the indices and captured the main trends in these indices (Fig. 32).

The main difference between the models was in their estimate of K and the quantities that depend on it e.g., B_{MSY} (Fig. 32, Table 5). The estimate of K depended partly on the prior for starting biomass (compare models 1, 3, 4, and 7; or 2 and 6). Models 1-5 were parameterized in terms of P_t, i.e. biomass as a proportion of K. The data contained essentially no information on P_0, the starting biomass as a proportion of K (Fig. 33). When a uniform prior was used for P_0, the posterior departed little from the prior, though there was a tendency for posterior density to be highest at the highest values within the range of the prior. When there was an increase in the prior median for P_0 there was a corresponding decrease in the posterior median for K. Since selection of a prior for P_0 was somewhat arbitrary, models were parameterized in terms of B_t (models 6-8), and the prior for B_0 was based on the q-corrected biomass index in the earliest year available (1971) and the catch between that year and t_0 (see above). Using this approach (e.g., model 7), estimates for K were 74%, 93% and 99% of the estimates of the corresponding models parameterized in terms of *P* (models 1, 3 and 4, respectively). Estimates of K were lower if models started in 1971 instead of 1961 (because they did not take into account the catch from 1961-1970, compare models 1 and 2, 6 and 7) and higher if index 1 was not included in the fitting (because they were not constrained by observations in 1971-1986, compare models 3 and 5, 7 and 8). Despite these differences, all models indicated that the stock is severely depleted, with biomass currently below the LRP (Table 6, Fig. 32). The probability that biomass in 2011 was below the LRP exceeded 75% for all models and 90% for all models that took into account data back to 1961 (Fig. 34).

We chose to go forward with model 7. This model was parameterized in terms of B_t rather than P_t, allowing the development of a less arbitrary prior for starting biomass, and took into account the catch data back to 1961 and the 4T index back to 1971. Process and observation errors from this model are shown in Figure 35. There was no strong pattern to the residuals from index 2. The residuals from index 3 tended to be positive early in this short time series and negative late in the time series. This reflected a conflict between the trends in this index and index 2. Index 3 showed a decline over the 2003 – 2011 period not evident in index 2. Process error was autocorrelated, though there was no long term trend in process error which would indicate a serious problem in model structure. The model accounted for the long term trend but had difficulty fitting the higher frequency bumps and valleys in the indices, resulting in a pattern in the process error (and the residuals to index 1).

Priors and posteriors of the model parameters and some estimated variables are shown for model 7 in Figures 36-39. The strongly informative priors on r and q_2 were updated slightly by the data, with the posterior for r shifted to slightly lower values and that for q_2 shifted to slightly higher values. The posteriors for K and for quantities depending on it (B_{MSY}, C_{MSY}) had long upper tails; this was typical of all the models examined. The posterior median for q_1 was 26% of that for q_2, about the level expected from the data for 1987-1992 (see above). The parameter q_3 was also low relative to q_2. Estimates of several quantities of management interest (with 80% credible limits in parentheses) are as follows: K = 52.6 kt (30.9 – 166.1); B_{MSY} = 26.3 kt (15.5 – 83.0); LRP = 10.5 kt (6.2 – 33.2); Biomass in 2011 = 5.0 kt (3.3 – 7.4); C_{MSY} = 1.9 kt (1.1 – 5.0); F_{MSY} = 0.072 (0.047 – 0.099). The biomass level in 2011 as a proportion of the LRP is estimated to be 0.46 (0.14 – 0.91), with a 93% probability of being below the LRP.

To examine model robustness, we removed the biomass index data for recent years (retaining the landings data) and projected the model forward over the years of missing data, comparing the revised predictions of population biomass to those obtained using all the data. Because of the short duration of the sentinel index (nine years), we removed the data for only the four recent years (2008-2011). The revised model predictions with the missing data compared well with those obtained using all the data (Fig. 40). However, as expected, uncertainty around the predicted biomass trajectory increased greatly for the years without index data.

Figure 41 describes the exploitation history of 4RST witch flounder based on model 7. In the 1960s, landings were high but so was predicted biomass, thus the exploitation rate was relatively low. Nonetheless biomass declined because the population was estimated to be near K and thus yielded little surplus production. By the mid to late 1970s, biomass was estimated to be near B_{MSY} but exploitation rates had risen to high levels, well above F_{MSY}, and estimated biomass declined further. Since then exploitation rates have generally remained high (relative to stock productivity), and further declines in biomass have occurred. Biomass appeared to improve after temporary reductions in exploitation rates in the mid 1970s, mid 1980s and mid 1990s. However, in each case, exploitation rate subsequently increased again and declines in biomass resumed.

Five-year projections were made at three levels of catch: 0, 300 and 850 t (Fig. 42). Median estimates of 30+ biomass increased over the 5-yr period at catch levels of 0 and 300 t and decreased at catches of 850 t. Even with no catch, the median estimate of 30+ biomass remained below the LRP in 2016. The probability of remaining below the LRP in 2016 was estimated to be 61%, 71% and 86% at catch levels of 0, 300 and 850 t. These probabilities are lower than the estimate for 2011 (93%) even for the case where biomass has declined further (catch = 850 t) because uncertainty in the biomass level increases greatly in the projection period.

After the review of this assessment (held on 22 Feb. 2012), model 7 was re-run with updated landings statistics for 2011. These updated statistics have been incorporated in Table 1 and Figures 1 and 3. The updated statistics contained an additional 94 t landed in 4R in August 2011. Results incorporating the updated landings were very similar to those reported here, and are shown in DFO (2012). Based on this updated model run, the revised estimates of quantities of management interest (with 80% credible limits in parentheses) are as follows: K = 53.5 kt (31.4 – 166.3); B_{MSY} = 26.7 kt (15.7 – 83.2); LRP = 10.7 kt (6.3 – 33.3); Biomass in 2011 = 5.0 kt (3.2 – 7.5); C_{MSY} = 2.0 kt (1.1 – 5.1); F_{MSY} = 0.072 (0.046 – 0.100). The biomass level in 2011 as a proportion of the LRP is estimated to be 0.45 (0.14 – 0.91), with a 93% probability of being below the LRP. The estimated exploitation rate in 2011 (actually Sept. 2010 to Aug. 2011) is 0.09, slightly above the exploitation rate at MSY (0.07).

Results – changing productivity regimes

The possibility of changes in the productivity regime was examined by allowing *r* to vary at a decadal scale. The model was the same as model 7 except that *r* was allowed to differ between the following four periods: 1961-1979, 1980-1989, 1990-1999 and 2000-2011. The prior for *r* in the first period was the same as the prior used in model 7 for all periods. The prior for *r* in the remaining periods was uniform between -0.2 and 0.5.

Estimates of *r* for the 1990s and 2000s were somewhat lower than those for the 1960s-1980s (Figs. 43 and 46). Posterior medians for *r* declined from 0.175 and 0.212 in the 1961-1979 and 1980-1989 periods to 0.075 and 0.093 in 1990-1999 and 2000-2011, respectively. However, posterior distributions for *r* overlapped broadly between all four periods, and the evidence for a decline in productivity is thus weak. Fit to the biomass indices, and patterns in the process and observation errors were very similar between this model (Figs. 44 and 45) and model 7 (Figs. 32 and 35), again indicating very little improvement in model fit with the addition of parameters for decadal variation in *r. DIC* was 166.104 for model 7 and 166.049 for the model allowing decadal variation in *r*.

Prior and posterior distributions for parameters of the decadal-*r* model as well as the posteriors for quantities of management interest are shown in Figures 46 to 50. Posteriors are very similar to those from model 7, except that the posterior for *r*1 is not updated slightly downwards. Posterior distributions were shifted slightly downward for *K* (median 46.0 kt, 28.2-112.3) and thus for B_{MSY} (median 23.0 kt, 14.1-56.1) and the LRP (median 9.2, 5.6-22.5). The biomass level in 2011 as a proportion of the LRP is estimated to be 0.53 (0.20 – 1.03), with an 89% probability of being below the LRP.

Because productivity varies decadally in this model, estimates of the exploitation and catch at maximum sustainable yield also very decadally (Table 7). Maximum sustainable yield varies from 2,000 to 2,500 t in 1960-1989 to about 1,000 t in 1990-2011. The exploitation rate yielding these catches when the stock is at B_{MSY} decline from about 0.09-0.11 prior to 1990 to 0.04-0.05 since then.

CONCLUSIONS

1) Witch flounder is an unproductive species. Growth is very slow and maturation is at a late age. In the 1974-1981 period, the mean length at an age of 12 years is estimated to have been only 40 cm for males and 41 cm for females. For this same period, estimated lengths and ages at 50% maturity are 33.2 cm and 7.5 years for males and 38.6 cm and 10.4 years for females. Species with such low productivity are particularly vulnerable to overexploitation. An apparent shift towards earlier maturation in the 4RST stock in the 2000s (with lengths at 50% maturity now at 26 and 28 cm for males and females, respectively) suggests that this stock has experienced unusually high adult mortality in recent decades.

2) Commercial (30+ cm) biomass of 4RST witch flounder declined sharply in the early 1990s. There appeared to be some recovery in biomass following a reduction in landings to 300-500 t. However, this partial recovery ceased and has been eroded following an increase in landings to the 700-900 t level. Thus, the stock appears to no longer be able to support landings of only 700-900 t even though annual landings averaged over 3,500 t in the 1960s and 1970s.

3) There has been a dramatic contraction in the size composition of the stock since the 1970s and early 1980s. Fish 40 cm or longer comprised 70-80% of the landings and 86% of the September RV catch in the late 1970s but only 20% of the landings and 8% of the September RV catch in 2006-2011.

4). Pre-recruit abundance has increased to a high level in 4T in the late 1990s and the 2000s. At the stock level, a number of strong year-classes have been evident in the 1990s and 2000s. Despite this strong recruitment there has been no recovery in the abundance of 40+ cm fish, suggesting high mortality once witch flounder reach lengths of 30 cm or more.

5) These results are indicative of a severely depleted stock no longer able to support even relatively low fishery removals, on the order of 1,000 t. This conclusion is supported by the results of surplus production models. These models indicate that commercial (30+ cm) biomass has declined drastically since the early 1960s, with biomass in 2011 estimated to be about 10% of the level in 1961. B_{MSY} for this stock is estimated to be 26,700 t. At this biomass, the maximum sustainable yield is estimated to be about 1,990 t, corresponding to an exploitation rate of 7%. The Limit Reference Point (LRP) for this stock (40% of $\mathrm{B_{MSY}}$) is estimated to be 10,700 t. The median estimate of the current stock level is less than 50% of the LRP, and the probability that the stock is below the LRP is 93% based on the surplus production model. Medium term (5 year) projections predict that the stock will increase with removals of 0 or 300 t and decline further with removals of 850 t; in all three cases, the median estimate of 30+ biomass in 2016 remains below the LRP.

6) Based on a model allowing decadal variation in *r*, median estimates for *r* in periods since 1990 are less than half the values estimated for periods between 1961 and 1989, suggesting a decline in productivity. However, the evidence for a decline in productivity is weak, with the posterior distributions for *r* overlapping broadly between all periods. The variable-productivity model leads to the same conclusions about stock status as the constant-productivity model, with the stock severely depleted, having declined to a level about 50% of the LRP. Based on this model the probability that the stock was below the LRP in 2011 is 89%. The main consequence of the variable-productivity model (compared to the constant-productivity model) is that MSY and the exploitation rate at MSY for the period since 1990s are estimated to be less than half the values estimated for the period prior to 1990.

7) A number of strong year-classes have appeared in the RV survey length frequency distributions in the 1990s and 2000s. These year-classes have not resulted in a rebuilding of biomass at lengths greater than 40 cm, likely due fishery catches that are unsustainable at the current low stock level. Another strong year-class, evident in the 2009-2011 survey data, is now approaching commercial sizes. Protecting this year-class by keeping catches as low as possible for the next decade may promote rebuilding of the 40+ cm size group.

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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. Total allowable catch (TAC) is also shown.

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	64	671	0	0	0	735	1000
2005	0	3	100	832	0	0	0	935	1000
2006	0	0	87	856	0	0	0	944	1000
2007	0	0	72	834	1	7	0	914	1000
2008	0	3	56	676	1	0	0	736	1000
2009	0	0	29	440	0	0	0	470	1000
2010	0	0	11	217	0	1	0	229	1000
2011	0	0	3	439	0	0	0	442	1000
MEAN	193	324	350	1173	19	12	50	2121	

Table 2. Numbers of witch flounder sampled for length from mobile-gear landings in NAFO Divisions 4RST, 1971 to 1986 and 2000 to 2011 (4R samples were applied to 4RS landings). Catch-at-length for 4RST in 1987 to 1999 is described in earlier research documents.

				Observer trips			
Year	Area	Landings (t)	Port samples	Commercial	Sentinel	Number measured	Sample used (year)
1971	4R	1649.0	0	0	0	1999	1975, 1976
	4T	2011.0	0	0	0	1199	1974, 1976
1972	4R	1422.0	0	0	0	1999	1975, 1976
	4T	548.0	0	0	0	1199	1974, 1976
1973	4R	1341.0	0	0	0	1999	1975, 1976
	4T	735.0	0	0	0	1199	1974, 1976
1974	4R	1025.0	0	0	0	1999	1975, 1976
	4T	2205.0	1	0	0	1199	1974, 1976
1975	4R	1039.0	2	0	0	1999	1975, 1976
	4T	1654.0	0	0	0	1399	1974, 1976, 1977
1976	4R	3252.0	8	0	0	1599	1976
	4T	3614.0	5	0	0	785	1976
1977	4R	1070.0	1	0	0	2111	1976, 1977, 1978
	4T	1959.0	1	0	0	1185	1976, 1977
1978	4R	1014.0	2	0	0	406	1978
	4T	3424.0	0	0	0	1385	1976, 1977, 1979
1979	4R	1350.0	0	0	0	1285	1978, 1980
	4T	3063.0	1	0	0	1385	1976, 1977, 1979
1980	4R	1217.0	4	0	0	1253	1980
	4T	2155.0	0	0	0	1285	1979, 1983
1981	4R	991.0	0	0	0	3257	1980, 1983
	4T	862.0	0	0	0	1253	1979, 1983
1982	4R	346.0	0	0	0	3257	1980, 1983
	4T	908.0	0	0	0	1253	1979, 1983
1983	4R	463.0	14	0	0	2378	1983
	4T	671.0	13	0	0	1053	1983
1984	4R	971.0	8	0	0	613	1984
	4T	64.0	7	0	0	459	1984
1985	4R	963.0	5	0	0	878	1985
	4T	653.0	1	0	0	876	1984, 1985, 1986
1986	4R	1265.0	0	0	0	1128	1985, 1987
	4T	550.0	17	0	0	876	1984, 1985, 1986
2000	4R	435.6	7	4	0	3453	2000
	4T	558.9	8	16	18	7592	2000
2001	4R	445.2	6	0	0	2403	2001
	4T	370.8	10	12	8	6730	2001
2002	4R	439.9	0	0	0	2115	2001, 2003
	4T	582.7	16	13	8	8976	2002
2003	4R	273.7	4	0	0	1040	2003
	4T	384.4	7	21	1	11401	2003
2004	4R	407.0	0	0	0	1557	2003, 2005
	4T	327.5	10	20	0	8853	2004

Table 2. Continued.

Year	Area	Landings (t)	Port samples	Observer trips		Number measured	sample used (year)
				Commercial	Sentinel		
2005	4R	478.0	2	0	0	517	2005
	4T	456.8	10	23	0	14014	2005
2006	4R	412.3	1	0	0	1524	2006, 2007
	4T	531.5	16	29	0	12522	2006
2007	4R	428.0	5	0	0	1274	2007
	4T	485.6	15	5	0	5258	2007
2008	4R	301.4	0	0	0	1548	2007, 2009
	4T	434.1	8	11	0	4895	2008
2009	4R	244.2	1	0	0	821	2009, 2010
	4T	225.7	12	5	0	3840	2009
2010	4R	118.4	2	0	0	547	2010
	4T	111.0	7	8	0	2943	2010
2011	4R	196.5	2	0	0	540	2011
	4T	100.0	4	4	0	2188	2011

Table 3. Estimated catch-at-length (thousands) for mobile-gear witch flounder landings in NAFO divisions 4RST, 1971-2011.

Lengthh	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.3	0.3	1.1	0.0	0.0	0.0	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	0.4	0.2	0.2	0.6	0.0	0.0	0.0	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	1.5	0.6	0.6	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.2	0.2	0.5	0.0	0.0	0.0	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	3.3	1.4	1.4	4.8	0.0	0.0	0.0	0.0	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	2.2	0.9	1.0	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	1.4	1.4	4.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	1.1	1.1	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.7	2.7	2.9	9.6	0.0	0.0	0.0	0.0	0.0	6.6	0.0	0.0
25	1.0	0.9	0.8	1.4	0.6	2.7	0.7	0.0	0.0	4.8	2.0	2.1	6.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	7.6	2.8	3.1	8.1	0.0	27.0	33.4	0.0	22.3	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	7.0	2.3	2.7	4.3	0.0	0.2	1.1	7.1	19.2	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	11.6	5.2	6.0	11.7	0.0	15.4	20.8	10.1	42.4	25.5	0.0	1.6
29	1.4	0.4	0.5	0.7	1.0	0.0	0.1	2.3	2.4	23.5	10.4	11.1	8.9	0.0	77.8	99.5	34.1	81.4	0.0	0.2	11.5
30	0.0	0.0	0.0	0.0	0.0	0.0	1.0	9.2	5.0	17.6	9.9	11.5	25.3	12.8	162.5	205.8	43.1	73.3	38.9	18.5	4.8
31	8.7	3.7	4.2	6.4	6.1	24.9	10.0	28.1	27.7	41.3	19.1	23.4	27.7	9.5	170.9	219.9	56.0	191.9	116.4	32.6	19.0
32	24.5	13.0	13.7	21.6	16.8	33.2	20.1	32.3	52.3	48.5	36.8	45.8	37.8	19.7	243.8	297.3	138.4	314.2	244.2	98.8	30.7
33	37.7	18.9	20.2	31.7	25.8	66.0	30.6	88.0	106.6	227.0	111.1	126.3	45.1	59.3	310.3	387.7	225.0	343.9	276.5	115.5	61.2
34	53.5	31.9	32.6	51.9	35.3	259.4	39.7	94.4	124.5	232.4	117.1	137.2	59.0	72.1	295.3	328.8	298.1	407.5	305.8	162.5	79.8
35	175.7	72.6	82.3	126.4	121.8	427.2	149.2	268.4	302.3	443.0	189.1	211.7	57.6	94.1	282.7	321.5	411.3	497.7	412.1	190.2	131.8
36	248.2	98.2	113.0	172.6	173.4	677.7	234.0	414.0	438.4	355.1	182.1	209.6	70.2	64.1	311.0	366.7	564.3	592.5	429.6	189.5	126.0
37	320.8	142.0	157.5	243.7	220.7	680.7	277.1	521.2	551.9	602.2	271.2	309.2	72.7	120.9	382.2	432.6	504.0	512.9	516.2	200.9	151.7
38	370.1	166.9	184.3	284.8	250.6	922.7	310.0	547.3	621.7	734.2	330.6	376.9	86.4	89.3	155.9	189.5	628.5	476.0	409.2	159.8	148.7
39	311.5	152.6	164.3	256.3	210.4	940.7	269.6	456.6	551.0	559.3	298.6	351.3	111.8	143.9	176.1	201.4	514.5	355.2	416.0	151.4	138.2
40	382.6	178.8	195.2	302.9	259.9	1127.1	321.5	555.0	652.8	576.1	334.5	392.5	109.4	168.7	216.6	251.8	528.3	352.1	303.9	183.9	102.9
41	454.3	216.4	234.9	365.1	307.0	834.0	358.5	550.6	614.4	516.1	279.8	325.0	127.0	72.3	123.7	136.2	391.5	252.6	306.1	155.6	116.6
42	382.9	214.3	222.6	351.9	256.8	1000.8	313.9	453.2	519.0	454.0	250.9	298.5	131.5	119.0	139.3	155.8	363.9	208.1	262.8	170.0	137.0
43	441.1	248.1	257.3	406.3	291.1	802.0	340.8	477.0	509.8	473.1	265.4	308.5	127.6	127.0	124.5	138.3	317.7	203.1	188.3	134.2	84.2
44	480.0	247.5	262.9	410.6	317.5	804.9	373.2	507.1	538.8	365.5	208.1	245.7	134.2	129.6	104.5	120.5	289.2	216.7	193.4	114.0	94.4
45	448.2	220.2	237.2	368.3	298.4	736.8	367.9	543.7	541.2	337.4	195.0	226.9	125.0	104.3	114.9	133.5	241.1	170.0	150.6	96.5	52.7
46	404.9	232.9	240.4	380.1	266.1	596.2	301.6	352.1	376.8	238.1	159.0	187.6	101.6	187.9	66.1	74.6	186.9	160.3	209.8	80.5	57.3
47	280.3	167.2	170.9	271.1	184.8	465.2	219.3	290.2	281.2	119.8	105.0	129.2	104.2	83.4	80.5	86.5	107.9	104.0	94.4	82.3	44.1
48	289.1	150.9	159.8	249.7	191.2	423.3	226.7	301.4	290.9	140.2	87.2	104.4	96.5	89.3	60.0	71.6	154.9	115.6	59.9	54.5	26.0
49	222.3	119.3	125.4	196.8	148.4	221.0	174.5	253.5	215.9	144.6	70.0	78.2	67.6	54.6	29.3	34.5	77.3	71.6	63.4	51.6	21.0
50	194.1	111.8	115.3	182.4	128.4	290.4	155.3	183.4	176.3	63.6	41.7	50.4	35.9	48.9	24.4	30.1	83.7	58.4	52.1	31.4	17.5
51	165.4	85.0	90.5	140.9	109.8	174.2	139.8	197.5	180.3	61.9	40.9	48.2	52.3	15.8	17.1	17.9	59.8	36.4	43.2	18.2	52.6
52	83.4	53.9	54.0	86.5	55.6	171.5	58.6	72.7	63.1	63.4	31.7	36.8	42.5	5.7	19.6	19.0	26.5	28.6	17.0	14.8	13.4
53	73.7	38.6	40.9	63.9	49.2	83.6	61.1	71.5	82.6	59.0	32.5	37.4	15.5	9.8	10.0	8.3	29.6	19.5	28.3	5.9	18.9
54	65.0	34.8	36.6	57.3	43.0	64.7	50.3	60.8	68.9	17.1	19.8	23.9	27.2	0.2	13.1	11.7	25.7	22.9	7.4	4.4	28.2
55	45.8	24.3	25.6	40.0	29.9	38.9	33.2	43.4	40.3	10.9	3.9	4.6	6.9	8.4	20.5	17.0	28.5	15.4	5.9	14.0	19.8
56	24.4	15.0	15.2	24.2	15.8	29.8	18.2	15.7	14.5	3.1	2.0	2.3	5.7	0.1	8.3	7.7	21.9	25.6	1.6	13.4	13.3
57	14.6	6.5	7.2	11.0	9.9	15.9	14.0	20.3	19.0	13.6	4.6	5.3	10.1	3.4	16.4	13.5	11.7	10.7	0.0	7.7	7.2
58	8.0	2.7	2.5	4.1	1.9	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.1	11.9	14.2	2.9	11.8	2.2	3.3
59	3.2	4.0	4.3	6.6	5.3	2.0	5.4	7.8	7.2	0.0	0.8	1.0	1.3	0.0	12.1	10.0	1.4	0.3	1.6	4.4	3.3
60	4.9	1.2	1.7	2.4	3.3	1.9	4.8	7.8	7.2	0.4	0.5	0.5	1.1	0.0	4.0	3.3	2.2	0.0	0.0	0.0	0.0
61	0.8	0.7	0.7	1.1	0.5	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0
62	8.3	3.3	3.8	5.7	5.5	7.2	6.2	7.9	7.3	0.0	0.4	0.5	0.8	0.0	8.0	6.6	0.0	0.0	0.0	0.0	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	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	4.0	3.3	0.0	0.0	0.0	0.0	0.0
65	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	1.5	0.0	0.0	0.0	0.0

Table 3. continued.

Lengthh	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
16	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	0.1	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	0.3	0.0	0.0	0.0	0.0	0.0	0.0	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	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	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	0.1	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	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.5	0.0	0.1	0.0
21	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	0.1	0.0	0.0	0.0	0.1	0.0
22	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	0.1	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.1	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0
24	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	0.0	0.2	0.0	0.0	0.6	0.2	0.0
25	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	1.3	2.3	1.4	0.6	0.1	0.0
26	3.5	3.2	0.0	0.0	0.6	0.0	2.9	1.9	0.5	2.6	2.1	2.0	2.2	0.1	1.2	1.0	1.0	0.8	0.1	0.3
27	6.2	5.1	0.1	1.4	0.5	0.2	10.2	2.9	1.7	3.3	4.2	4.3	3.0	0.4	2.7	5.1	5.0	2.1	0.3	0.5
28	7.7	11.9	2.4	1.9	6.4	2.1	24.6	4.8	2.3	5.7	4.1	4.0	7.3	20.4	9.2	13.1	8.2	4.6	2.2	0.6
29	17.7	21.1	4.3	2.8	9.6	6.7	30.5	6.1	9.1	4.5	14.0	19.7	19.7	21.8	14.1	19.6	12.9	8.8	3.6	7.9
30	20.2	36.3	8.5	7.9	20.7	17.8	49.5	20.2	24.8	17.8	37.2	42.2	42.7	70.2	37.8	55.4	32.2	21.4	8.5	19.3
31	56.8	48.0	17.1	15.8	23.4	24.6	78.5	30.6	45.0	55.6	68.3	80.6	69.1	90.4	76.5	92.4	58.1	53.5	29.6	35.2
32	58.6	48.1	19.8	19.0	34.8	39.5	116.7	59.5	77.0	89.4	114.9	116.1	113.0	148.7	101.9	145.0	77.7	99.9	56.0	67.0
33	90.1	75.6	31.0	27.6	51.3	42.8	146.8	89.0	114.5	138.8	189.7	173.5	189.1	265.9	158.3	188.1	115.6	133.5	79.9	93.6
34	126.1	118.9	50.3	35.8	73.3	70.5	173.9	126.4	180.8	205.4	259.0	193.1	233.4	319.9	230.1	280.2	181.6	143.6	81.1	123.5
35	150.0	132.1	53.1	63.7	117.9	84.7	209.7	163.7	222.6	220.7	262.0	203.1	223.3	315.7	259.6	277.5	189.5	164.3	85.1	139.0
36	143.3	167.0	71.5	68.3	140.3	118.1	246.9	188.8	258.4	234.8	308.3	235.6	243.2	311.8	290.4	315.7	257.5	150.1	86.9	141.8
37	178.2	181.4	77.5	66.7	144.2	100.4	262.7	213.0	282.4	265.1	289.8	214.4	202.2	236.6	292.0	292.5	253.9	156.7	81.0	106.8
38	172.2	170.7	94.9	68.6	141.3	132.5	216.1	211.5	302.7	245.8	279.7	176.7	187.4	278.3	269.5	223.9	227.3	133.4	58.5	85.7
39	223.7	159.1	78.6	82.4	104.6	129.4	205.6	180.2	265.6	205.5	241.5	137.5	161.2	274.7	239.0	220.6	214.0	121.0	56.0	62.2
40	195.8	138.2	69.6	85.4	97.6	108.7	155.4	150.9	213.6	174.0	223.5	110.7	107.9	118.3	201.1	176.1	161.8	83.0	34.1	39.8
41	142.4	140.3	66.6	45.1	80.2	96.6	132.0	129.0	171.2	131.8	167.6	93.7	96.2	99.1	159.3	114.2	117.2	67.5	26.9	28.8
42	121.2	127.9	65.9	29.0	53.0	74.4	97.2	97.8	123.8	99.3	136.3	64.5	75.0	83.3	112.1	86.5	93.2	42.5	17.2	15.6
43	108.8	119.5	45.5	45.9	44.1	51.4	68.9	75.5	99.7	76.4	94.5	43.8	53.8	56.0	75.4	47.7	56.5	23.0	6.9	8.8
44	86.6	92.6	46.0	16.6	43.3	38.8	54.5	49.0	70.1	45.4	72.8	34.5	45.3	46.1	52.6	41.8	35.4	15.1	7.0	6.3
45	76.8	69.8	25.2	14.5	22.6	23.8	34.5	32.7	48.7	35.2	44.9	15.4	18.8	24.9	41.4	41.3	34.4	11.0	5.3	0.5
46	51.1	49.6	26.6	17.9	25.2	39.1	31.6	29.5	31.7	19.6	22.0	7.2	13.5	21.4	19.5	17.1	17.5	8.2	2.8	1.0
47	41.1	47.7	18.3	16.3	14.0	22.9	17.5	12.7	18.3	8.4	15.8	6.7	9.0	9.7	12.0	13.1	9.9	6.8	2.1	0.5
48	36.2	31.2	15.5	19.2	12.2	17.6	11.4	8.6	10.3	5.2	12.2	7.6	10.3	10.2	9.0	7.6	3.8	3.2	0.5	1.9
49	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	4.1	3.5	4.0	1.7	0.8	0.1	0.2
50	11.0	24.2	6.9	13.1	3.2	7.9	7.1	6.3	5.0	1.2	5.8	2.5	3.6	1.3	2.3	2.9	3.6	0.0	0.0	0.0
51	20.3	16.1	7.1	5.1	2.3	3.0	5.1	3.1	2.9	3.0	1.6	0.2	0.7	2.4	1.6	2.7	0.0	0.0	0.0	0.1
52	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	1.8	0.8	1.2	0.0	0.6	0.1	0.0
53	9.4	7.6	4.2	0.8	2.1	2.9	2.5	0.9	2.1	0.3	0.4	0.1	0.1	0.4	0.8	1.2	0.2	0.0	0.0	0.0
54	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	0.1	0.4	0.5	0.0	0.0	0.0	0.0
55	2.0	3.9	2.7	0.3	0.8	0.4	2.1	1.1	0.3	0.1	0.3	0.0	0.2	0.5	0.0	0.0	0.0	0.0	0.0	0.0
56	1.3	6.9	1.9	0.5	1.8	0.5	1.0	0.1	2.2	0.1	0.2	0.1	0.1	0.4	0.1	0.0	0.5	0.0	0.0	0.0
57	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	0.0	0.0	0.0	0.0	0.0	0.0
58	1.5	1.7	3.8	0.0	1.0	2.8	0.5	0.2	0.2	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.2	0.5	0.0	0.0
59	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	0.0	0.0	0.0	0.0	0.0	0.0
60	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	0.0	0.0	0.0	0.0	0.0	0.0
61	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	0.0	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	0.7	0.0	0.0	0.0	0.0	0.0	0.0	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	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	0.0
65	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	0.0

Table 4. Estimated von Bertalanffy growth parameters for witch flounder from the southern Gulf of St. Lawrence, 1974-1981.

	Females		Males	
Parameter	Estimate	SD	Estimate	SD
$L\infty$	69.335	3.841	54.366	2.619
k	0.05319	0.00808	0.09214	0.01873
t_0	-4.3989	1.0643	-2.4662	1.4753

Table 5. Summary of differences between the surplus production models assuming a constant productivity regime.

Model	P or B?	Prior P_0 or B_0	Index 1 used?	Start year
1	P	unif(0.2,1.0)	Yes	1961
2	P	unif(0.2,1.0)	Yes	1971
3	P	unif(0.5,1.2)	Yes	1961
4	P	Lognormal(-0.16252,0.5)	Yes	1961
5	P	unif(0.5,1.2)	No	1961
6	B	Lognormal(3.7612,0.35)	Yes	1971
7	B	Lognormal(4.1271,0.35)	Yes	1961
8	B	Lognormal(4.1271,0.35)	No	1961

Table 6. Median posterior values of selected parameters and other estimated values from the models described in Table 5. Bratio is biomass in 2011 as a proportion of B_{MSY}.

	Model							
Variable	1	2	3	4	5	6	7	8
B_{1961} (kt)	43.7		48.0	50.3	61.2		55.5	61.1
B_{1971} (kt)	24. 5	24.5	25.2	25.3	43.6	29.3	25.2	38.5
B_{2011} (kt)	5.0	5.0	5.0	5.1	4.9	5.2	5.0	4.9
r	0.14	0.15	0.15	0.15	0.13	0.15	0.14	0.13
K (kt)	71.4	45.6	56.8	53	71.5	41.4	52.6	61.6
p_0	0.66	0.63	0.88	0.97	0.89	0.71	1.06	1.01
B_{MSY} (kt)	35.7	22.8	28.4	26.5	35.7	20.7	26.3	30.8
C_{MSY} (kt)	2.51	1.70	2.06	1.98	0.91	1.56	1.95	2.04
F_{MSY}	0.071	0.075	0.074	0.075	0.065	0.073	0.072	0.065
Bratio	0.14	0.22	0.17	0.19	0.13	0.24	0.18	0.15

Table 7. Posterior distributions for CMSY (kt) and exploitation rate at MSY (FMSY) from a model allowing decadal variation in r.

Variable	1961-1979	1980-1989	1990-1999	2000-2012
C_{MSY} (kt)				
10th percentile	1.023	0.655	-0.551	-0.315
median	2.116	2.500	0.919	1.136
10th percentile	4.547	5.320	3.030	3.277
F_{MSY}				
10th percentile	0.054	0.025	-0.021	-0.013
median	0.087	0.106	0.038	0.047
10th percentile	0.120	0.196	0.112	0.113

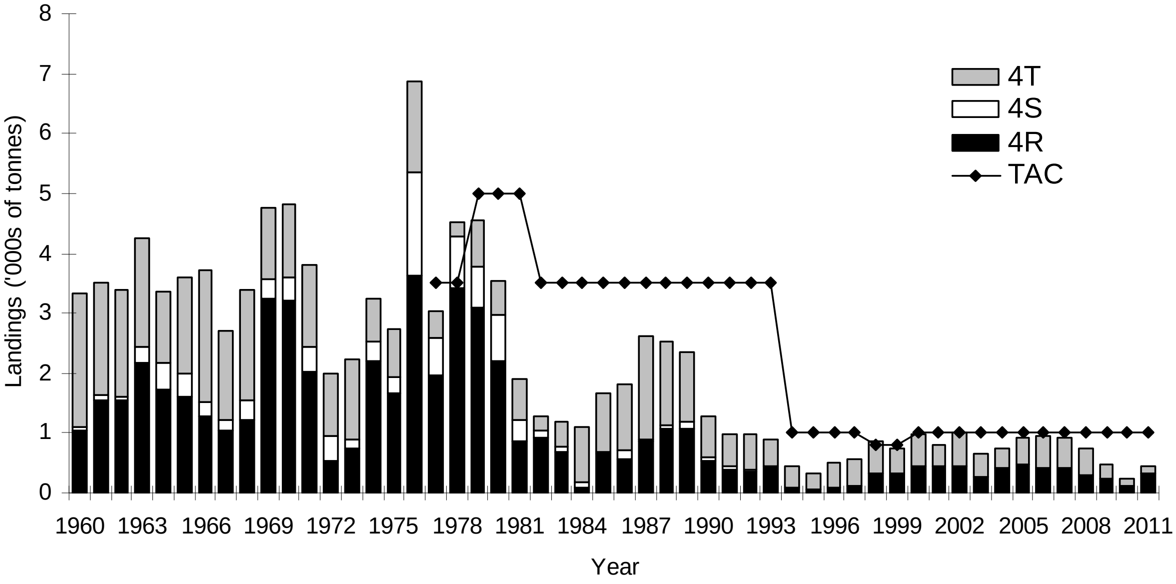

Figure 1. Landings and TAC of witch flounder in NAFO divisions 4RST.

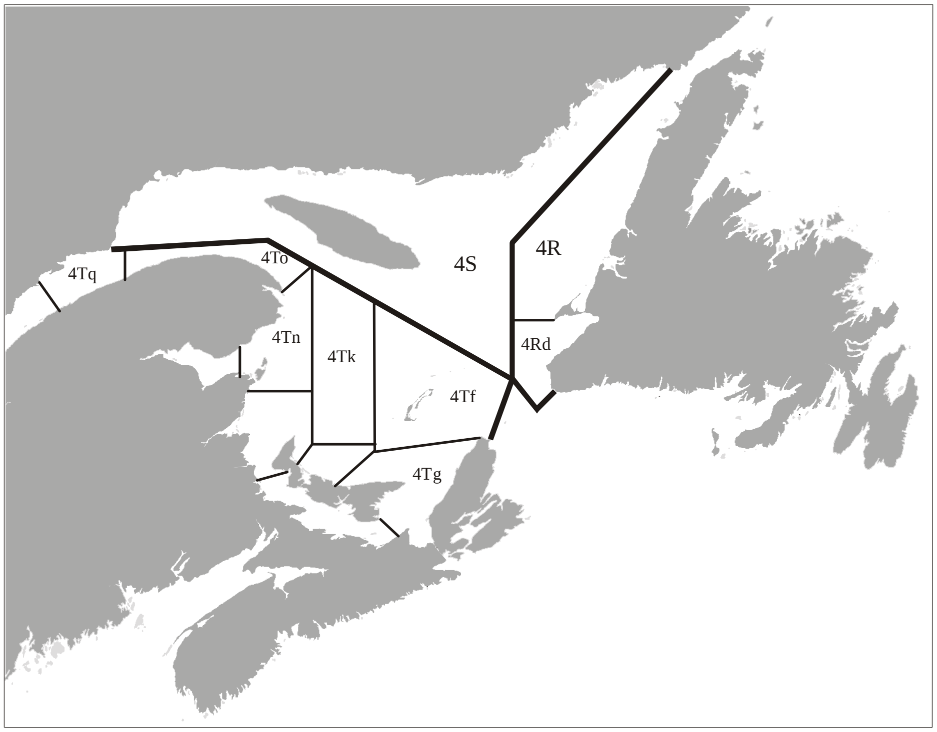

Figure 2. NAFO divisions 4R, 4S and 4T (bordered by heavy lines). Unit areas where most witch flounder are caught in commercial fisheries are labelled in lower case.

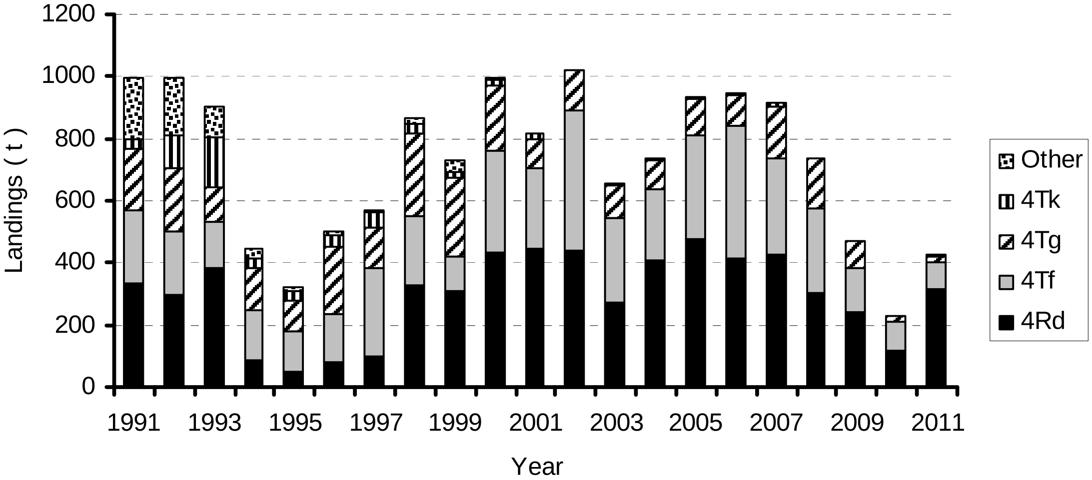

Figure 3. Landings of 4RST witch flounder by NAFO unit area.

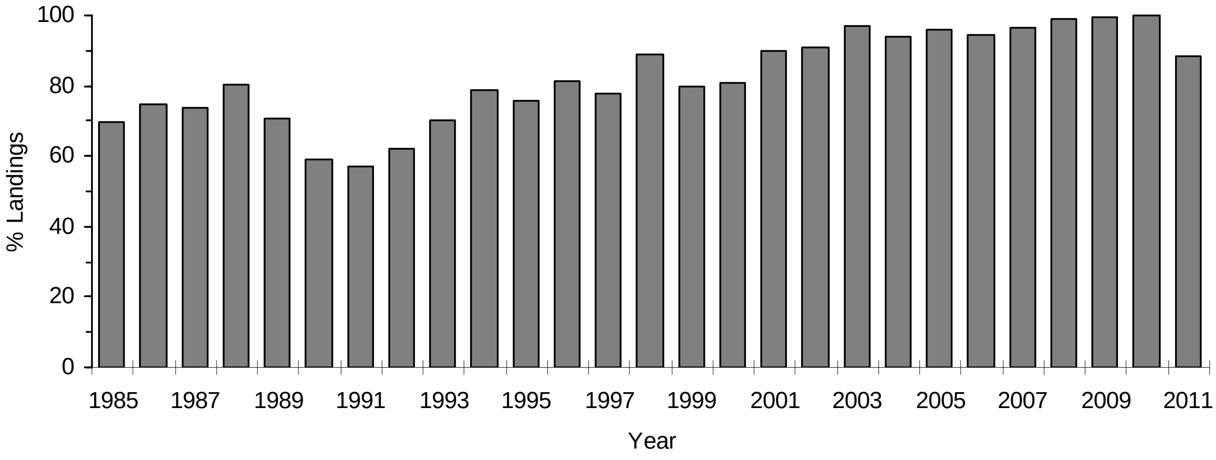

Figure 4. Percent of mobile-gear landings of 4RST witch flounder with witch as the main species caught.

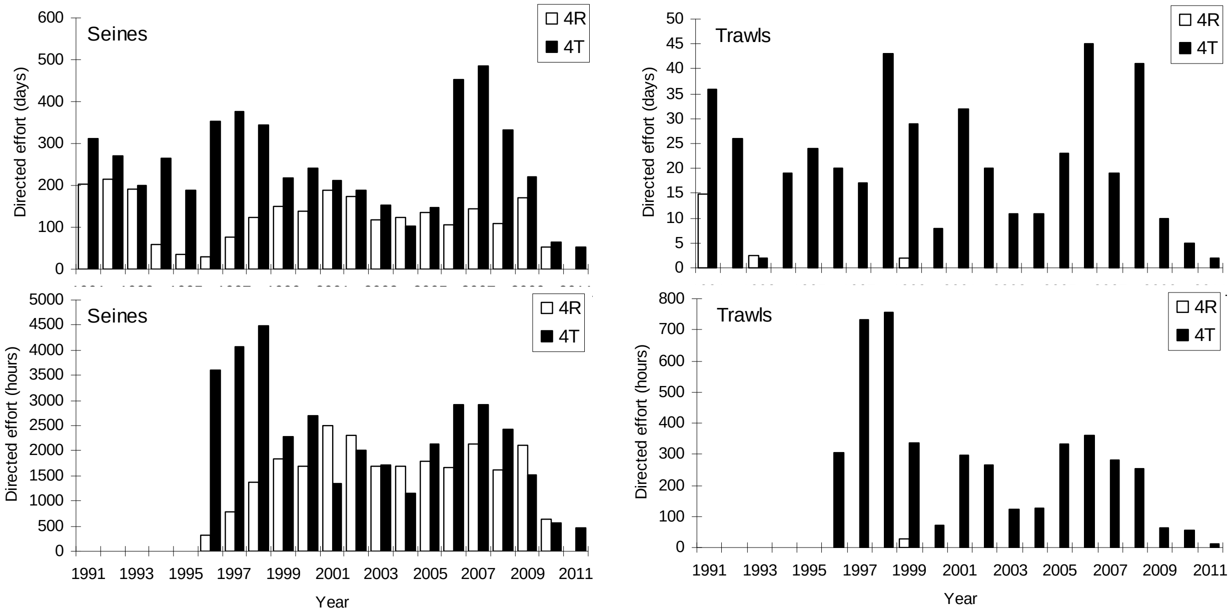

Figure 5. Fishing effort by seines and trawls directing for witch flounder in NAFO divisions 4R and 4T. Effort data are not available for 4R in 2011.

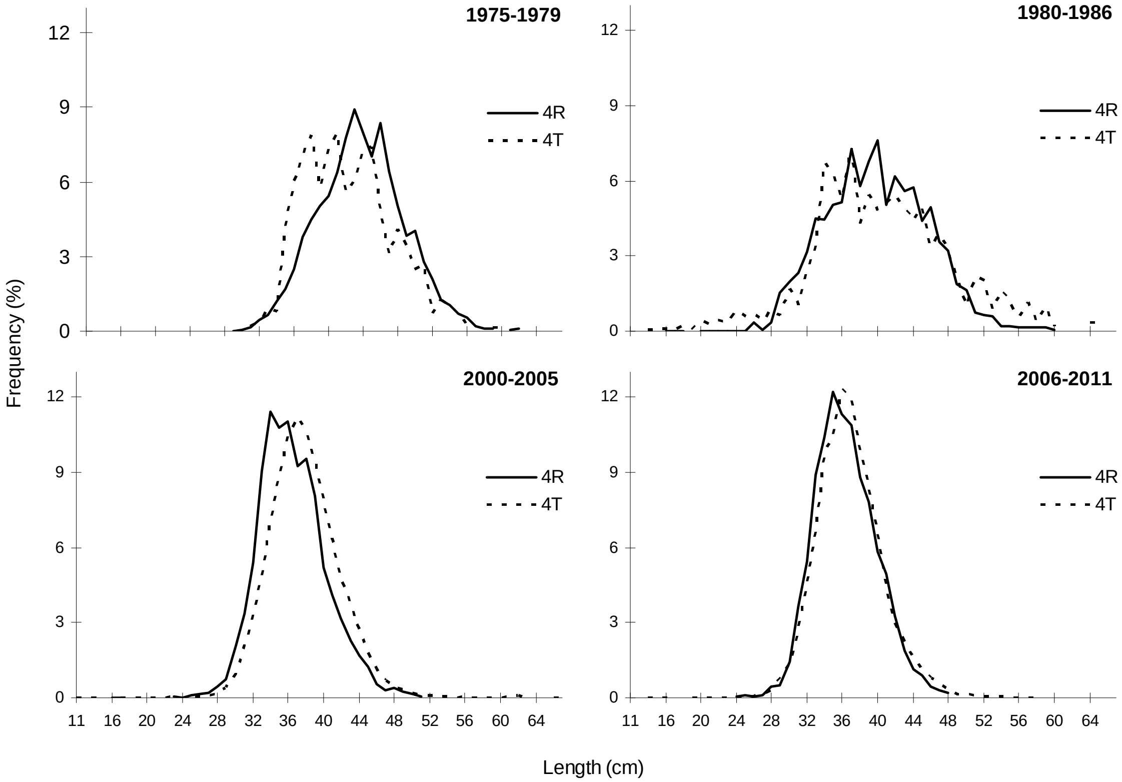

Figure 6. Average length frequencies (%) of witch flounder caught by mobile gear in NAFO divisions 4RST, in four periods. Averages were weighted by the landings associated with each length frequency sample.

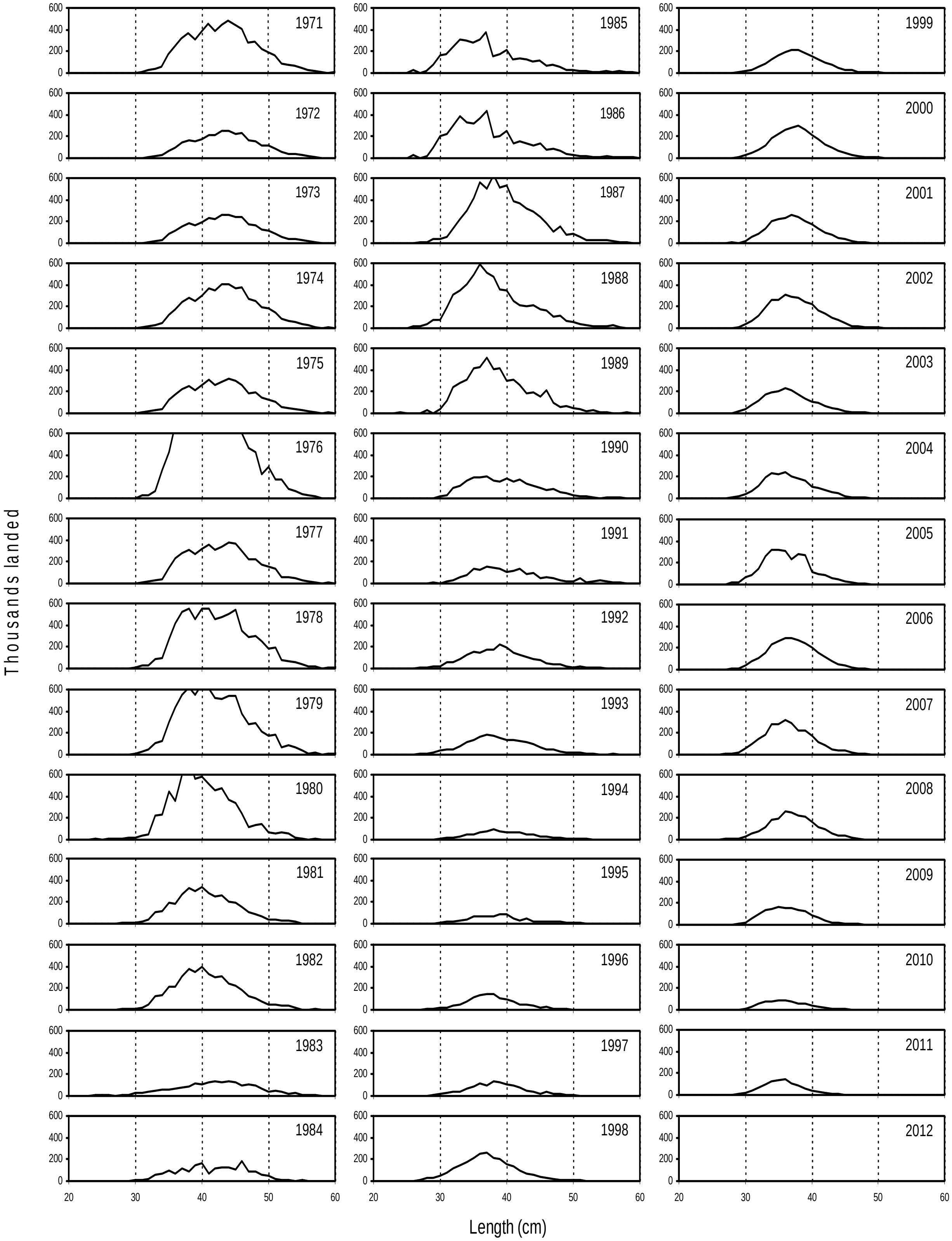

Figure 7. Estimated catch-at-length for mobile-gear landings of witch flounder in NAFO 4RST, 1971-2011.

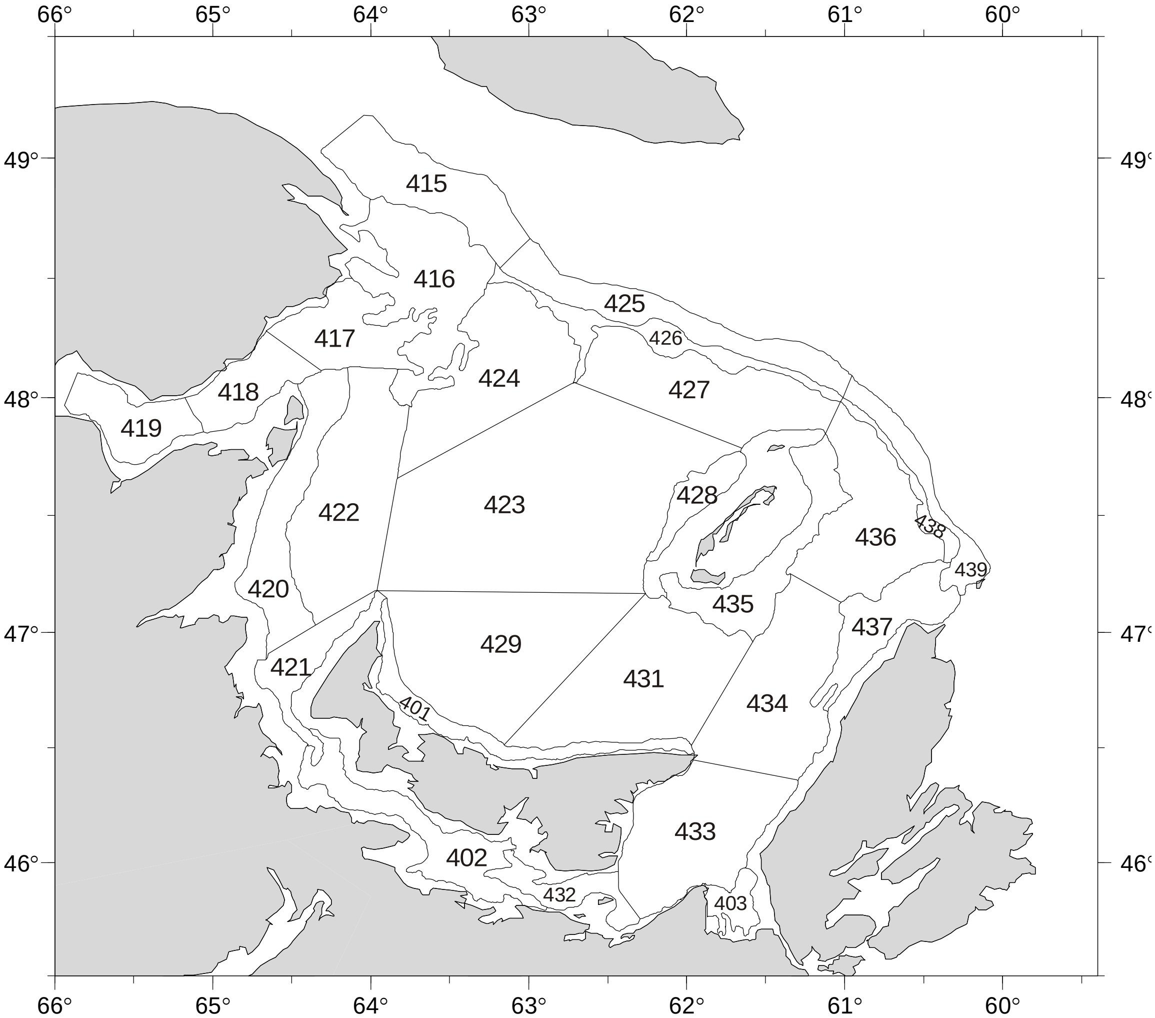

Figure 8. Stratum boundaries for the September bottom-trawl survey of the southern Gulf of St. Lawrence.

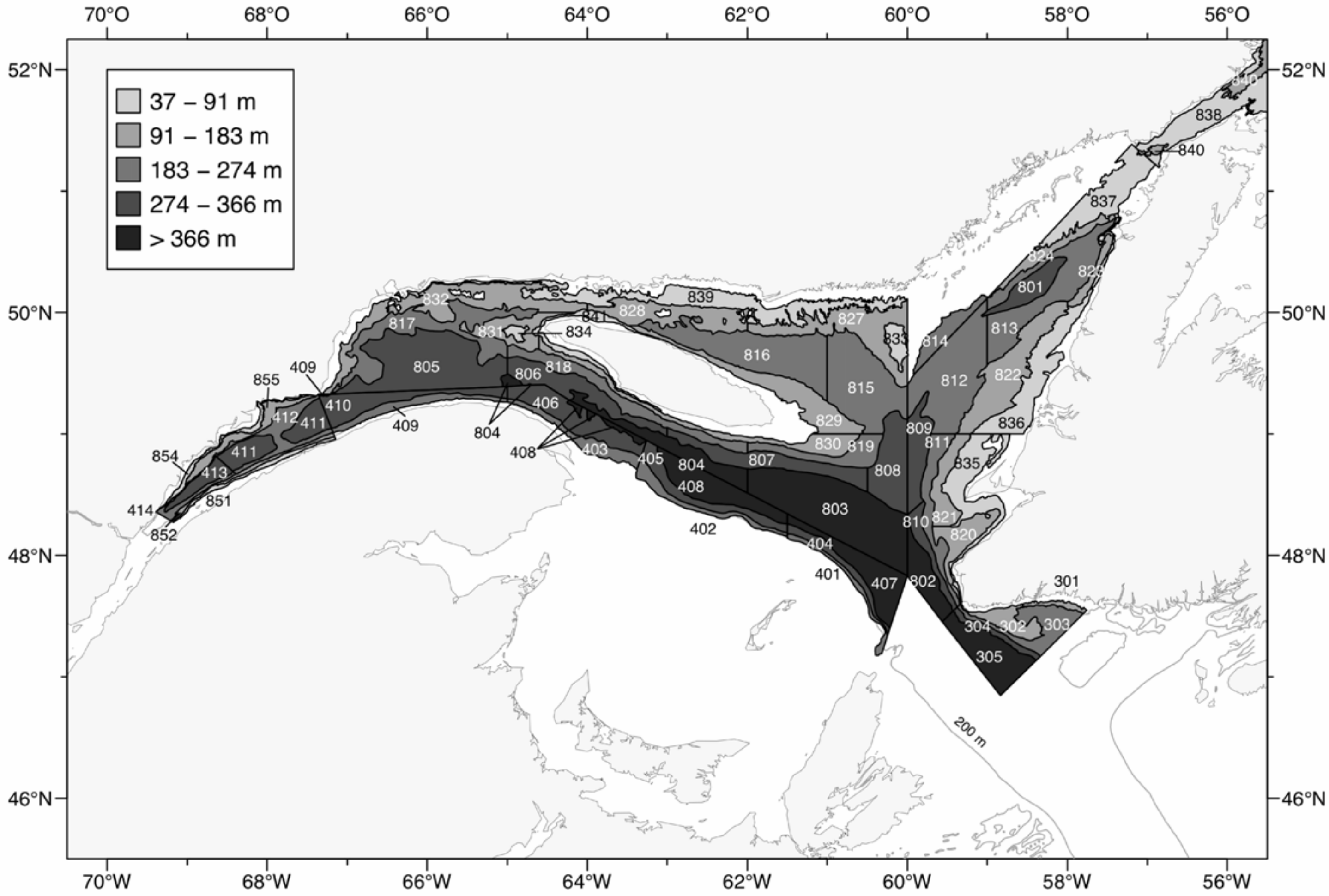

Figure 9. Stratum boundaries for the August bottom-trawl survey of the northern Gulf of St. Lawrence.

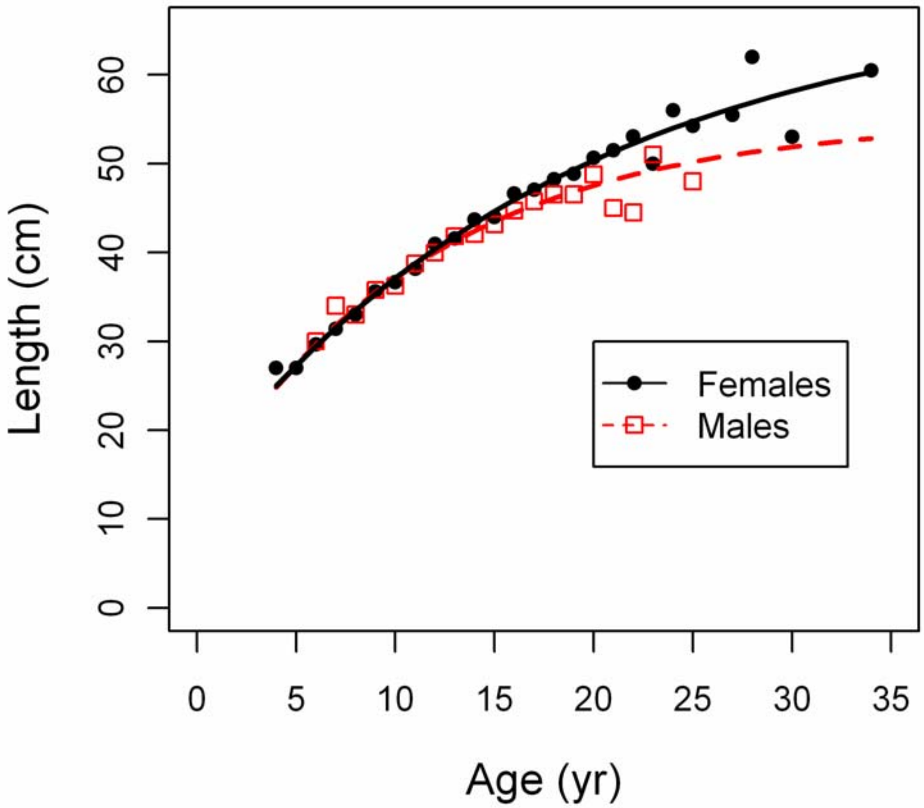

Figure 10. Growth of witch flounder based on samples collected from the southern Gulf of St. Lawrence in September, 1974-1981.

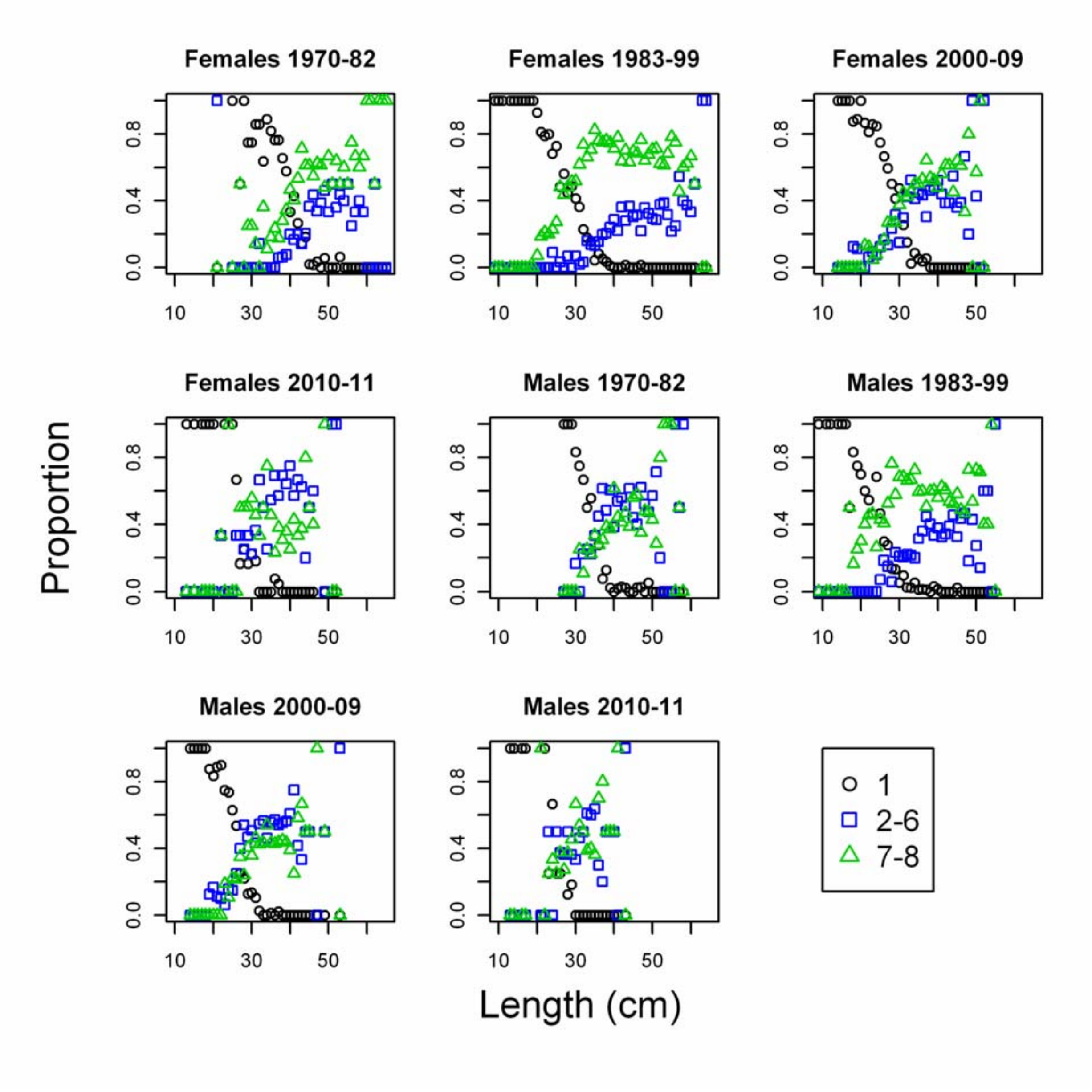

Figure 11. Maturity codes of witch flounder collected during September surveys of the southern Gulf of St. Lawrence during four periods.

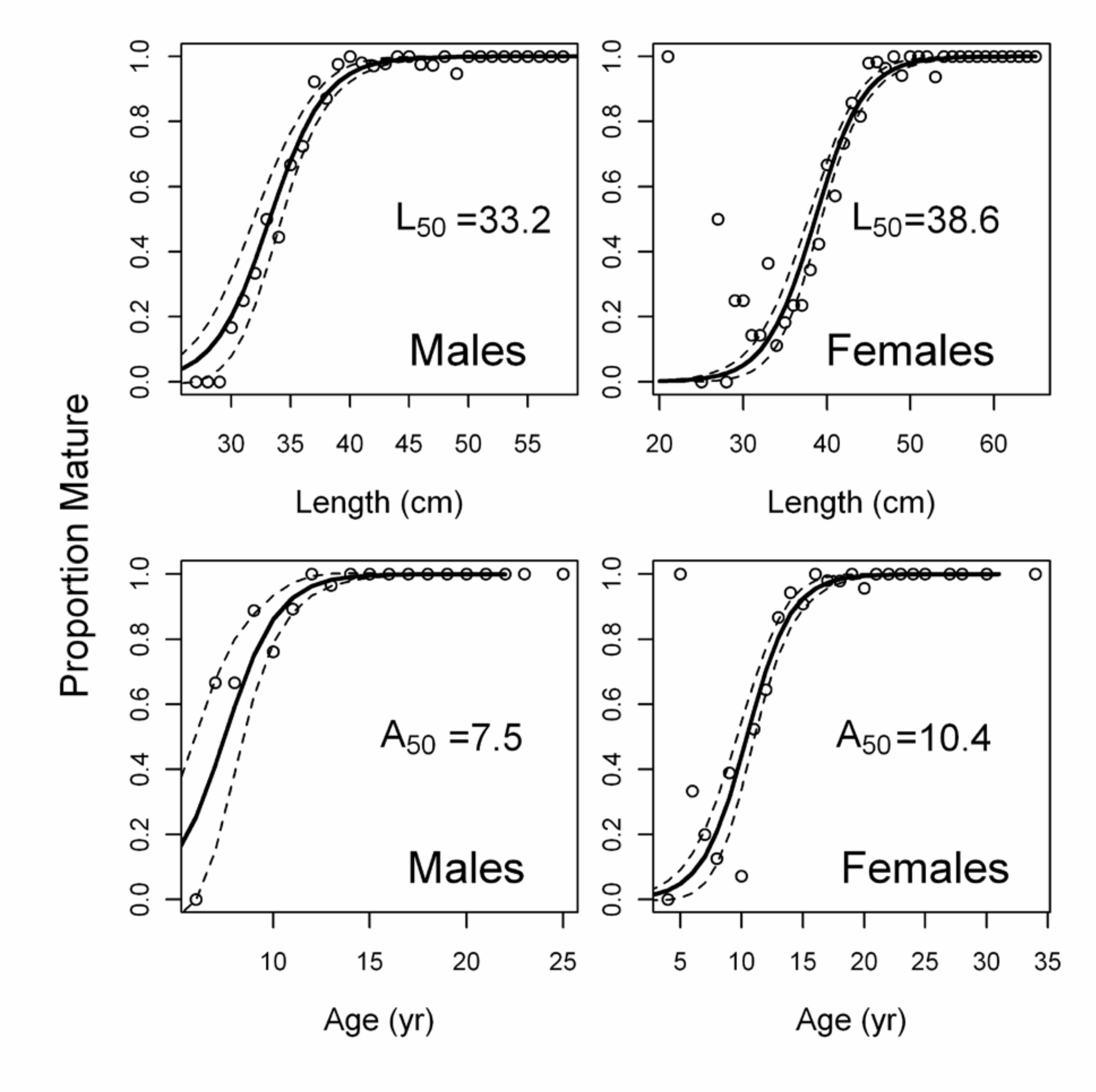

Figure 12. Maturity ogives for witch flounder based on September survey data, 1970-1982. Circles are the observed data and lines show the fitted models (predicted values ± 2SE). The predicted lengths and ages at 50% maturity (L_{50}, A_{50}) are noted in the figure.

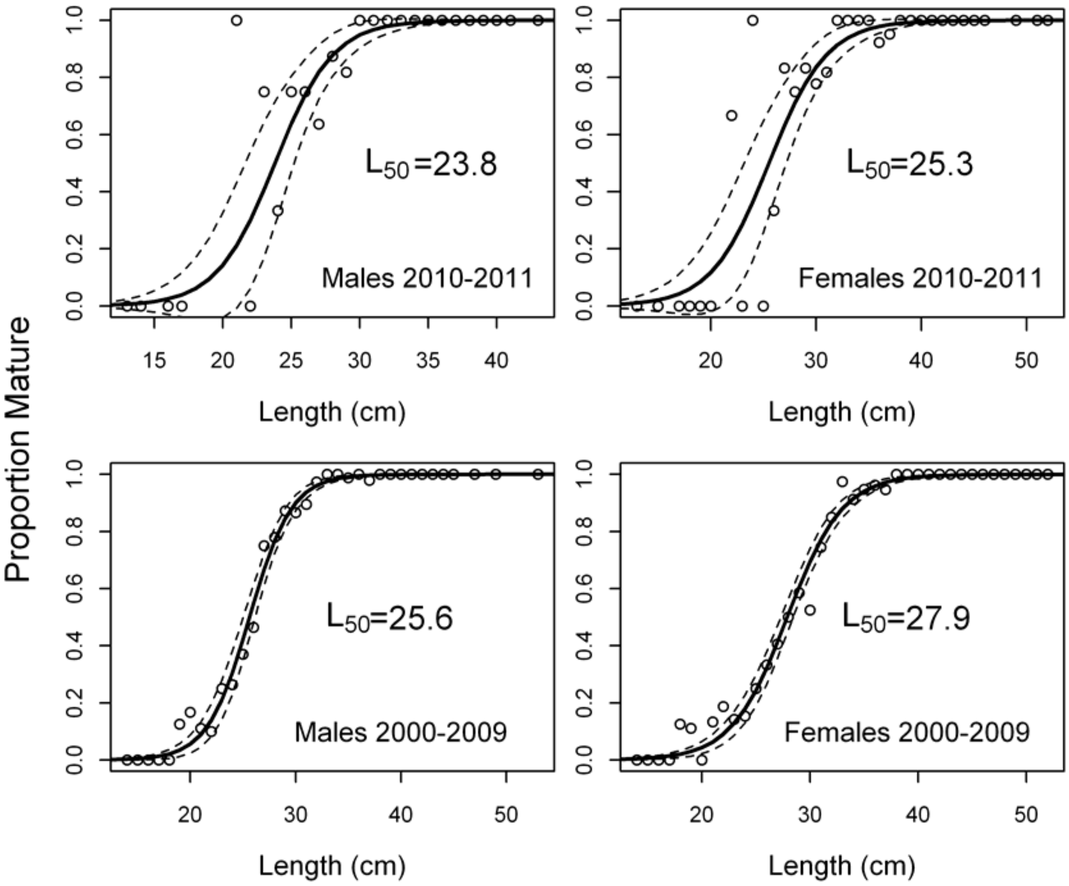

Figure 13. Maturity ogives for witch flounder based on September survey data, 2000-2011. Circles are the observed data and lines show the fitted models (predicted values ± 2SE). The predicted lengths at 50% maturity (L_{50}) are noted in the figure.

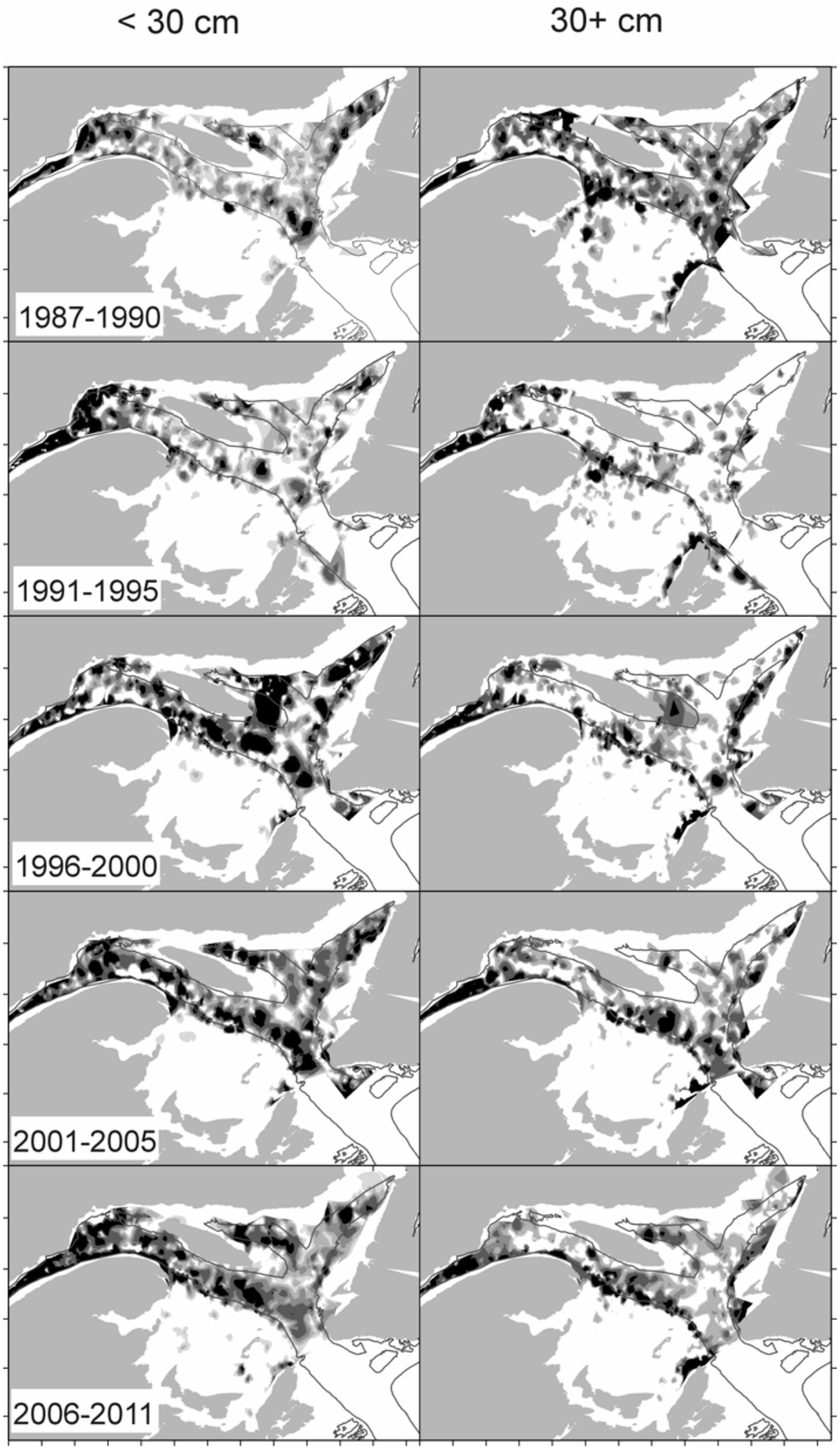

Figure 14. Distribution of two size classes of witch flounder in summer surveys of the Gulf of St. Lawrence. Darker shading indicates higher local density. Contour intervals are the 1st, 10th, 25th, 50th, and 75th percentiles of non-zero catches within each size class. Strata >833 omitted for consistency over time.

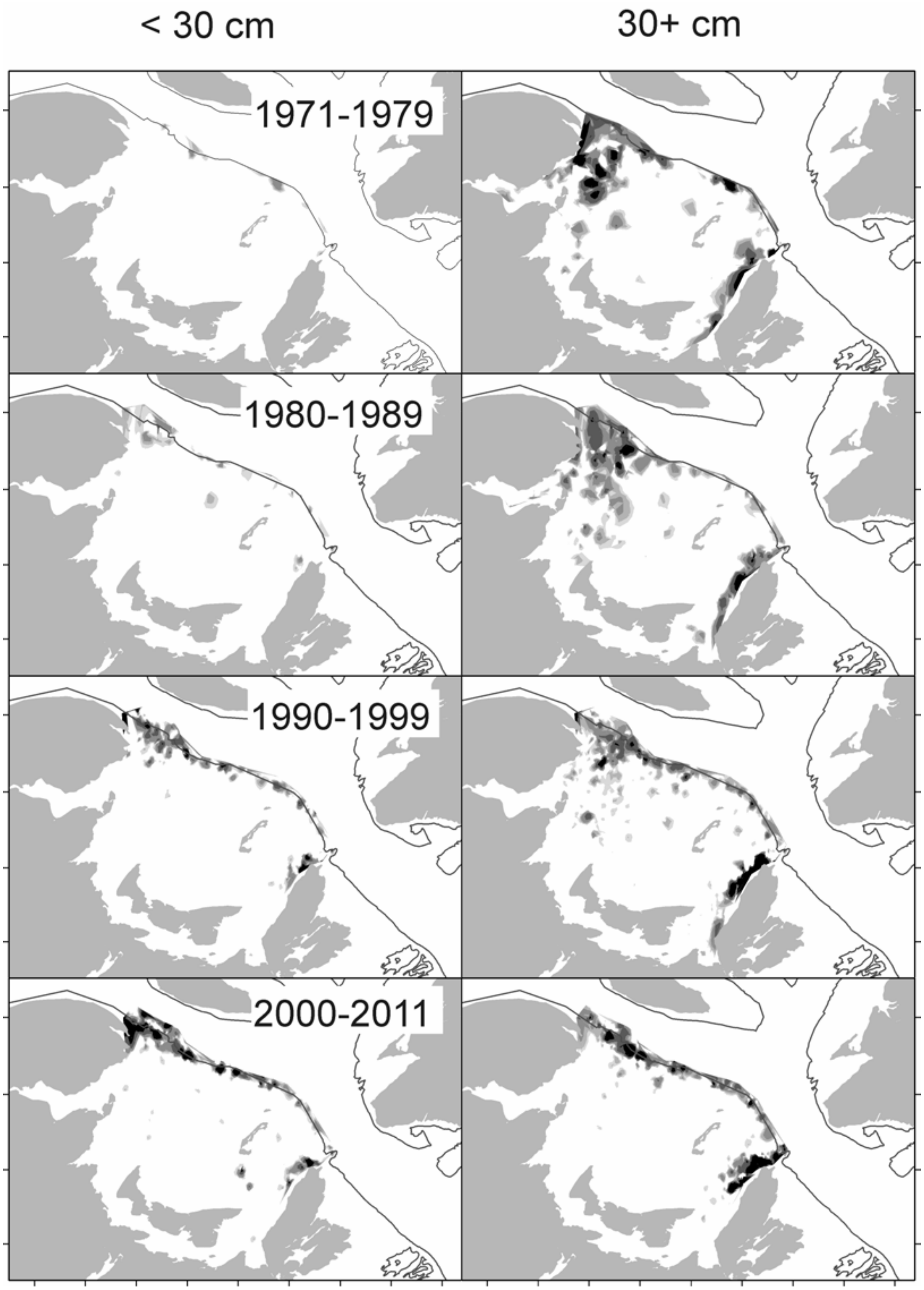

Figure 15. Distribution of two size classes of witch flounder in September surveys of the southern Gulf of St. Lawrence. Darker shading indicates higher local density. Contour intervals are the 1st, 10th, 25th, 50th, and 75th percentiles of non-zero catches within each size class.

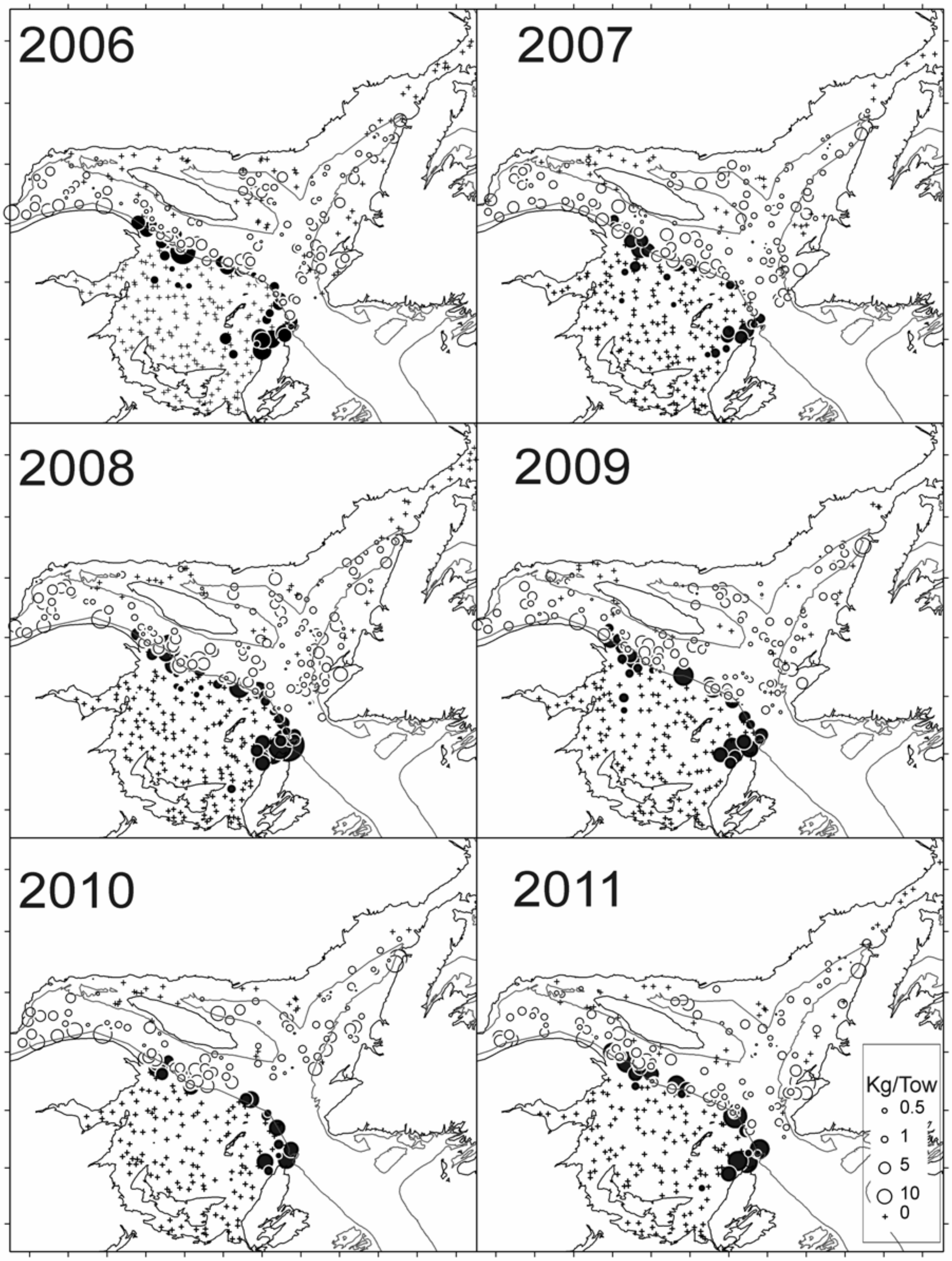

Figure 16. Distribution of witch flounder catches (kg/tow) in the 2006-2011 RV surveys of the northern (August, open circles) and southern (September, filled circles) Gulf of St. Lawrence.

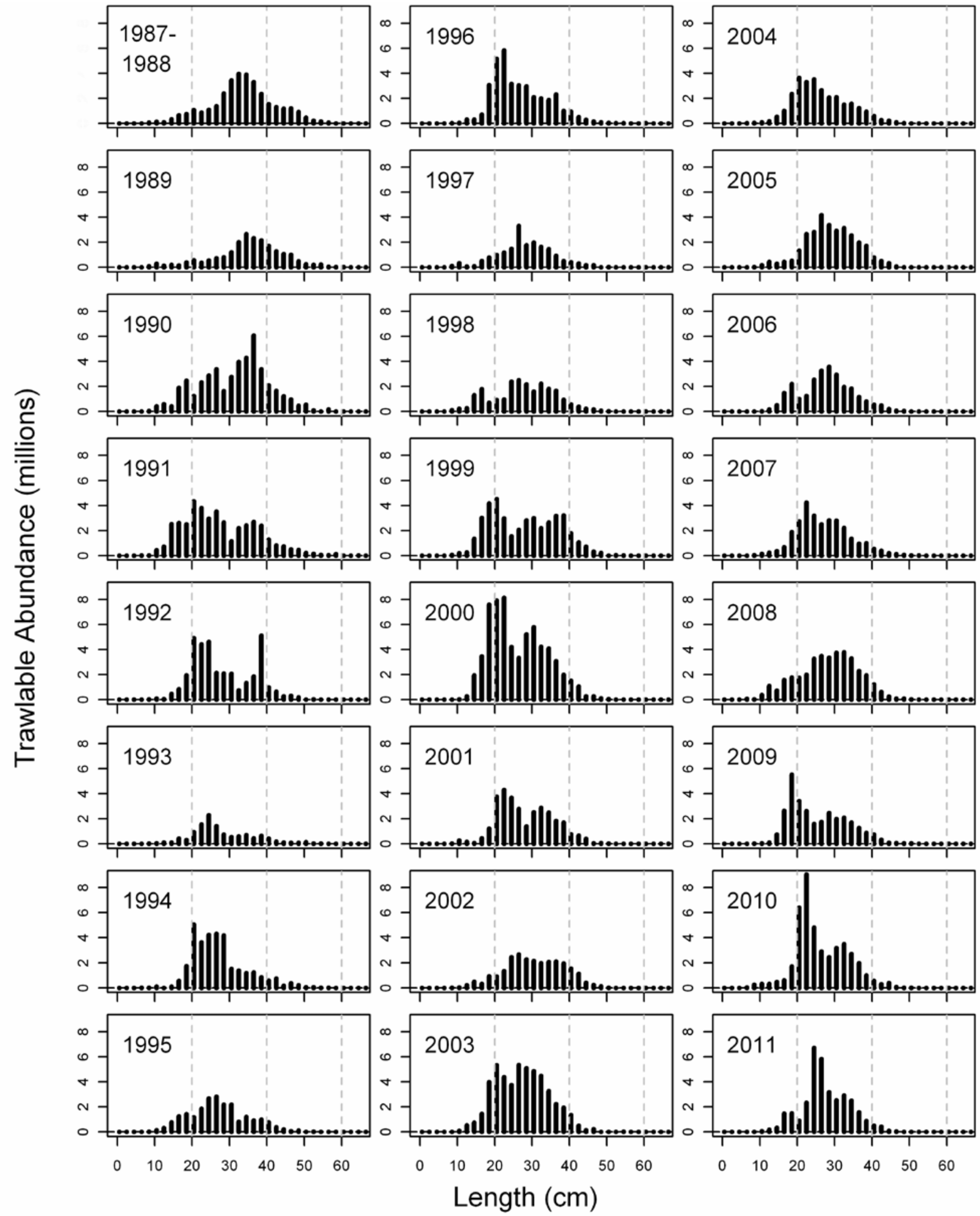

Figure 17. Length distribution of witch flounder caught in the August/September surveys of the Gulf of St. Lawrence. Catches are adjusted to a night tow of 1.75 nm by the Lady Hammond using a Western IIA trawl.

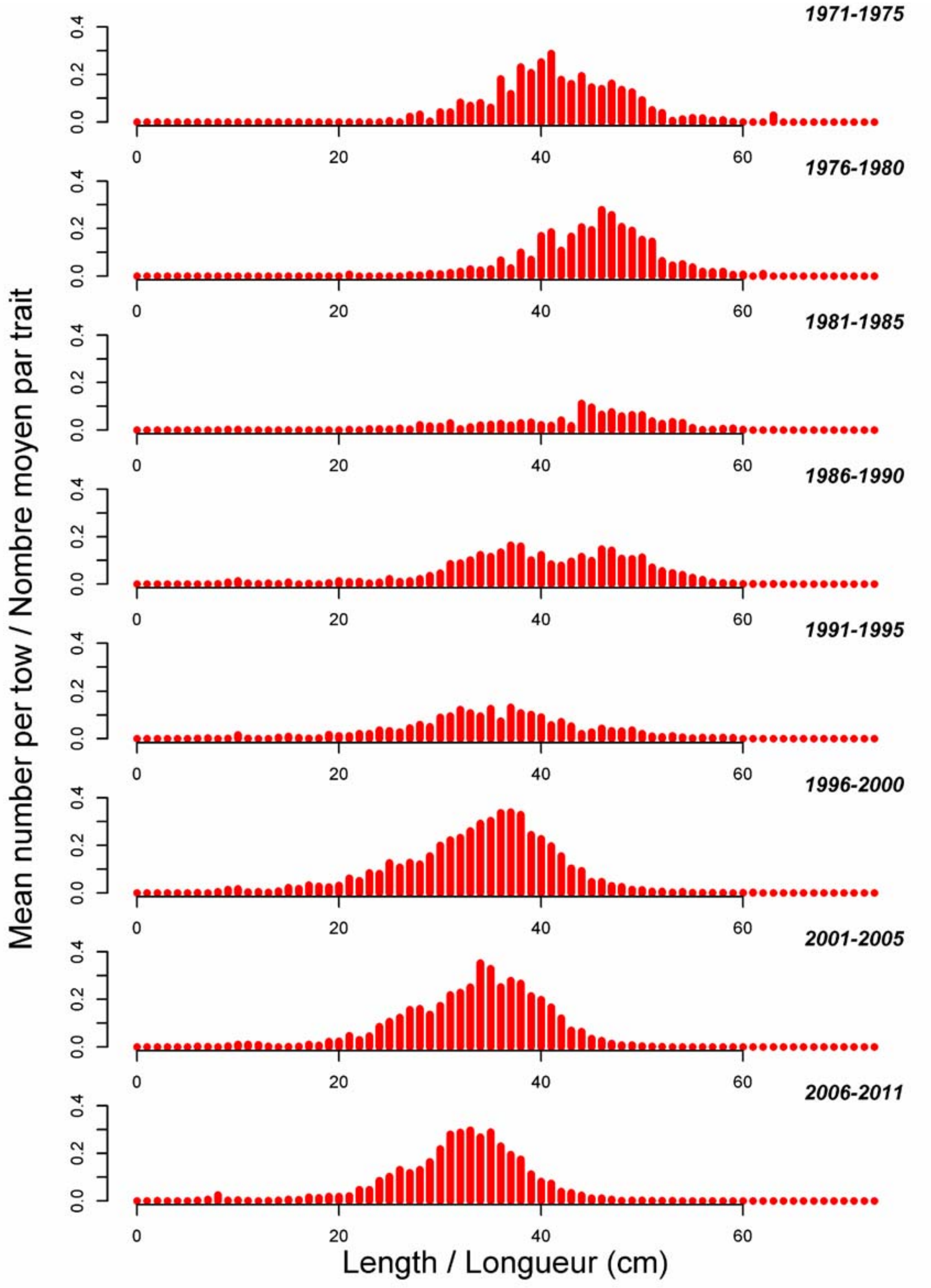

Figure 18. Length distribution of witch flounder caught in the September survey of the southern Gulf of St. Lawrence. Catches are adjusted to a night tow of 1.75 nm by the Lady Hammond using a Western IIA trawl.

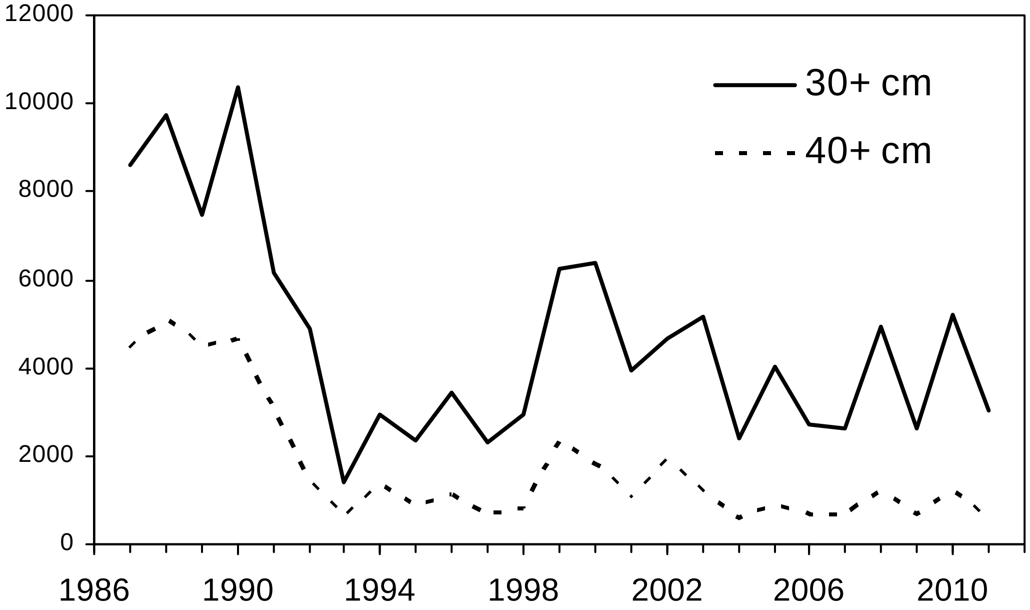

Figure 19. Biomass trends for witch flounder ≥30 cm and ≥40 cm in length in the August and September surveys of the Gulf of St. Lawrence.

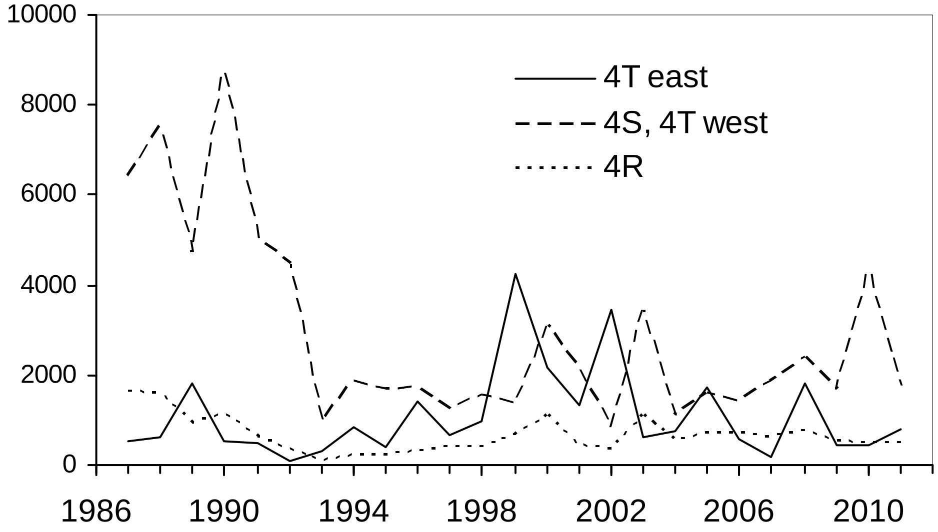

Figure 20. RV survey biomass indices by subregion of the Gulf of St. Lawrence for witch flounder ≥30 cm in length.

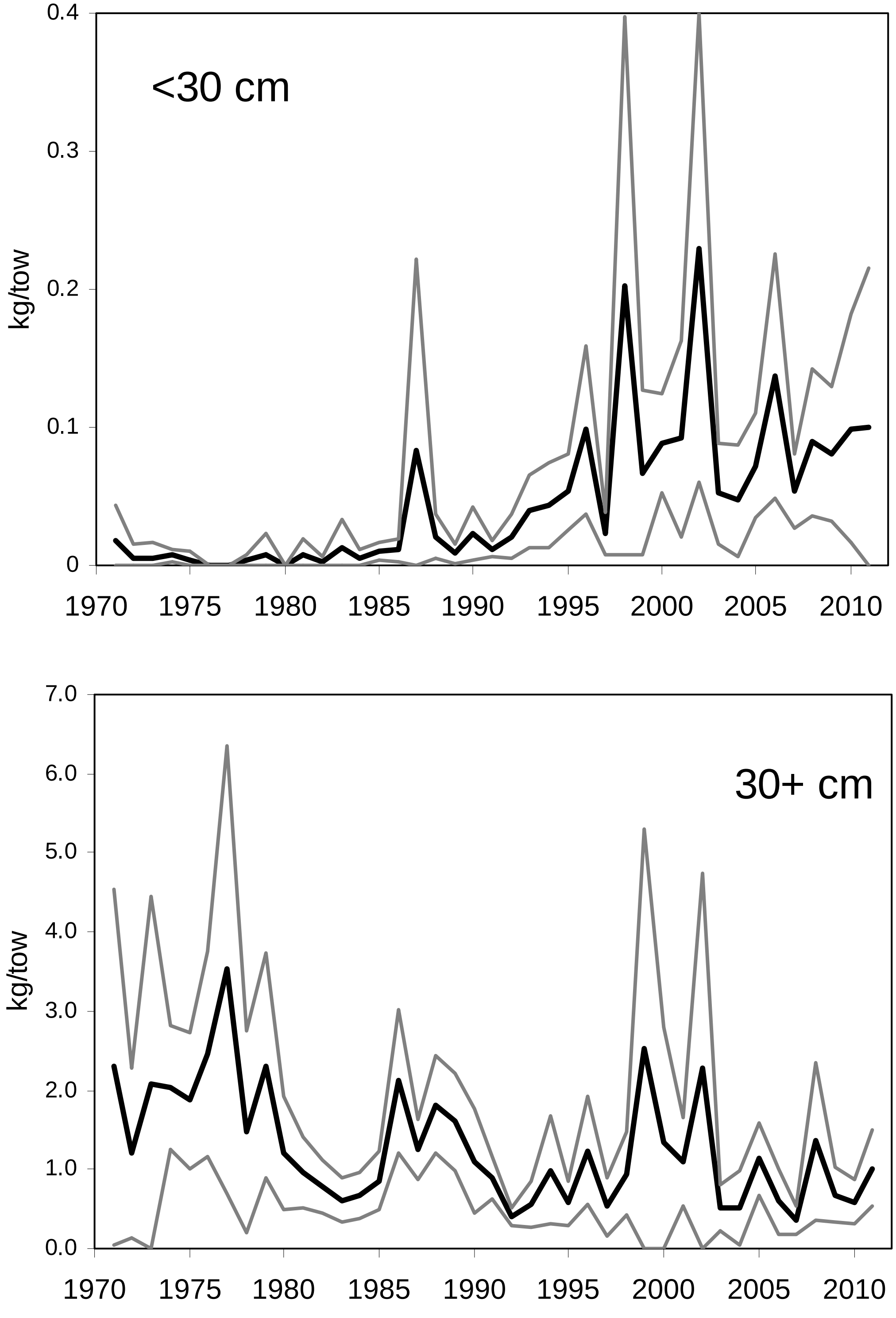

Figure 21. Biomass of two size classes of witch flounder in the September RV survey of the southern Gulf of St. Lawrence. Heavy black lines show the mean kg/tow and grey lines show ± 2 SE.

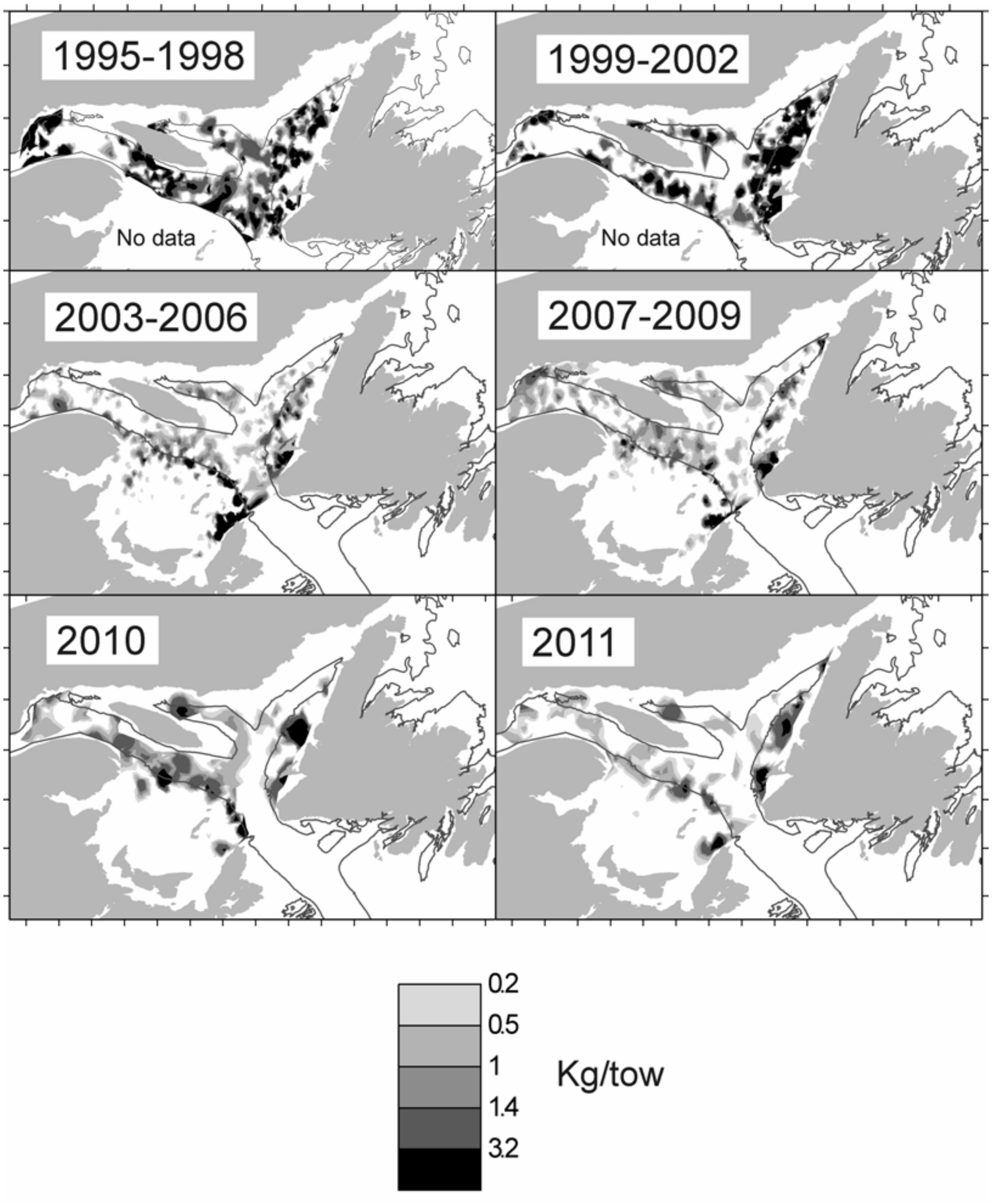

Figure 22. Distribution of witch flounder catches (kg/tow) in the mobile-gear sentinel surveys of the northern (July 1995-2011) and southern (August 2003-2011) Gulf of St. Lawrence.

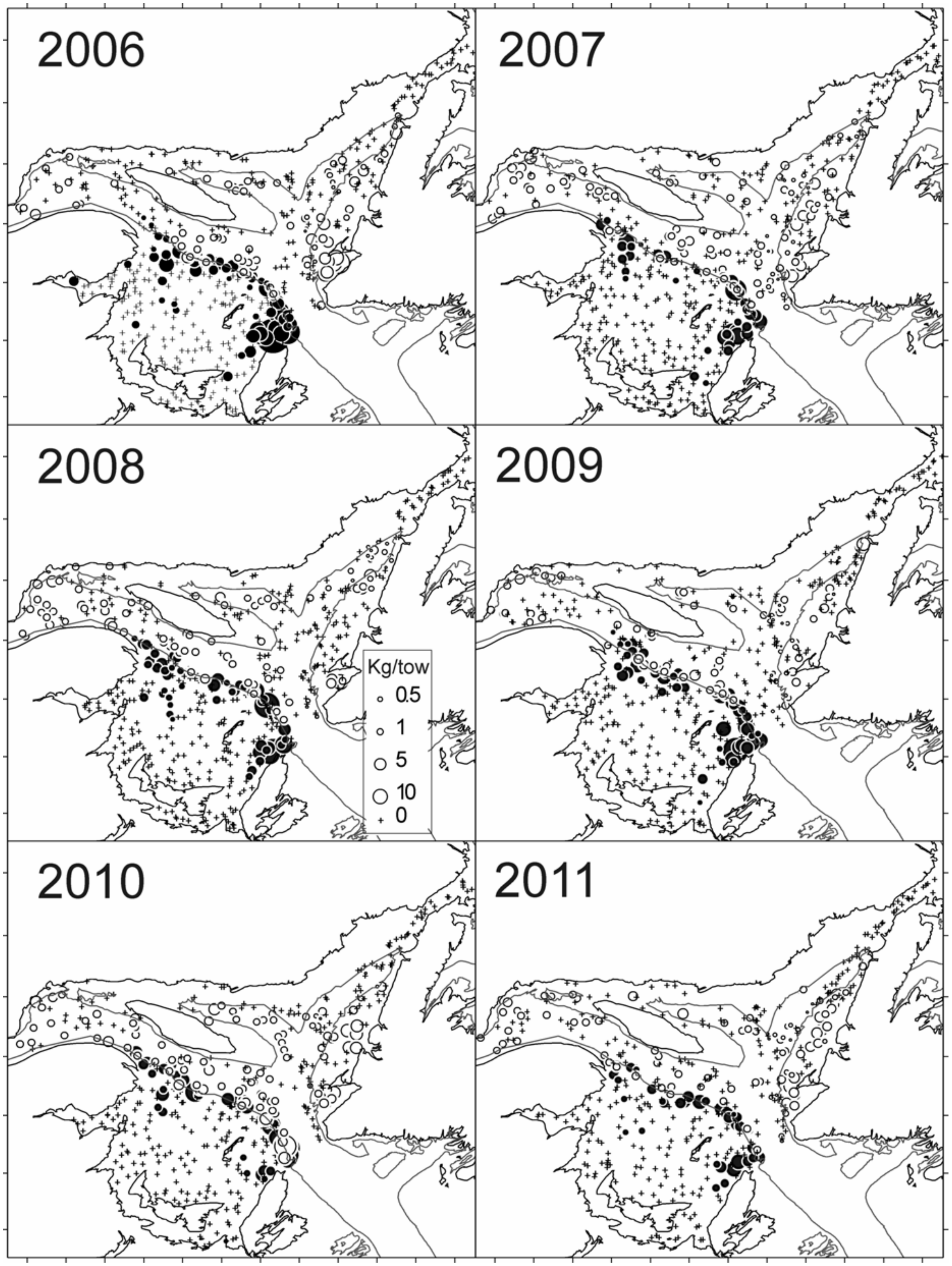

Figure 23. Distribution of witch flounder catches (kg/tow) in the 2006-2011 mobile-gear sentinel surveys of the northern (July, open circles) and southern (August, filled circles) Gulf of St. Lawrence.

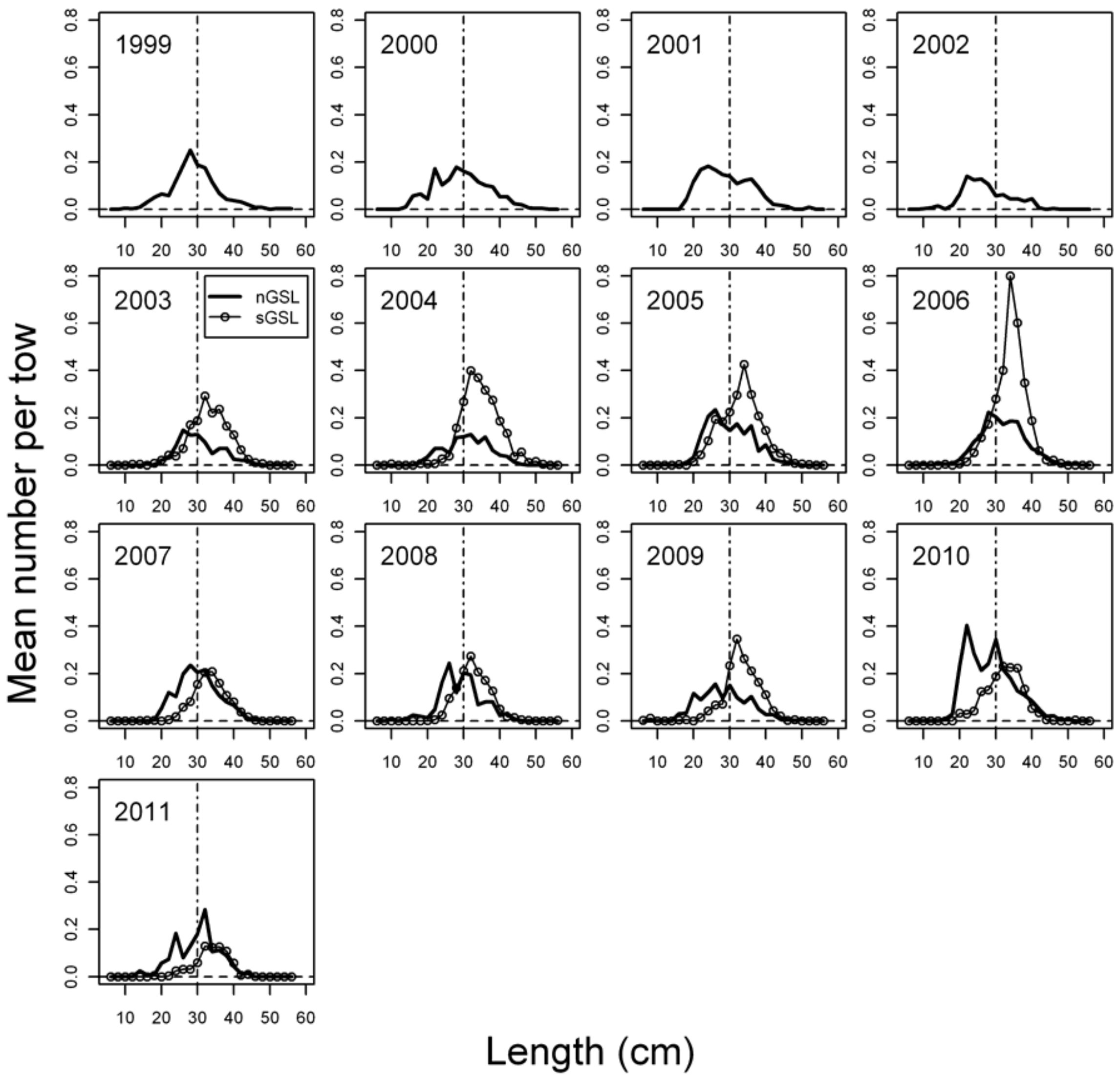

Figure 24. Stratified mean length frequency distributions of witch flounder caught in the July sentinel survey of the northern Gulf of St. Lawrence (nGSL) and the August sentinel survey of the southern Gulf of St. Lawrence (sGSL).

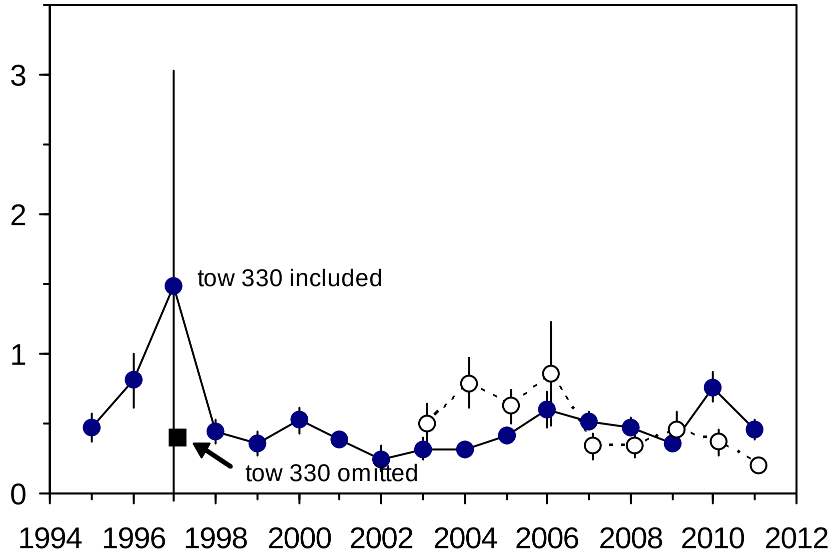

Figure 25. Stratified mean catch rates (kg/tow) in the July sentinel survey of the northern Gulf (solid symbols) and the August survey of the southern Gulf (open circles). Vertical lines are ±1SE. The high 1997 value in July survey is due to a single tow. The square shows the mean catch rate omitting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

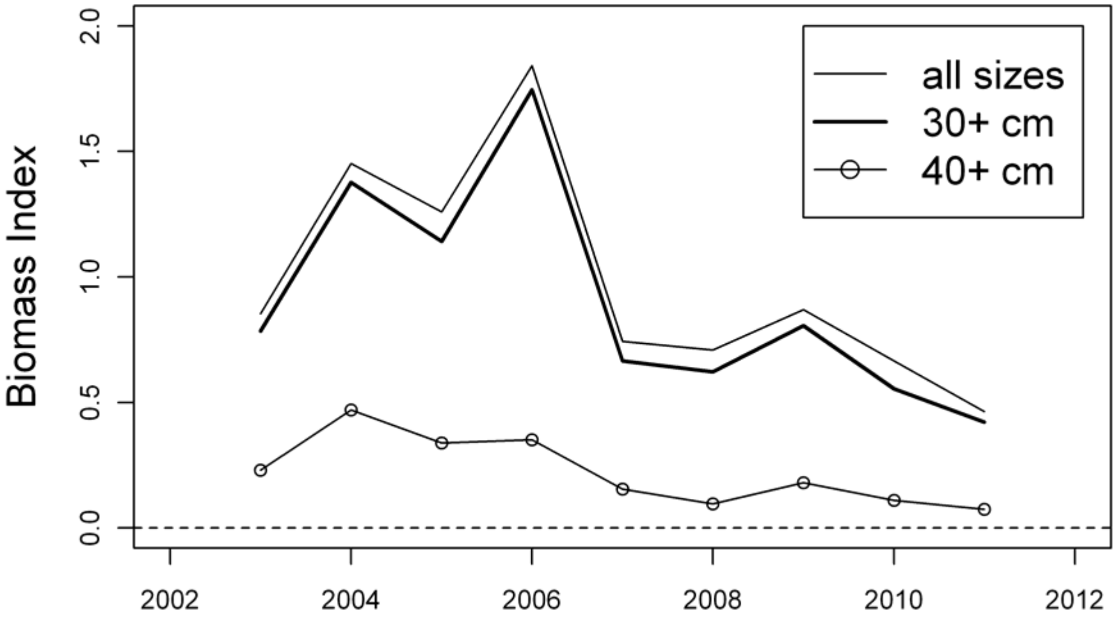

Figure 26. Biomass indices for witch flounder combining the July sentinel survey of the northern Gulf of St. Lawrence and the August sentinel survey of the southern Gulf.

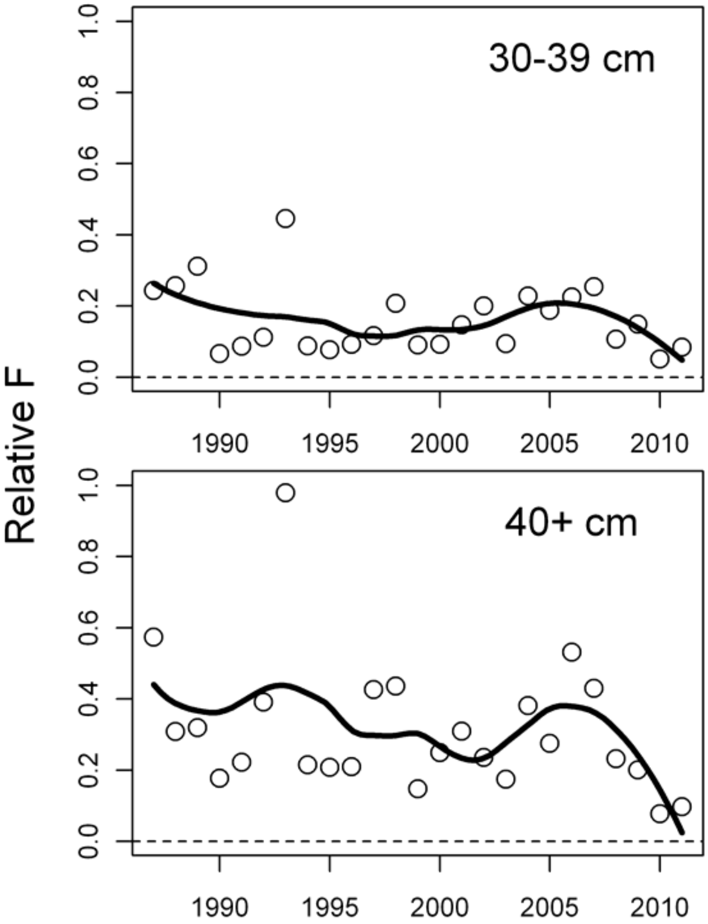

Figure 27. Relative fishing mortality of 4RST witch flounder, estimated as the ratio of catch in a length class divided by the RV survey estimate of trawlable abundance in that length class. Lines are loess fits (span=0.5) to the annual estimates.

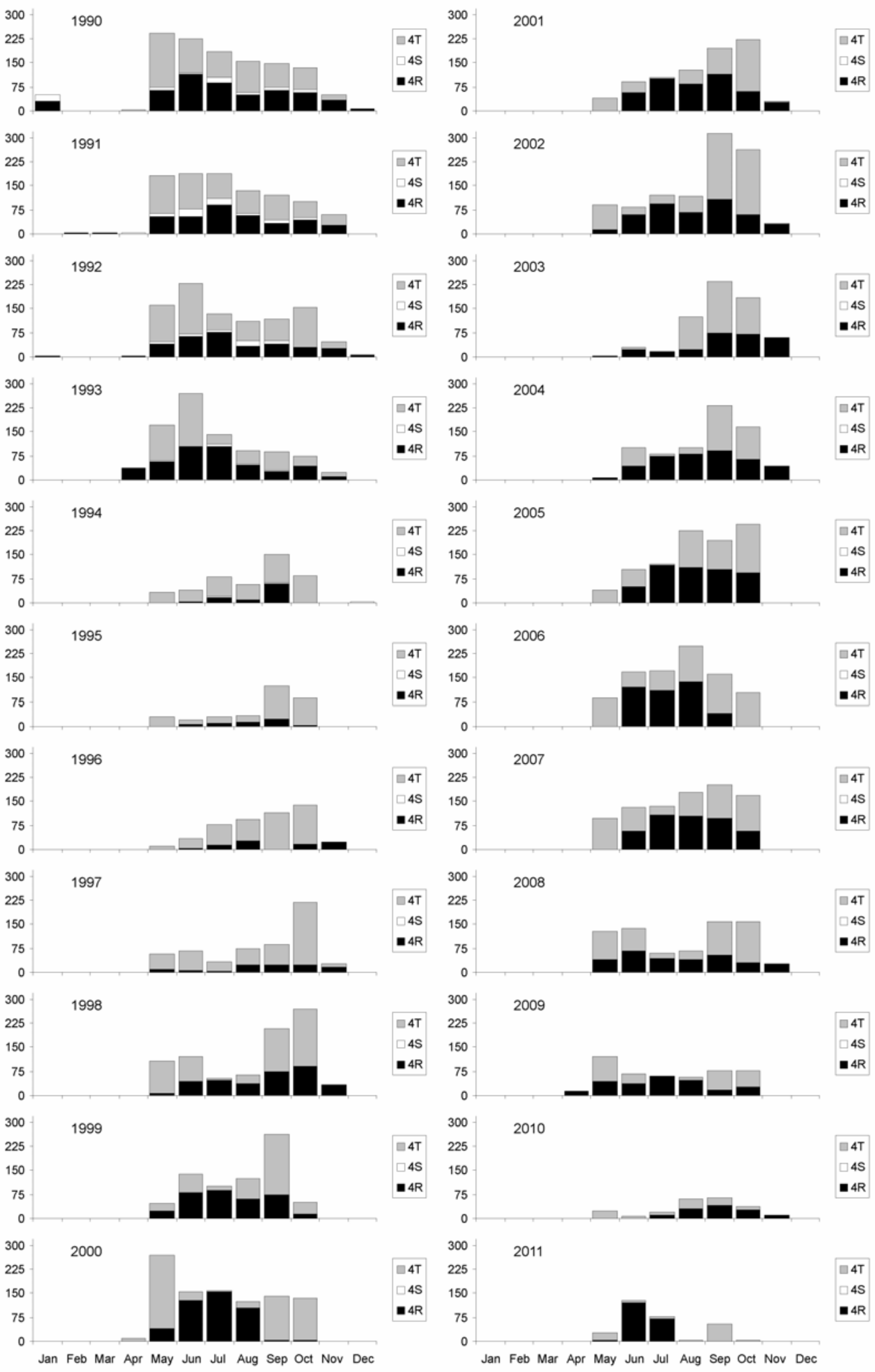

Figure 28. Monthly distribution of witch flounder landings in NAFO divisions 4RST.

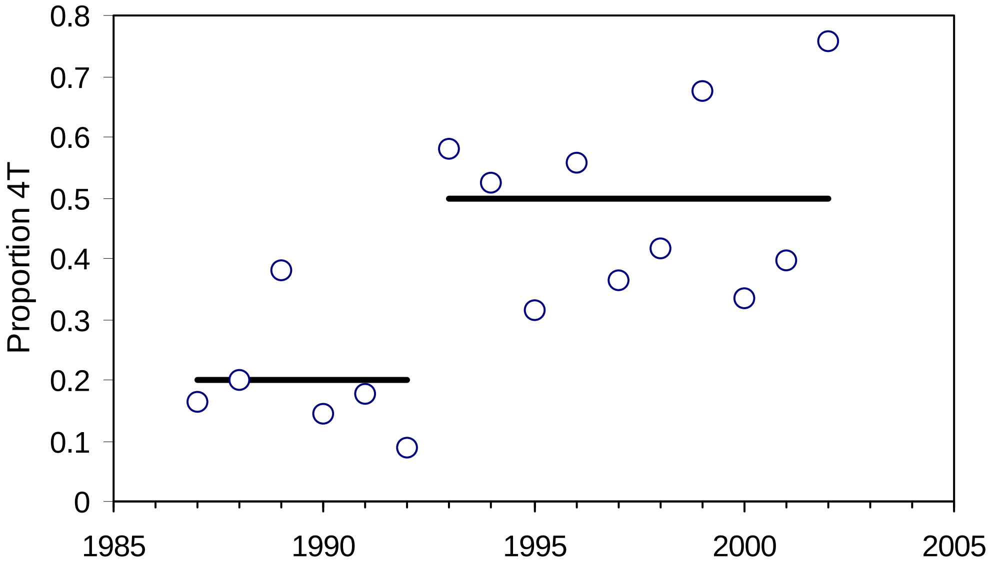

Figure 29. Proportion of the trawlable biomass of witch flounder 30 cm and longer in the 4RST RV surveys (August and September) that is caught in the September RV survey.

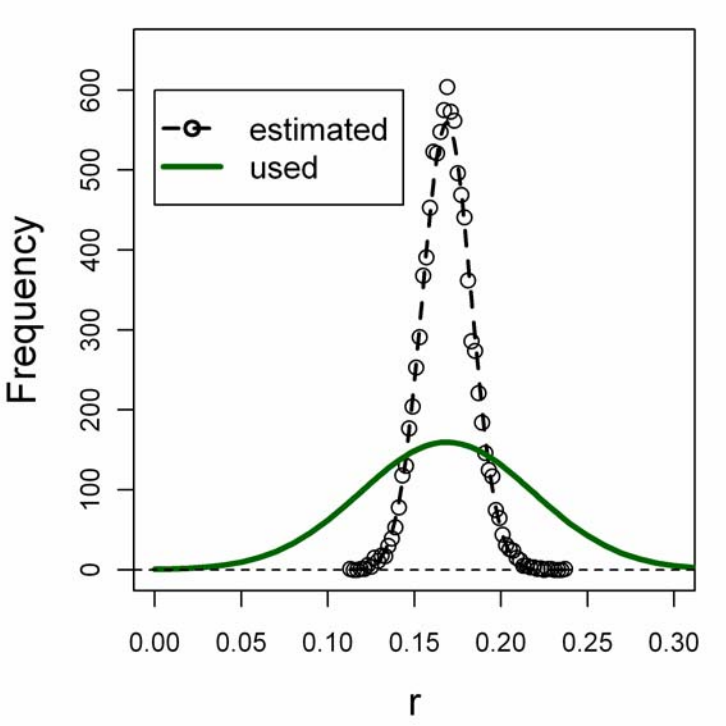

Figure 30. Prior for r estimated using demographic methods (circles, dashed line) and the prior distribution used in modelling (solid green line).

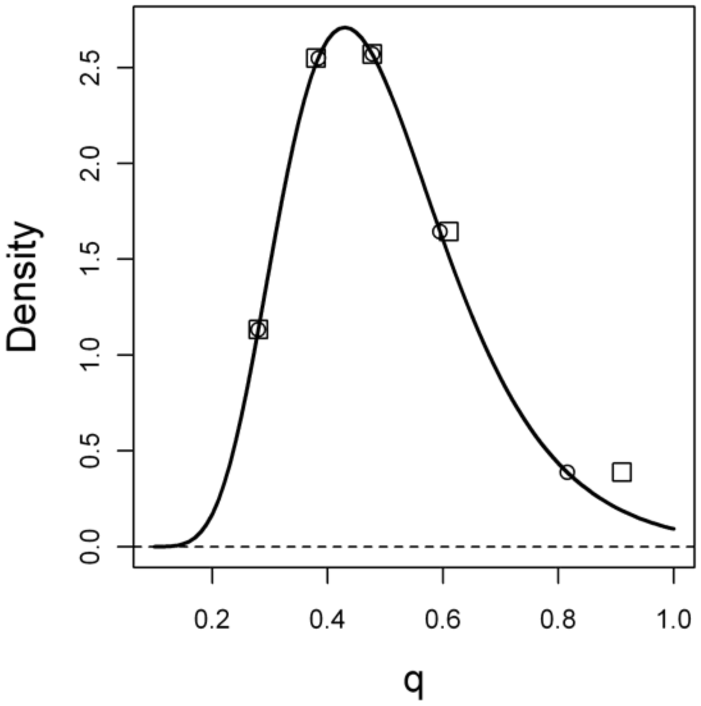

Figure 31. Prior for q of index 2. Circles mark the 5th, 25th, 50th, 75th and 95th quantiles of the prior distribution. Squares denote the corresponding quantiles derived from the posterior distribution for length-dependent catchability of flatfish to summer/fall RV surveys estimated by Harley and Myers (2001). See text for details.

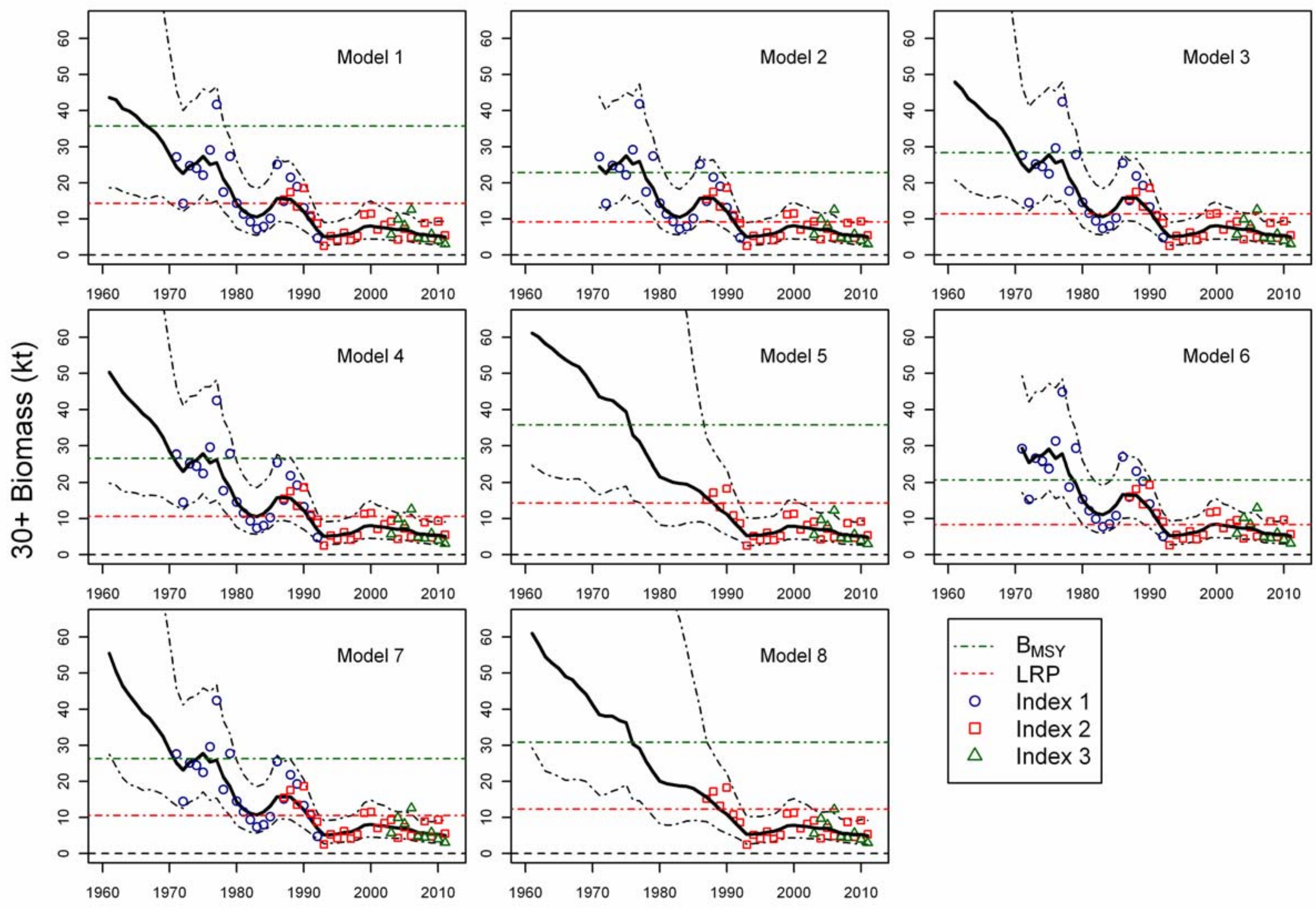

Figure 32. Predicted 30+ biomass from surplus production models of 4RST witch flounder. Heavy line is the posterior median and light black lines show the 2.5th and 97.5th percentiles. Symbols show q-corrected biomass indices. The median estimates for the biomass at maximum sustainable yield (B_{MSY}) and the Limit Reference Point (LRP, 40% of B_{MSY}) are also shown.

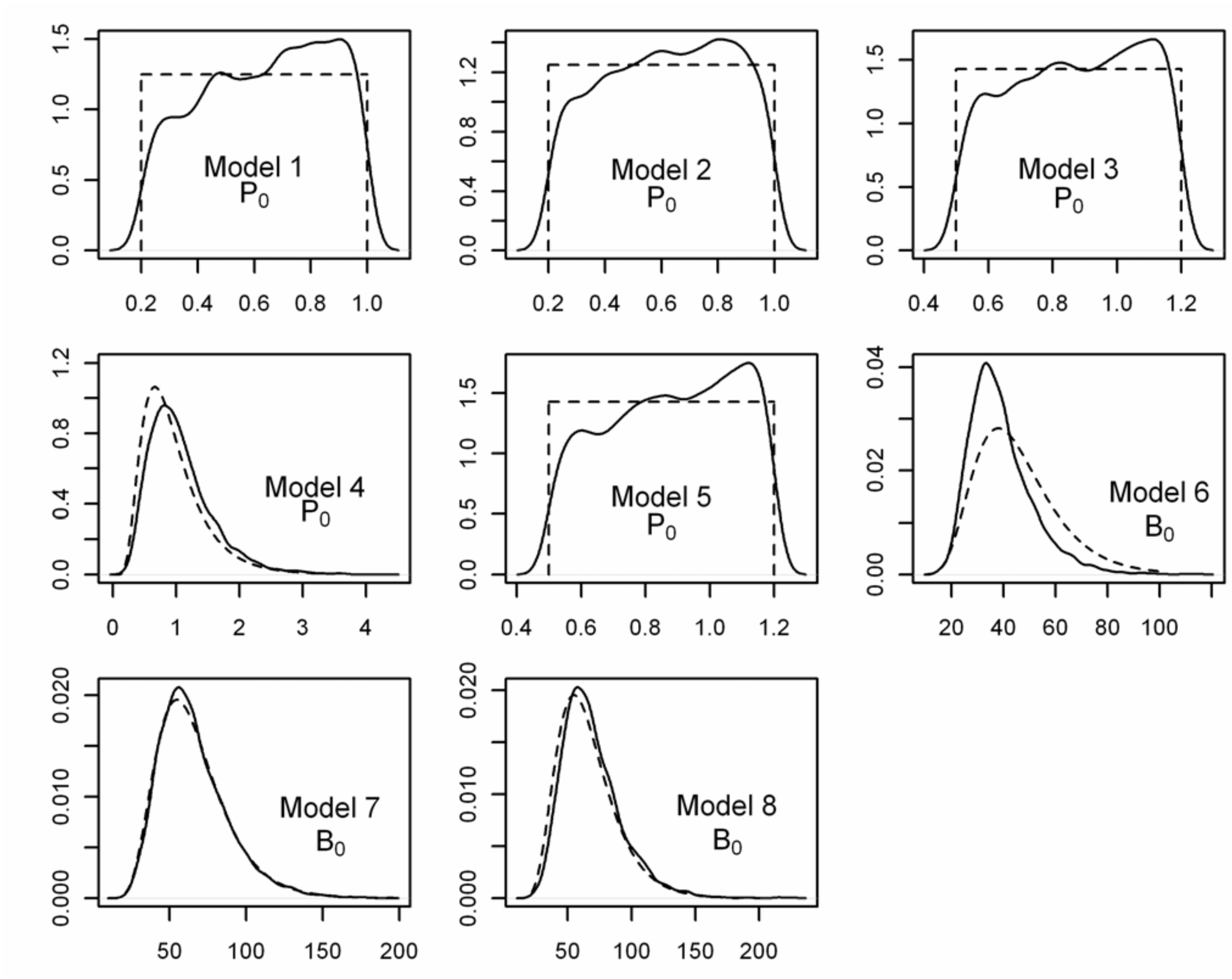

Figure 33. Priors (dashed line) and posteriors (solid lines) for initial biomass in surplus production models of 4RST witch flounder. Initial biomass is expressed as a proportion of carrying capacity (P_0) or is in kt (B_0).

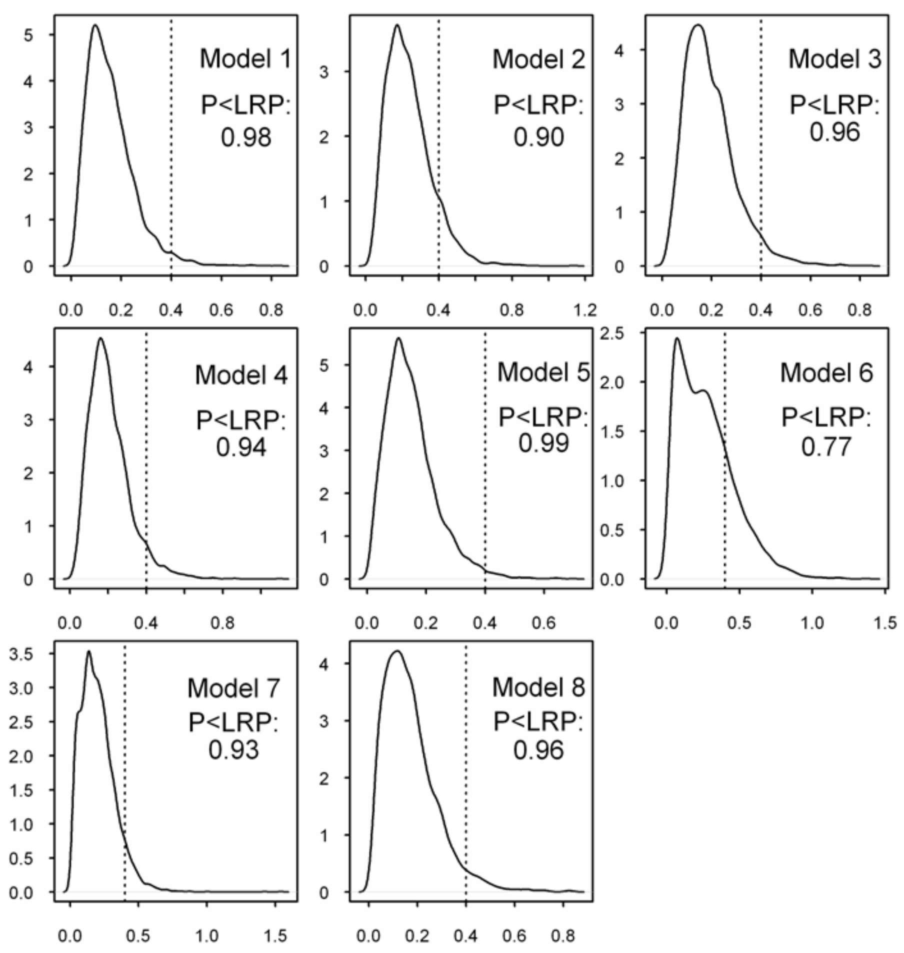

Figure 34.Posterior distributions for biomass in 2011 as a proportion of B_{MSY}. The probability that biomass in 2011 is less than the LRP (40% of B_{MSY}) is shown.

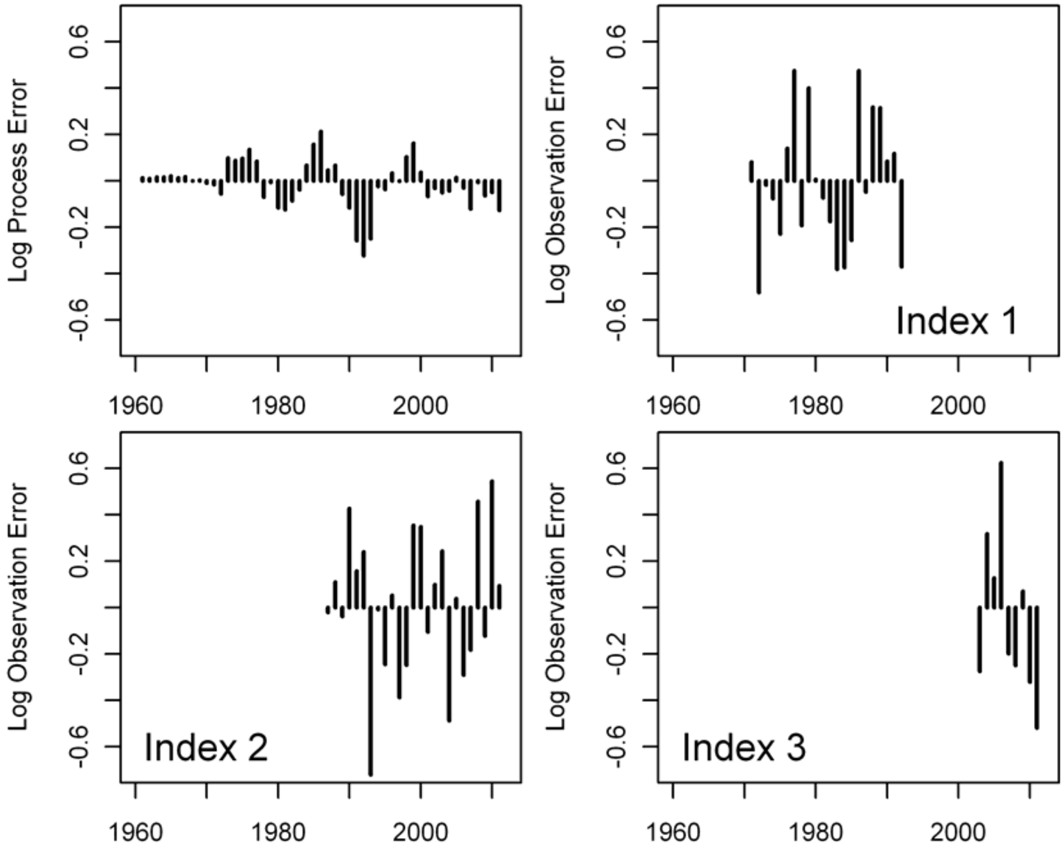

Figure 35. Process and observation errors from Model 7.

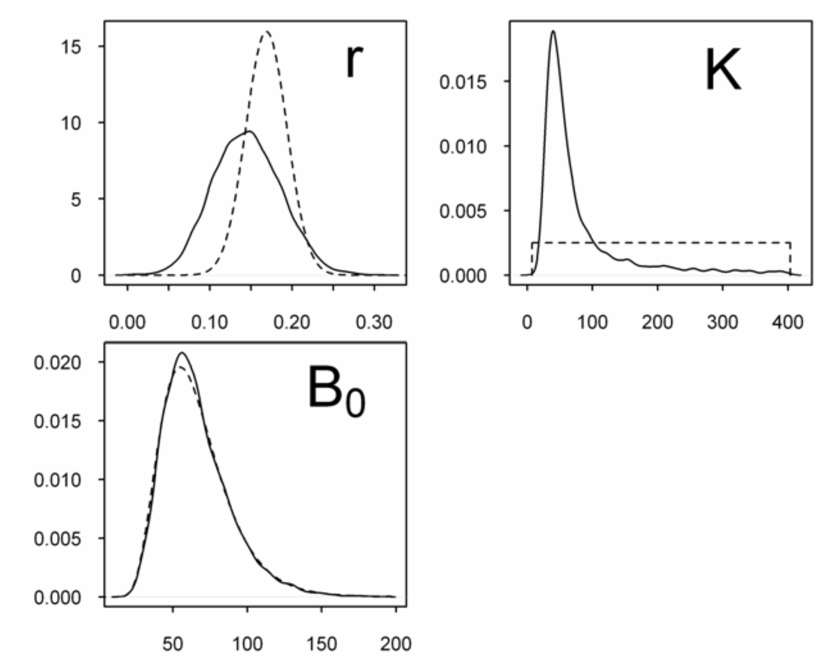

Figure 36. Prior (dashed line) and posterior (solid line) distributions of the intrinsic rate of increase r, carrying capacity K and starting biomass B_0 for model 7.

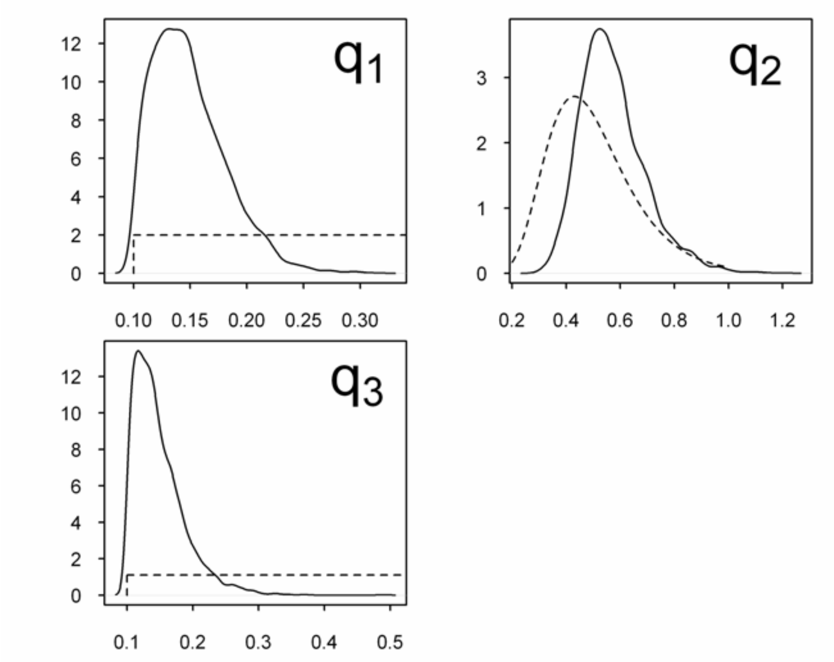

Figure 37. Prior (dashed line) and posterior (solid line) distributions of the catchability to indices 1, 2 and 3 for model 7.

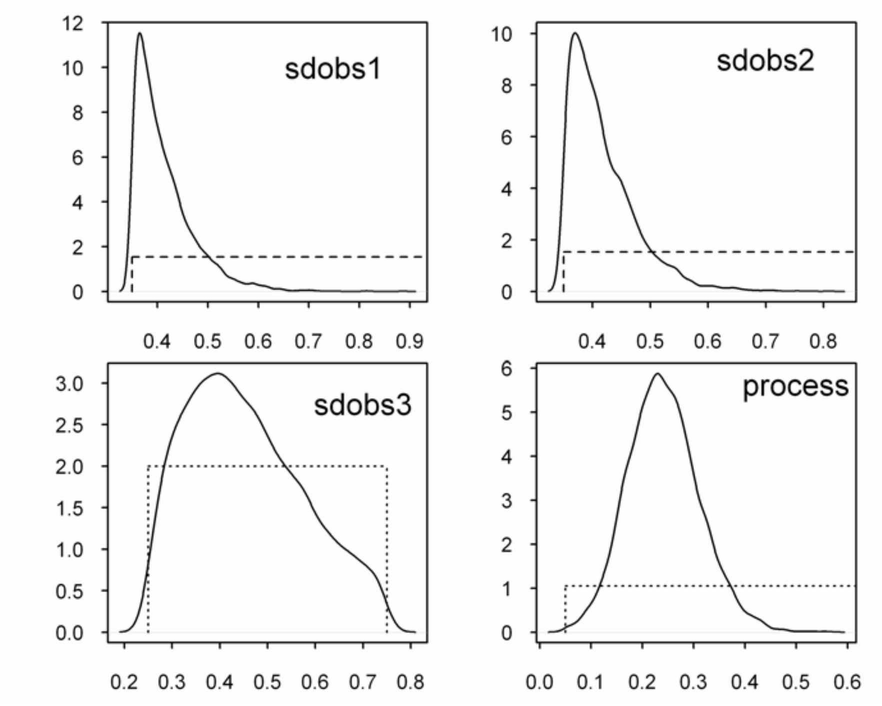

Figure 38. Prior (dashed line) and posterior (solid line) distributions of the standard deviations of observation and process error in model 7.

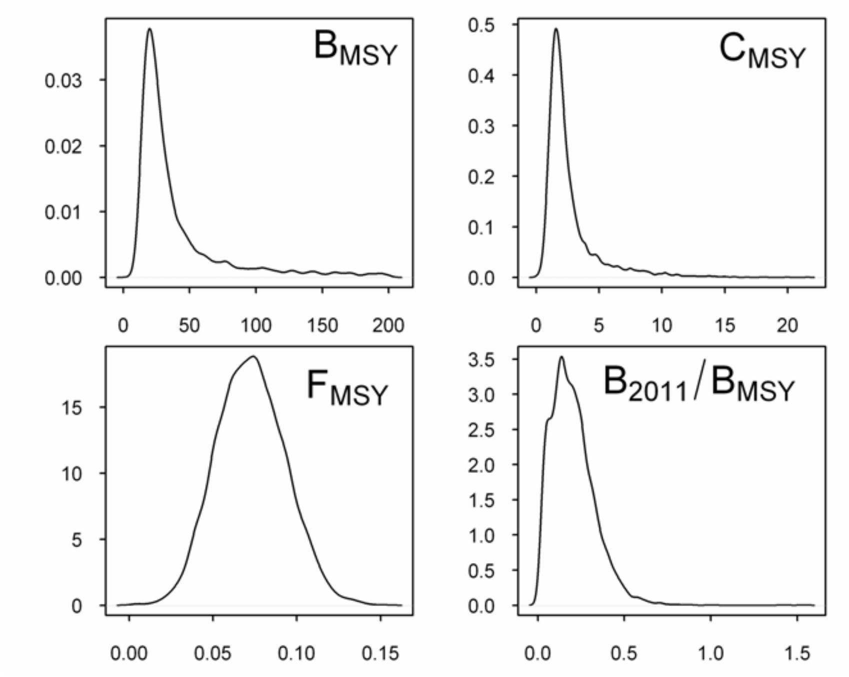

Figure 39. Posterior distribution for B_{MSY}, MSY (C_{MSY}), exploitation rate at MSY (F_{MSY}) and the ratio of 30+ biomass in 2011 to B_{MSY} for model 7.

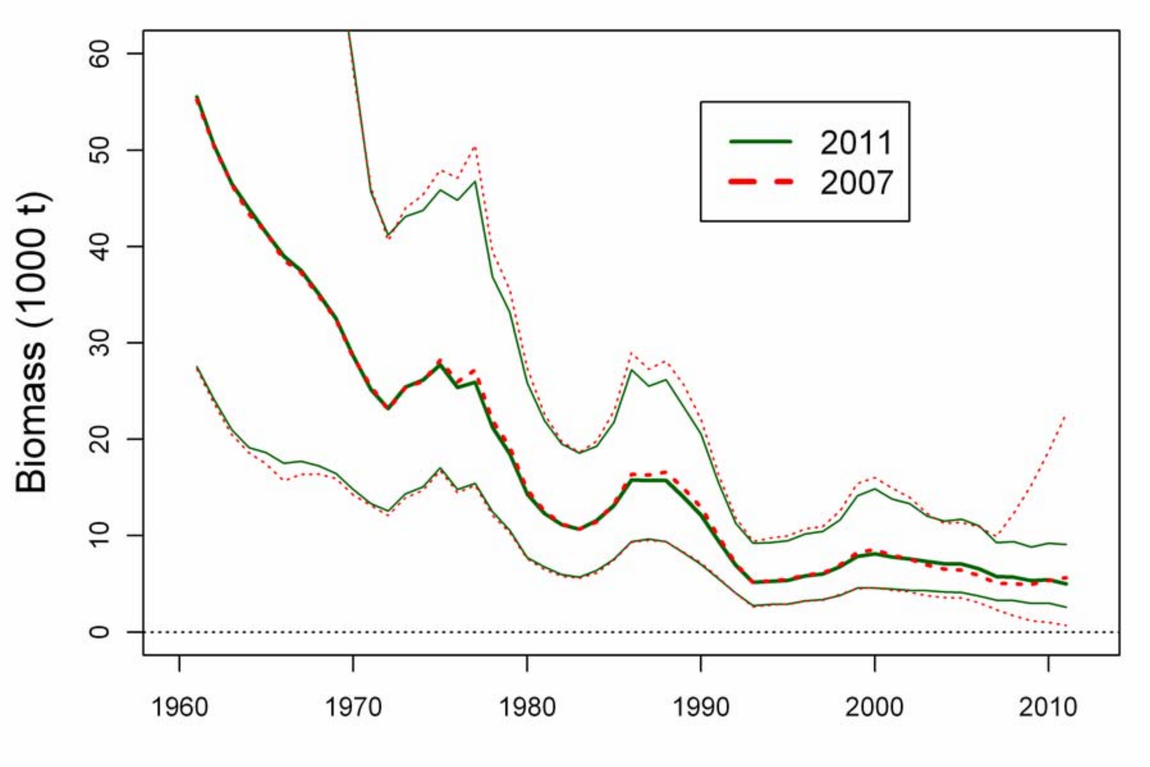

Figure 40. Estimated 30+ biomass fitting the model with all the biomass index data (solid green line) or omitting the last 4 years of index data (dashed red line). Heavy lines are the median estimate and light lines show the 2.5th and 97.5th percentiles.

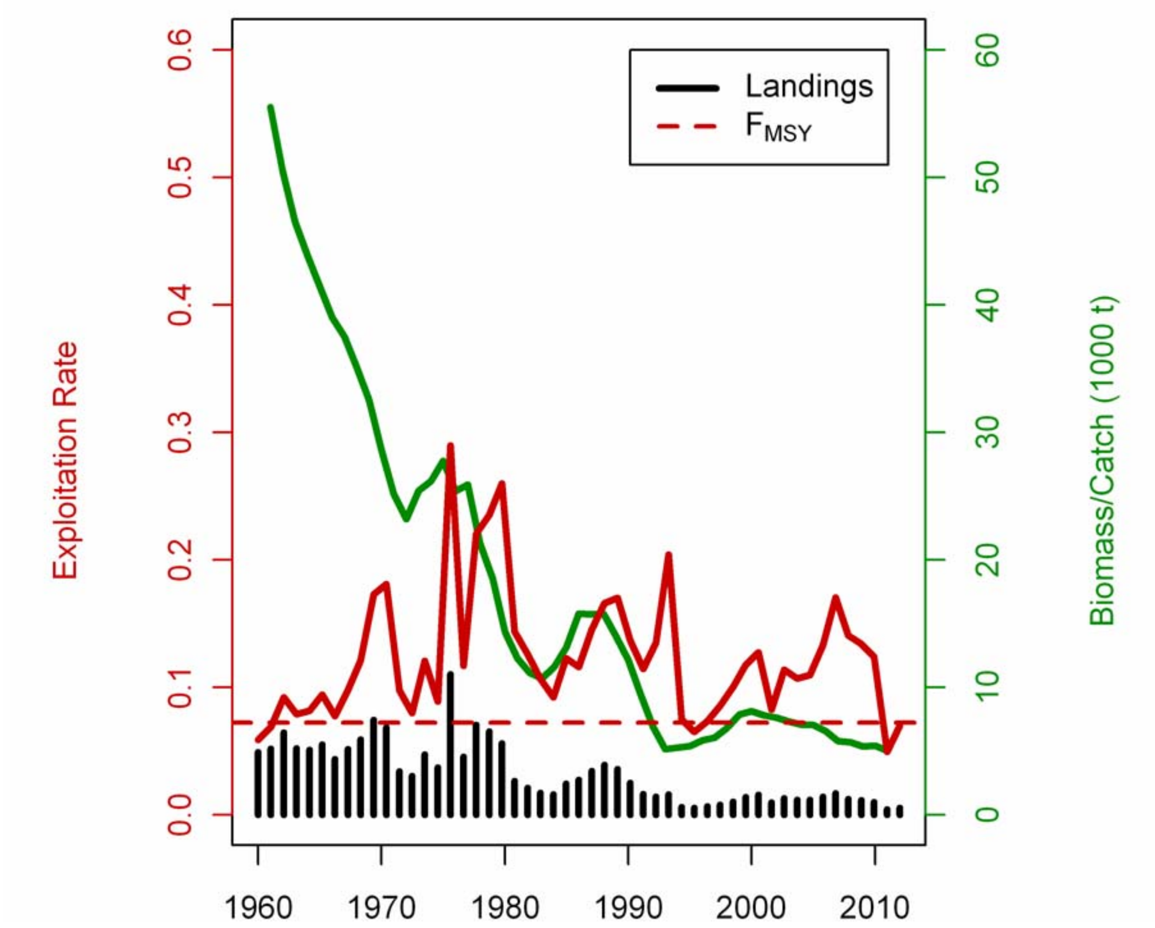

Figure 41. Comparison between landings (black bars) and the median estimates for 30+ biomass (green line) and exploitation rate (solid red line) from model 7.

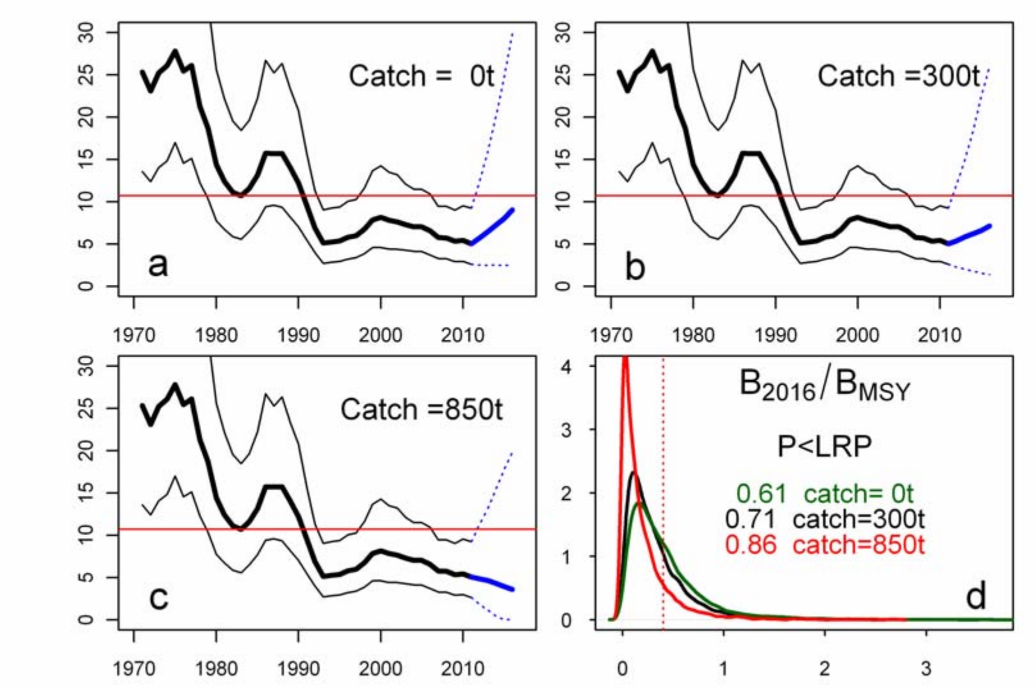

Figure 42. Projected 30+ cm biomass (kt) of 4RST witch flounder at various levels of catch in 2012-2016 (panels a-c) and estimated biomass in 2016 as a proportion of B_{MSY} (panel d). In panels a-c, heavy lines are posterior medians and light lines the 2.5th and 97.5th percentiles; blue lines are projected estimates. Red horizontal (a-c) or vertical (d) lines show the LRP.

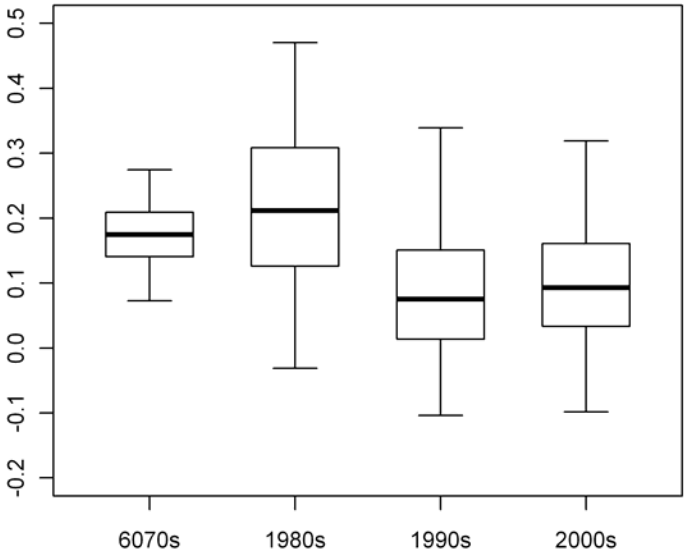

Figure 43. Posterior distributions for r in a model allowing decadal variation in r. Boxplots show the 2.5th, 25th, 50th, 75th, and 97.5th percentiles of the distributions.

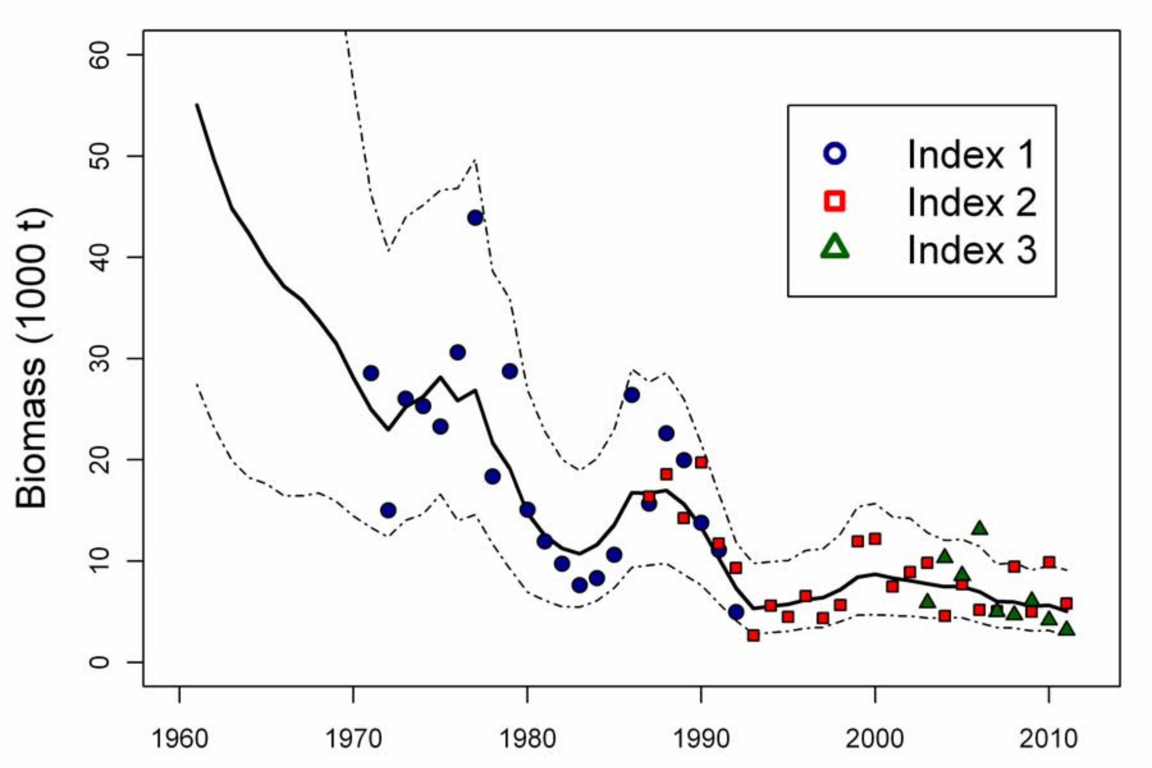

Figure 44. Fit of the variable-productivity model to the q-corrected biomass indices.

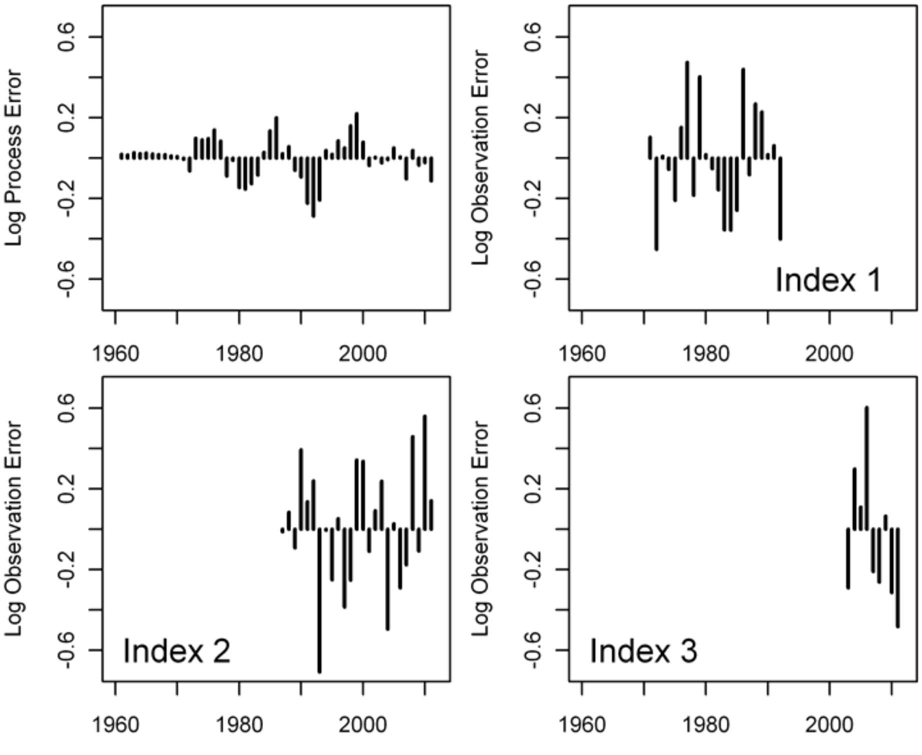

Figure 45. Process and observation errors for the variable-productivity model.

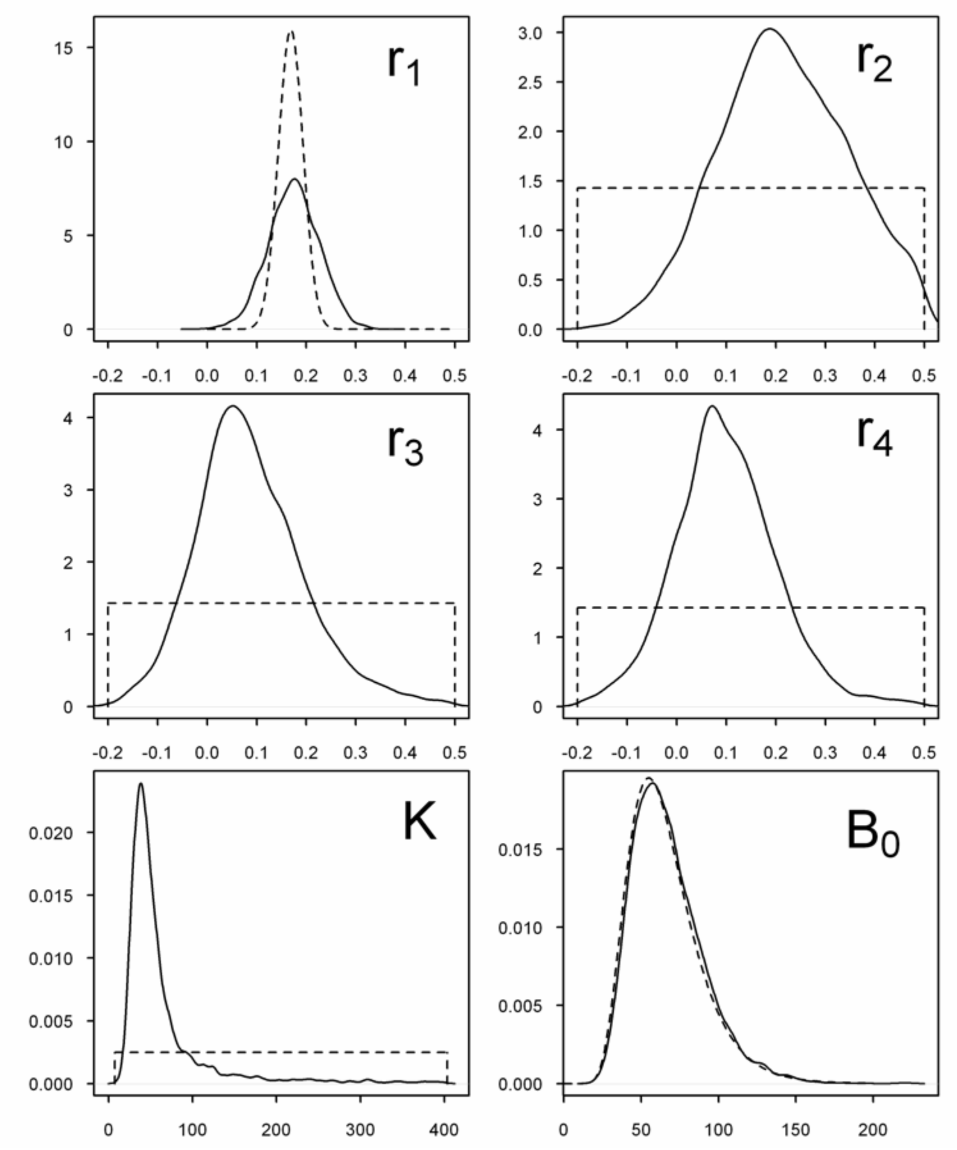

Figure 46. Prior (dashed line) and posterior (solid line) distributions of the intrinsic rate of increase r, carrying capacity K and starting biomass B_0 for a model allowing decadal variation in r. The r parameters apply during the following periods: r_1 – 1961-1979, r_2 – 1980-1989, r_3 – 1990-1999, r_4 – 2000-2011.

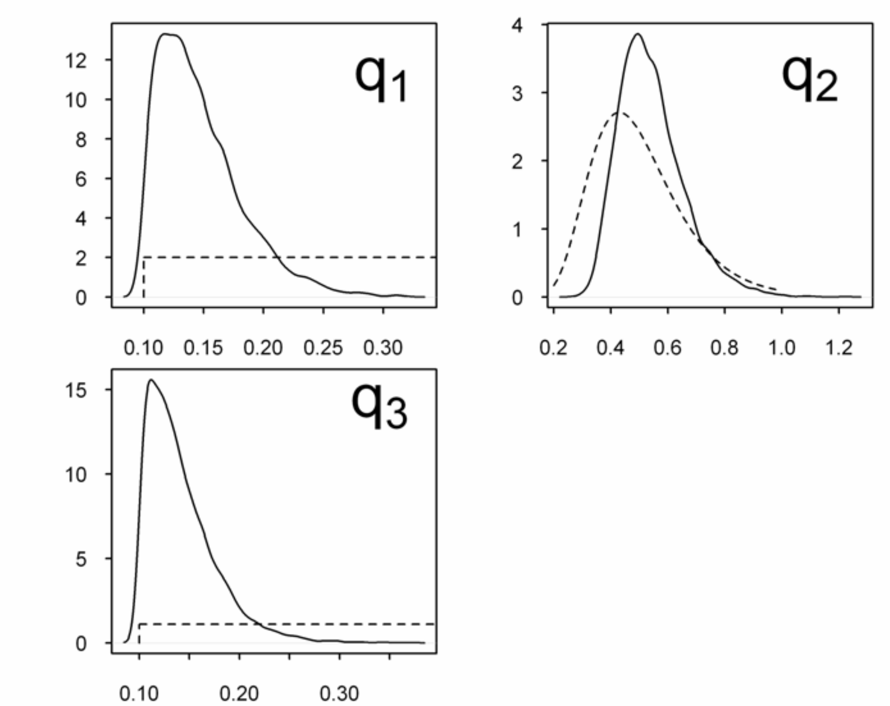

Figure 47. Prior (dashed line) and posterior (solid line) distributions of the catchability to indices 1, 2 and 3 for the model allowing decadal variation in r.

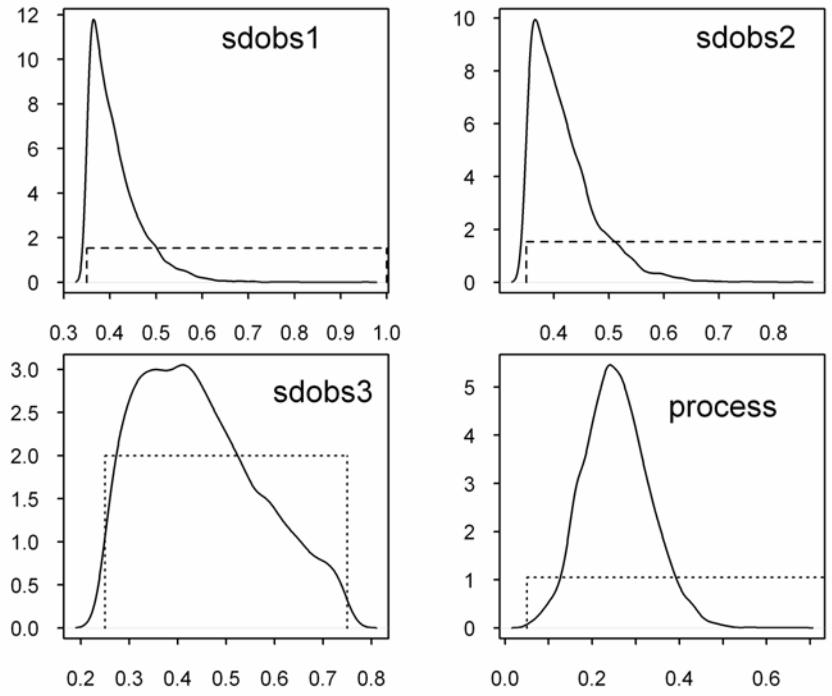

Figure 48. Prior (dashed line) and posterior (solid line) distributions of the standard deviations of observation and process error for the model allowing decadal variation in r.

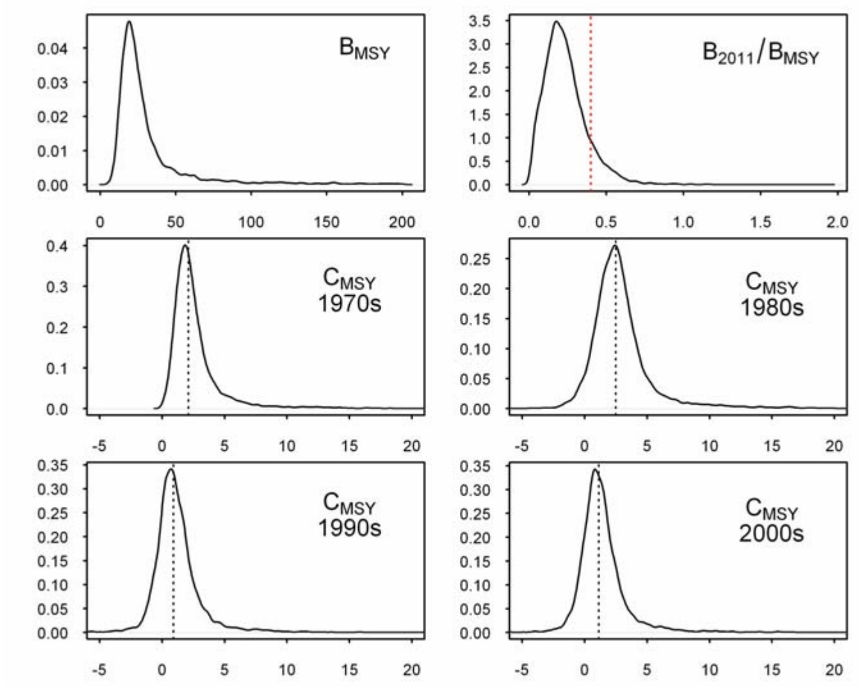

Figure 49. Posterior distributions for B_{MSY}, MSY (C_{MSY}) and the ratio of 30+ cm biomass in 2011 to B_{MSY} for the model allowing decadal variation in r. Dashed vertical lines show the median estimates for the LRP (red line) or C_{MSY} (black lines).

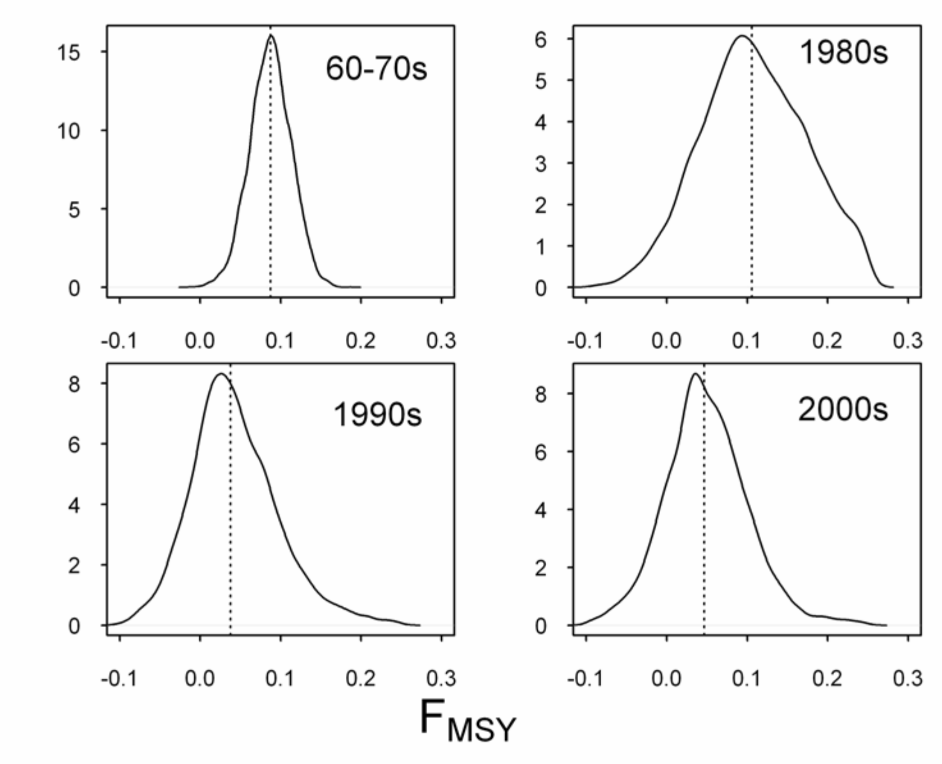

Figure 50. Posterior distributions for the exploitation rate at MSY for the model allowing decadal variation in r. Vertical lines denote the medians.

Appendix Table 1. Landed by-catch by species landed (t) in fishing activities directing for witch flounder in NAFO divisions 4RST. Landings <0.5 tonne are indicated by "0". Species acronyms are as follows: WIT = witch flounder, COD = Atlantic cod, HAD = haddock, RED = redfish, HAL = Atlantic halibut, PLA = American plaice, YEL = yellowtail flounder, WFL = winter flounder, GHL = Greenland halibut, SKA = skate (unspec.), POK = Pollock, HWK = white hake, CAT = catfish, ANG = monkfish, DGX = dogfish, SHX = shark (unspec.), and LUM = lumpfish, and SHR = shrimp.

YEAR	NAFO 4T																
	WIT	COD	HAD	RED	HAL	PLA	YEL	WFL	GHL	SKA	POK	HKW	CAT	ANG	DGX	SHX	LUM
1985	563	263	22	11	1	71	3	1	16		0	62	1	0			0
1986	736	200	65	29	1	78		1	56		0	79	0	2			
1987	1068	237	28	60	15	162	3	23	105		1	136	0	1			0
1988	971	315	13	49	8	158		1	72		2	140	0	1			
1989	637	178	6	20	4	72			24		2	153	1	3			
1990	239	84	1	12	0	39			8		0	40	0	1	0		
1991	196	63	1	4		54		1	5		0	44	0	0		0	
1992	306	83	0	8	0	61		0	8	0	0	53	0	0			
1993	341	46	0	2	0	79			9		0	26	1	0			
1994	268	17	0	1	1	102		2	20	6	0	8	0	1			
1995	199	17	0	1	1	73		1	19	1	0	1	0	0	0		
1996	358	19	0	0	5	191			23	2	0	2	0	0			
1997	360	51	0	0	11	148	0	1	22	0	0	5	0	0	1		
1998	431	67	0	1	6	188	0	2	40	5	0	15	0	0	0	0	
1999	241	84	0	3	4	67			69	3	0	16	0	0			0
2000	391	99		0	0	116			17	0		9	0	0			
2001	303	155	0	1	1	146	10		11	0		6	0	0		0	
2002	518	65	0	0	0	58	1	0	10			6	0	0			
2003	349	38	0	1	2	37			23	0		3	0	0			
2004	287	39	0	0	0	49		1	3	0		3	0	0			
2005	429	37	0	0	1	27			3			6		0			
2006	479	60	0	1	2	60			10	1		8		0			
2007	453	85	0	4	6	71		0	18	1	0	8		0			
2008	425	70	0	0	2	42			3			8		0			
2009	222	39	0	0	1	30			4	0		5		0			
2010	103	7		1	0	20	0	0	1			1		0			
2011	66	3	0	0	0	5			1			1		0			

Appendix Table 1 (continued).

YEAR	NAFO 4R													
	WIT	COD	HAD	RED	HAL	PLA	YEL	WFL	GHL	SKA	POK	HKW	CAT	ANG
1985	335	114	46	0		72	1					3	4	
1986	410	111	52	1	0	83	0	3				4	5	
1987	646	158	57	2		102	1		0			2	4	
1988	926	210	36	4	0	116	4	0			0	5	3	0
1989	734	237	39	6	0	129	4	1	0		0	3	9	
1990	339	89	8	2	0	91	5				0	1	4	0
1991	226	70	1	31	0	58	8	0	0		0	1	4	
1992	251	132	5	31	0	92	2		0		1	4	8	
1993	321	91	4	8	0	93	1	1	0			0	11	
1994	85	8	0	2		19	0		0	3		1	1	
1995	50	4	0	0		32			0	2		0	1	
1996	43	5		6		28		1	0	0			0	
1997	87	6		0	0	79			2			0	0	
1998	334	30		3		138			3	1		0	1	
1999	339	33		0	0	91			2	0		0	2	
2000	436	36	0		0	39	0		1	1		0	4	
2001	435	63	0	2	0	43			2	1	0	0	4	
2002	440	29		0	0	36			1	2		0	5	0
2003	273	25	2	1	0	32			2	0		2	1	0
2004	401	44	3	3	0	34	0		2		0	3		
2005	469	49	0	0	0	48			3	2		0		
2006	412	38	0	0	0	29			0			1		
2007	427	31	0	0	0	35			1	2		0		0
2008	301	25	0	2	0	34			2	1		2		
2009	244	23	0	0	0	29			1	1		0		
2010	118	12	0	1		21			1			0		
2011	196	6	0			6			1			0		

YEAR	NAFO 4S												
	WIT	COD	HAD	RED	HAL	PLA	GHL	SKA	POK	HKW	CAT	ANG	SHR
1985	16	23		2		5	1						
1986	13	14	2	3		4	2						
1987	8	11		4		4	4						
1988	19	32		6	0	10	3			0		0	
1989	1	7		0	0	6	2			0			
1990	10	24		2		10	3		0				17
1991	3	0		0						0			
1992	0												
1993	1			0			0						0
1994	1	0		0	0	4	2				0		
1995													
1996													
1997													
1998	2	0		0	1	0	13	1		0		0	
1999	0	0			1	0	14	0					
2000													
2001													
2002													
2003													
2004							0						
2005													
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2011													