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A Review of the Biology, Population Dynamics, and Exploitation Of Short-finned Squid in the Northwest Atlantic Ocean, In Relation to Assessment and Management of the Resource

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1.0 Introduction

The northern short-finned squid (*Illex illecebrosus*) can be considered to be a data poor species with respect to applying management initiatives such as the precautionary approach. Unique aspects of this species life cycle, distribution and abundance require careful consideration when attempting quantitative determination of biological reference points.

This species has a 1-year life cycle and is broadly distributed throughout the northwest Atlantic Ocean. It ranges on the continental shelf from central Florida to southern Labrador and is commercially fished between Cape Hatteras, North Carolina and Newfoundland (NAFO Subareas 2-6).Temporal and spatial distribution patterns are correlated with environmental factors and vary greatly, as do annual recruitment levels. Recruitment dynamics are complex and annual levels cannot be reliably predicted.

The short-finned squid resource in USA waters (Subareas 5+6) was considered to be fully-exploited and at a medium level of biomass in 1993 when it was last assessed (Hendrickson et al. 1996). This assessment involved applying a surplus production model to landings per unit effort (LPUE) indices for the U.S. domestic fishery. Landings and biomass indices from the more northerly areas (Subareas 2-4) were not included in the model, as catches from these regions comprised a minor proportion of the total landings during 1982-1993 (Hendrickson et al. 1996). The current total allowable catch (TAC) of 150,000 t for the Subarea 2-4 portion of the stock was established in 1980 and no new analyses have been done to review the TAC since then. Research on short-finned squid has been quite limited during the past decade.

In this paper we review fishery trends and management measures for short-finned squid throughout the Northwest Atlantic. We also review the biology and population dynamics of this species in relation to problems with assessment and management of the resource.

2.0 Distribution

2.1 Spatial and Temporal Distribution Patterns

Short-finned squid larvae have been collected during all seasons (Lu and Roper 1979), but predominantly during January-February (Dawe and Beck 1985a, Hatanaka et al. 1985, Rowell et al. 1985, Rowell and Trites 1985). Egg balloons and larvae are transported northeastward by the Gulf Stream and small juveniles, about 1-3 cm mantle length (ML), become entrained within the Gulf Stream Front (Fig. 1). Numerous surveys indicate a continuous distribution of juveniles along the axis of the Gulf Stream. Juveniles have been found south of Cape Hatteras, and northeastward beyond the tail of the Grand Bank in winter-spring (Fedulov and Froerman 1980, Dawe et al. 1982, Dawe and Beck 1985b, Hatanaka et al. 1985, Rowell and Trites 1985). Similarly, larvae have been found south of Cape Hatteras (Dawe and Beck 1985a, Rowell et al. 1985), and as far northeast as the Grand Bank (53°W) during January-March (Dawe and Beck 1985a, Hatanaka et al. 1985). However, hatchlings have only been collected south of Cape Hatteras (Dawe and Beck 1985a, Rowell et al. 1985), indicating that the larval source for all areas is probably south of Cape Hatteras.

Trites (1983) concluded based on Gulf Stream dynamics that larvae and small juveniles were neutrally buoyant and could be transported rapidly (100 km/day) northeastward toward the Grand Bank. Extensive southward spawning migrations are presumed to take place in autumn from all fishery areas. Tagging studies conducted in Subareas 3 and 4 have not confirmed the occurrence of this spawning migration due to low tag returns. However, a single squid tagged in Newfoundland during September was recovered off the coast of Maryland (Subarea 5+6) during December of that same year (Dawe et al. 1981).

The spatial distribution of pre-recruits (≤10 cm ML) on the USA continental shelf indicates considerable seasonal variation in the availability of this oceanic species to survey and commercial fishing gear (Fig. 2) (Hendrickson et al. 1996). During winter, low numbers of squid are captured and only in the seaward-most survey sampling strata because this survey coincides with the winter spawning peak outside the survey area. The spring distribution shows that juveniles carried northeastward by the Gulf Stream have begun to migrate onto the continental shelf to feed. By summer, they are broadly distributed across the continental shelf. During autumn surveys, densities are greatest in the two seaward-most strata, suggesting a net off-shelf migration. A similar seasonal distribution pattern is observed for recruits (≥11 cm ML). It is not known what fraction of the population resides in continental slope waters deeper than the survey strata (366 m), where adults have been found in other surveys (Rathjen , 1981) or in oceanic waters.

2.2 Environmental Influences

Short-finned squid distribution is directly related to water temperature. Squid on the Scotian Shelf (Subarea 4) have generally been associated with bottom water temperatures greater than 6°C (Rowell et al. 1985). Occurrence of squid inshore at Newfoundland (Subarea 3) coincides with the period when coastal temperatures remain greater than 5°C (Beck et al. 1994). This species also exhibits size-specific temperature and depth preferences (Brodziak and Hendrickson, in press) in Subareas 5+6. During autumn surveys, catch rates are greatest at bottom temperatures of 9-13°C and surface temperatures of 13-20°C. Survey catches of recruits (≥11 cm ML) tend to increase with surface temperature.

Annual trends in recruitment to the northern fishery areas (Subareas 3+4) are also related to environmental variation (Dawe et al., 1998). Trends in catch are significantly related to meteorological and oceanographic indices, including indices which reflect circulation of the Gulf Stream System.

3.0 The Fisheries

3.1 Temporal and spatial fishing patterns

The directed fisheries occur during summer through autumn. Fisheries are prosecuted at Newfoundland (Subarea 3) and, rarely, at Labrador (Subareas 2), on the Scotian Shelf (Subarea 4), and on the continental shelf of the United States, between the Gulf of Maine and Cape Hatteras, North Carolina (Subarea 5 and Statistical Area 6). Temporal and spatial fishing patterns are related to recruitment patterns. Consequently, the timing of peak landings differs slightly among Subareas, although some commercial fishing occurs during July-November in all Subareas. Migration onto the shelf generally begins earliest in Subareas 5+6, where fishing in some years has begun as early as May. Peak landings in the most southern area (SA 6) occur during either July or August (Hendrickson et al. 1996). At the northern extreme, squid are not available to the Newfoundland fishery until at least July and the peak varies between August and October, slightly later than in the Subarea 6 fishery (Mercer 1973, Beck et al. 1994). Historically, the Subarea 4 offshore fishery occurred during April-November, with peak catches occurring between late July and early September (Amaratunga 1981). However, the Subarea 4 inshore catches peaked later during September in 1977 (Amaratunga et al. 1978).

During 1977-1982, distant water fleets fished in SA 5+6 but were restricted to five squid management areas (SQU1-SQU5), which straddled the 100-meter isobath, and were subject to temporal restrictions (Fig. 3) (Tibbetts 1977) . During 1982-1993, a USA domestic fishery developed and expanded from the Mid-Atlantic region (SA 6B-C) to Southern New England (SA 5Zw and 6A) and Georges Bank (SA 5Ze) but the majority of the U.S. landings were still derived from Subarea 6 (Fig. 4), during June-September. 1998).

3.2 Trends in Catch

Most of the catch in Subarea 3 is derived from the Newfoundland inshore fishery, which relies upon jigging from small open boats near shore. Traps are also used in some local areas. Offshore trawl fisheries developed on the USA continental shelf (SA 5+6) in 1968 and on the Scotian Shelf since 1970.

Estimates of annual landings date back to 1911 for Subarea 3 and to 1920 for Subarea 4 (Mercer 1973, Dawe 1981). Before 1953 Canadian landings, mostly from Subarea 3 exceeded 2000 t in only 4 years with a maximum of 6,600 t in 1926. During 1953-67 Canadian landings ranged from 3,000 to 11,000 t, primarily from the Subarea 3 inshore fishery (Table 1, Fig. 5). During 1928-67, combined landings of short-finned squid and long-finned squid (*Loligo pealei*) in Subareas 5+6 ranged 500-2000t (Lange and Sissenwine 1980).

Total landings ranged 1,600-29,000 t during 1968-74 with most of the catch (75%) derived from SA 5+6. Total landings increased from 35,600 t in 1975 to 179,000 t in 1979 and then declined regularly to 31,500 t in 1982. These large catches during 1975-82 were due to high squid abundance and increased fishing effort in northern fishing areas. Most of the catch (76%) was from SA 3+4. The following 13-year period was one of poor recruitment to Canadian fishery areas. Total landings ranged from 2,700-24,300 t during 1983-95 with most of the catch taken in Subareas 5+6. Low catches in Canadian waters were due to low abundance of squid and concomitant reduction in effort expenditure. Subarea 4 catches have mostly been bycatch from the silver hake fishery since 1982. Total landings almost doubled since 1995, to 29,000 t in 1997, due to increased catches in SA 3+4, and particularly at Newfoundland (Table 1). Landings in 1997 from SA 3+4 (15,500 t) were the highest since 1981 and exceeded those from Subareas 5+6 (13,600 t).

4.0 Trends in Abundance and Biomass

Trends in relative abundance and biomass indices are presented in Tables 2-3 and Figure 5. Stratified mean weight and number per tow from Subarea 4 July bottom trawl surveys are assumed to reflect abundance and biomass levels at the start of the fishing season. Stratified mean number and weight per tow from SA 5+6 autumn research bottom trawl surveys, are assumed to reflect abundance and biomass levels at the end of the fishing season. All offshore strata sampled in the SA 5+6 surveys (Fig. 6) were used to derive the survey indices. Subarea 5+6 survey indices were standardized for gear and vessel changes. However, diel correction factors were not applied to these indices because Brodziak and Hendrickson (in press) determined that diel effects on autumn survey catches of recruits (11 cm ML and larger), comprise the major proportion of autumn survey catches were not significant.

A short time series of landings per unit effort data (LPUE), 1982-1993, exists for the U.S. domestic trawl fishery. Effort standardization was accomplished using a general linear model with the main factors of year, area, and vessel tonnage class (Hendrickson et al. 1996). No standardized catch per unit effort data are available for Subareas 3-4. Although annual catches are affected by variation in fishing effort, it is believed that catches have reflected annual recruitment since about 1970 in Subareas 3-4.

Correlations among subarea-specific annual catches and survey indices reflect similarity in recruitment trends among fishing areas (Table 4). Positive correlations between catches from all three subareas were significant ($p < 0.05$). Although interannual variability within each of the survey series was high (Fig. 5), they were positively correlated. The Subarea 4 survey wt/tow index was highly correlated with the Subarea 5+6 wt/tow index ($p = 0.0005$) and no./tow index ($p = 0.0057$). Most interesting, however, is that catches in both Canadian fishing areas were more strongly correlated with both SA 5+6 survey indices (p ranging 0.0001 to 0.0009) than they were with the SA 4 survey indices (p ranging 0.0008 to 0.14, Table 4).

5.0 Historical and Current Management Regimes

5.1 TAC Management

The northwest Atlantic stocks of *Loligo pealei* and *Illex illecebrosus* were initially managed through ICNAF. A pre-emptive quota for SA 5+6, initially established due to increases in catches by distant water fleets, was set at 71,000 t in 1974 (and again in 1975) for both species combined (Table 1). A Subarea 3-4 preemptive TAC was first established in 1975, at 25,000 t (ICNAF 1975). A separate SA 5+6 TAC, of 30,000 t, was established for short-finned squid in 1976 which was increased to 35,000 t in 1977 (Lange and Sissenwine 1980).

In 1977, both the USA and Canada extended their jurisdiction to assume responsibility for fishery resources within 200 miles of their coastlines. Since that time, the USA has managed its squid resources independent of ICNAF/NAFO and Canada. Canada has continued to manage its short-finned squid resource through NAFO.

Under the USA management system, an allowable biological catch (ABC) for short-finned squid is established annually by the Mid-Atlantic Fishery Management Council (MAFMC). During 1978-1995, the SA 5+6 ABC was 30,000 t. It was reduced from 21,000 t in 1996 to 19,000 t in 1997 and 1998, based on the most recent stock assessment (Hendrickson et al. 1996), which concluded that the MSY was approximately 24,000 t during 1982-93, rather than 30,000 t as had been previously estimated. Commercial catch is monitored via a mandatory dealer reporting system whereby weekly purchase quantities are reported to NMFS. Under this system, the directed fishery is closed when 95% of the ABC is landed. The ABC has never been exceeded. A moratorium on the number of vessels for which short-finned squid fishing permits could be obtained went into effect in June of 1997 (MAFMC 1997). Currently, there are approximately 50 vessels in the directed fishery and captains are required to submit logbook reports of their fishing activities.

The TAC for Canadian waters (Subareas 3+4) was 25,000 t during 1975-1977 (Table 1), but countries without specific allocations were additionally permitted to take 3,000 t each (ICNAF 1978). The TAC was increased from 25,000 t to 100,000 t during 1978 (ICNAF 1978). The 1978 TAC was estimated by applying a target exploitation rate of 0.40 to the 1977 biomass estimate (ICNAF 1978). The 1978 TAC was partitioned between Subarea 3 (45,000 t) and Subarea 4 (55,000 t). The Subarea 3+4 TAC was increased to 120,000 t in 1979; based on applying the same target exploitation rate to the estimated 1978 biomass. The 1979 TAC was exceeded by about 42,000 t and the TAC was subsequently increased in 1980 to 150,000 t (NAFO 1980). The 1980 TAC was based on application of the target exploitation rate (0.40) to the estimated 1978 biomass, the rationale being that 1978 represented an average year. This TAC level has been maintained ever since.

In recent years, the 150,000 t TAC has been partitioned among distant water fleets (with allocations by both NAFO and Canada), the Canadian offshore fleet (including an allocated by-catch for the Canadian SA 4 silver hake fishery of 4,000 t), and the Canadian inshore fleets in Subareas 3 and 4. Besides these allocations, a portion of the TAC is held in reserve for possible mid-season reallocation.

5.2 Mesh Size Restrictions

NAFO established a minimum codend mesh size of 130 mm in 1977 for all bottom trawls fishing inside of the slope area of the Scotian Shelf, as defined by a small-mesh gear line (ICNAF 1978). Outside of this small-mesh gear line, squid may be taken in a directed fishery or as a by-catch in the silver hake fishery which utilizes small-mesh bottom trawls with a minimum codend mesh size of 60 mm (NAFO 1984). In 1977, a minimum codend mesh size of 40 mm was established for distant water bottom trawlers fishing in Subareas 5+6, which was increased to 60 mm in 1978. A minimum codend mesh size of 45 mm was also established at that time for distant water midwater trawlers (ICNAF 1978).

5.3 Effort Restrictions

Effort regulations were first introduced in the Subarea 4 multi-national trawl fishery in 1978 in recognition that high TAC's could result in excessive exploitation in years of poor recruitment (ICNAF 1978). Fishing days in 1978 were allocated based on catch rates achieved in the previous year. Thus, if squid abundance was lower in 1978 than in 1977, the effort allocation would preclude the TAC from being taken and limit the risk of overexploitation. Annual effort levels in SA 3-4 have subsequently been allocated to the offshore multi-national fleets in this manner. It was found, however, that when squid recruitment declined to some marginal level (e.g. in 1982), multinational fleets did not fully utilize their allocated fishing days for squid and directed their fishing activity in toward other species (NAFO 1983). Since about 1982, there has not been an offshore directed squid fishery in SA 4; rather landings from this Subarea primarily represent bycatch from the silver hake fishery. However, near the end of the silver hake fishing season (e.g. August), squid may be targeted by this mixed-species fishery, if sufficiently abundant (M. Showell, pers. comm., DFO).

The Subarea 3 inshore squid fishery has been limited to licenced participants since 1990, with only full-time fishers being eligible to purchase licences. In 1997, for the first time, eligibility was further limited to those full-time fishers designated as 'core fishers'. This effort regulation limits the potential catch capacity of the inshore fleet (Fig. 7). This fishery has historically been considered to be 'self-regulating' (NAFO 1982) because effort decreases with squid availability.

5.4 Seasonality Restrictions

The fishing season for multinational fleets in Canadian waters was established to begin on June 15 in 1978 (ICNAF 1978), and to begin on July 1 in 1979 (ICNAF 1979). Currently, this fishing season extends from July 1-December 31, whereas the Canadian fishery (both inshore and offshore) extends from August 28-December 31. By-catch from the Scotian Shelf silver hake fishery is taken beginning June 1. There is currently no seasonal restriction on the US domestic squid fishery in SA 5+6.

6.0 Population Dynamics and Biological Characteristics

6.1 Size Composition

Comparisons of seasonal length frequency distributions from the commercial fisheries show differences in modal groups among Subareas. These modes may represent seasonal spawning peaks (Coelho et al. 1994), but this has yet to be confirmed through seasonal ageing studies. Ageing, based on statolith increment counts, must be used rather than size-frequency analysis to determine age structure, recruitment, and growth rates due to the effects of immigration and emigration and the possible differences in natural mortality and growth rates among seasonal groups (Caddy 1991). Length distributions are typically unimodal inshore at Newfoundland (Fig. 8), representing a single group produced by the predominate spawning peak during winter-spring (Dawe and Beck 1997). Further to the south, bimodal size frequency distributions are common. Length distributions are commonly bimodal on the Scotian Shelf (Fig. 9), with the secondary mode possibly representing progeny from summer spawning events. USA autumn survey size frequencies (Fig. 10) frequently show multiple modes, including a prominent mode of small squid which may also represent the progeny of summer spawning events in some years (Lange and Sissenwine 1983). Size distributions of squid from the SA 5+6 fishery show a broader range than those from the SA 3+4 fishery. However, these differences may partly be a result of differences in gear selectivity.

6.2 Age Composition, Growth and Recruitment

Ageing methods must be used to identify seasonal spawning groups by back-calculating a hatching date from the date of capture. This process is very labor-intensive and involves counting statolith increments. As a result, there are limited age data available; studies from the inshore Newfoundland jig fishery of 1990 (Dawe and Beck 1997) and 1994 (Gonzalez et al., in press). A comparative study of age and growth has been initiated based on samples collected in 1997 from the Newfoundland inshore fishery and from the U.S. autumn bottom trawl survey.

Growth studies using both statolith-based and gladius-based techniques indicate that growth in length is rapid and approximately linear (about 1 mm/day) for the later (exploited) portion of the life cycle (Dawe and Beck 1997, Perez et al. 1996). Growth in weight also appears to be rapid within the exploited population, with mean weight increasing by a factor of 4-5 from July to November (Dawe 1988). In Newfoundland, the artifact of asymptotic growth and late-season negative growth (Fig. 11) is due to continuous recruitment of young small squid and emigration of older, larger squid. Ageing results also indicate a continuous recruitment of squid spawned during December to June in this Subarea (Fig. 12) with annual variation in the timing of peak spawning (Dawe and Beck 1997, Gonzalez et al., in press). Furthermore, cannibalism is prominent during autumn. Since cannibalism is size-related, favouring survival of large animals, it may represent a bias in growth rate estimation. This may be particularly true for males which, as the smaller of the sexes, may be selectively removed by cannibalism. Declines in the proportion of males have been frequently observed in the Newfoundland area (O'Dor and Dawe, in press), but whether this is due to cannibalism or the earlier maturation and emigration of males than females is unknown. The possible effect of selectivity of jigs, used at Newfoundland, must also be considered in interpreting these trends in growth and sex composition from fishery data.

Although no age data are yet available for Subareas 4-6, it appears that population dynamics are similar to that described for inshore Subarea 3. In all areas, the continuous recruitment and emigration of squid spawned over a period of about 7 months is reflected by fishing seasons of about 5 months duration. Mid-season peaks in catch may reflect recruitment and emigration of progeny from the spawning peak. Furthermore, the artifact of asymptotic growth is evident in both southern continental shelf fishery areas (Amaratunga 1980, Lange and Sissenwine 1983), as is the prevalence and seasonal increase in cannibalism (Amaratunga 1983, Maurer and Bowman 1985). A seasonal decline in the percentage of males has also been described for Subarea 5+6 (Lange and Sissenwine 1983).

7.0 Species Interactions

Due to protracted spawning and rapid growth, short-finned squid function at several trophic levels during their 1-year life cycle. Its diet changes from reliance on crustaceans to fish prey to cannibalism as size increases. Caddy (1983) noted that squid may opportunistically replace fish in heavily-exploited ecosystems. On the continental shelf, in Subareas 4-6, short-finned squid interact closely with finfishes, particularly silver hake (*Merluccius bilinearis*). Correlation analysis suggests that annual abundance in these ecosystems may be related to competition with commercial finfishes, particularly silver hake (Dawe and Brodziak, *In press*).

Gut content analysis indicates that in Subarea 3 this squid switches sharply from a crustacean diet when occupying the edge of the Grand Bank, during spring, to a fish diet when they migrate inshore during summer. Capelin (*Mallotus villosus*) represents the most prevalent fish prey in July, followed by young-of-the-year Atlantic cod (*Gadus morhua*)in later months (Dawe et al. 1997). Sand lance (*Ammodytes* sp.) and Arctic cod (*Boreogadus saida*) are also important in northern inshore areas (Div. 3K). It appears that squid abundance at Newfoundland may be correlated with abundance of fish prey (Dawe and Brodziak, in press).

8.0 Stock Structure

The short-finned squid population is assumed to constitute a unit stock throughout its range from Newfoundland to central Florida. Although conclusive genetic stock identification studies have not been conducted, several factors lend support to the unit stock concept. The distribution and timing of the occurrence of larval and juvenile stages of this species in the waters between Newfoundland and south of Cape Hatteras suggest a spawning site south of Cape Hatteras, with a Gulf Stream dispersal mechanism which transports larvae and juveniles as far north as Newfoundland (Amaratunga et al. 1980, Fedulov and Froerman 1980, Dawe and Beck 1985a,b, Rowell and Trites 1985, Hatanaka et al. 1985). In all Subareas, the first occurrence of short-finned squid on the Continental Shelf is along the shelf edge during spring (Lange and Sissenwine 1983; Dawe and Warren 1993). This distribution pattern suggests a single stock which recruits to all fishery areas simultaneously from offshore.

Recruitment appears to be synchronous between Cape Hatteras and the Gulf of Maine, since region-specific fluctuations in relative abundance during the 1967-1994 USA autumn surveys (Fig. 13) were significantly positively correlated at the $\alpha = 0.01$ level (Hendrickson et al. 1996). Throughout the species range, catches and biomass indices are also significantly positively correlated (Fig. 5, Table 5). This synchrony in recruitment throughout the species range appears to be regulated by oceanographic processes which affect the entire Northwest Atlantic (Dawe et al., this meeting). Such broad-scale environmental effects on recruitment further support the existence of a single stock.

9.0 Concerns Regarding Assessment and Management

9.1 Availability and Reliability of Data

Data available for assessment purposes are limited. Annual landings are available for all fishery areas (1963-1997) and relative abundance and biomass indices are available from bottom trawl surveys conducted in Subareas 5+6, (September-November, 1967-1997), and Subarea 4 (July, 1970-1997). A short series of standardized LPUE indices (1982-1993) also exists for the domestic bottom trawl fishery in SA 5+6.

9.2 Total Landings and Discards

There are uncertainties regarding the accuracy of some of the landings data for this stock. Before 1976, not all squid landings were reported by species in the distant water fleet fisheries in SA 5+6 and squid was not reported by species until 1979 in the USA domestic fishery. Landings from SA 5+6 during 1963-78 were prorated by Lange and Sissenwine (1980) based on the temporal and spatial landings patterns of the two squid species, by country, from observer catch data.

Although there are no significant discards of short-finned squid in the Newfoundland jig fishery, discarding by trawlers has not been quantified. A cursory examination of the proportion, by weight, of short-finned squid bycatch in the directed fisheries for both short-finned squid and long-finned squid (*Loligo pealei*) in the U.S. EEZ suggests that bycatch from these sources is not significant.

9.3 Estimation of Population Size

Historically, biomass estimates have been generated separately for each Subarea, based on several different approaches. Minimum biomass estimates have been derived for SA 5+6 based on the application of area-swept methods incorporating autumn bottom trawl survey data beginning in 1968 (Lange and Sissenwine 1980) and for Subarea 4 using Scotian Shelf survey data beginning in 1970 (Konstantinov and Noskov 1977, Lange and Sissenwine 1983, Koeller 1980). While standardized bottom trawl surveys provide useful indices of relative biomass, they do not reliably estimate absolute biomass. This is primarily due to spatial and temporal sampling limitations as well as unknown catchabilities of the survey bottom trawls for this pelagic species.

Areal expansion methods applied to commercial fishery data have also been used to derive biomass estimates. For example, data from Soviet and Polish directed fisheries provided estimates for June-August 1977 on the Scotian Shelf (Div. 4W) of 60,000 t and 205,000 t, respectively. Another 1977 estimate, from the Cuban fishery directed for silver hake was 133,000 t (ICNAF 1977). Such variability in estimates reflect limitations already noted regarding the areal expansion of bottom trawl survey data, as well as variable catchabilities of survey trawls. Whereas research surveys tend to be limited in seasonal coverage, fishery data tend to be limited in areal coverage, since effort is focused on localized concentrations of the target species (Sissenwine 1976).

A Leslie-Delury depletion model and a modified (length-based) cohort analysis were used to estimate the 1977 biomass in Subarea 4. However, the resulting estimates of biomass and exploitation rate were considered unreliable (ICNAF 1978). The pitfalls of length-based characterizations of this stock have already been discussed. Furthermore, both models relied on the assumption of a closed population and the depletion model further assumed that the decline in catch rates was entirely due to fishery removals (i.e. $M = 0$).

All the above methods were utilized to estimate the 1979 biomass in Subareas 3 and 4. Although none of these estimates were considered to be reliable, it was concluded that the overall biomass in Subareas 3+4, during August 1979, was probably in the range of 500,000 to 3,000,000 t. Such biomass estimates did not take into account inshore-offshore migrations which occur in Newfoundland (SA 3) waters during the fishing season (Dawe and Beck 1997). Furthermore, an unknown portion of the population may exist outside fishery areas in some years, as suggested by the prominence of short-finned squid on the Flemish Cap in both 1990 and 1991 (Vazquez 1991, 1992), two years of low resource abundance in northern fishery areas.

Hendrickson et al. (1996) fit a non-equilibrium surplus production model (Walters and Hilborn 1976) to standardized CPUE data for the US domestic fishery to derive biomass estimates for SA 5+6 during 1982-1993. The model results suggested a decline in biomass during 1989-1993, concurrent with an increase in fishing mortality rate during this period (Fig. 14). However, there was considerable uncertainty in the biomass estimates. The resource status was classified as fully-utilized and at a medium level of biomass (NEFSC 1996).

9.4 Natural Mortality

The first estimates of natural mortality, based simply on mean life span, were M = 1.0-1.5 (Au 1975). However, these estimates did not recognize the effects of cannibalism. In a yield-per-recruit simulation, Mohn (1982) partitioned natural mortality among three components:

$$M = Mc + Mm + Mn$$

where:
Mc = mortality due to cannibalism
Mm = mortality due to migration, and
Mn = natural mortality due to sources other than cannibalism.

He estimated that mortality due to cannibalism may be as high as 0.6 per 2-week period, but this may be an over-estimate if victims are shared by several cannibals. He used values of Mn (mortality due to predation, starvation, disease, etc.) of 0.06 (Hurley and Beck 1979). He approximated loss due to emigration as half of an approximated, late-season maximum of 0.2 per 2-week period. Thus, M by this estimation method is equal to 0.76 per 2-week period.

Hendrickson et al. (1996) derived a monthly estimate of natural mortality equal to 0.30 based on an average of three estimates. A maximum life span of 250 days, based on squid aged from Newfoundland (Dawe and Beck 1997), was applied to Hoenig's (1983) predictive equation for mollusks, which resulted in a monthly value of M = 0.49. A monthly value of M = 0.22 was calculated based on animal size and bioenergetic constraints (Peterson and Wroblewski 1984) and a third M value used to compute an average M was by analogy to *Illex argentinus*, where a monthly value of M = 0.26 was estimated (Rosenberg et al. 1990). These monthly values are generally in agreement with an overall M = 2.8-3.4 for a 7-10 month pre-spawning adult phase of the life cycle, assuming an equilibrium population (Caddy 1996).

9.5 Biological Reference Points

A target exploitation rate of 0.40 was recommended in 1976 (ICNAF 1976) based on simulation of the effects of fishing on the squid resource in SA 5+6 (Sissenwine and Tibbetts 1977). However, these calculations relied upon best estimates of population parameters and assumptions about population dynamics, many of which were poorly estimated or have since proven invalid. These assumptions included that recruitment followed a 'knife-edge' pattern with the population subsequently closed to migration effects. It was also assumed that growth in length was accurately modelled by the asymptotic von Bertalanffy model and that natural mortality was rather low (M = 0.1). It was further assumed that the stock recruitment relationship was of the Beverton and Holt form, with recruitment moderately dependent on spawning stock size. However, a moderately strong stock-recruitment relationship is not likely since recruitment is strongly influenced by the environment.

For the USA fishery in SA 5+6, target and threshold overfishing definitions of $F_{50\%}$ (=0.11 per month) and $F_{20\%}$ (=0.28 per month), respectively, were adopted in 1997 (NEFSC 1996, Hendrickson et al. 1996). The $F_{50\%}$ target was selected by analogy to the target of 40% proportional escapement for the *Illex argentinus* stock on the Patagonian Shelf, which was, however, based on the target μ = 0.40 initially recommended by ICNAF (Beddington et al. 1990).

10.0 Consideration of Harvest Control Options

The application of a constant TAC to an annual species is risky, given the potential for recruitment overfishing during years of poor recruitment. The stock-recruitment relationship for short-finned squid is not yet fully understood and there is no reliable index of recruitment for the entire stock. Indices derived from bottom trawl research surveys for Subareas 4-6 are highly variable and do not cover the entire range of the stock. Therefore, it is not currently possible to accurately predict annual recruitment before the fishing season.

The main problems in determining an annual TAC for this species are that biomass levels are unknown as is an appropriate target exploitation rate, which would ensure adequate spawner escapement. TAC regulation may result in recruitment overfishing in years of low abundance and loss of potential yield in years of high abundance. However, with effective effort control, the catch may vary with abundance while the exploitation rate remains constant (ICNAF 1978). Fishing effort regulation has been recommended as a means of managing squid resources and has been applied through real-time management (Caddy 1983, Rosenberg et al. 1990).

The practicality of applying real-time management, based on in-season effort regulation, to the Subarea 5 and 6 fishery has recently been explored (Table 5) (Hendrickson et al. 1996). This approach was based on current management of the *Illex argentinus* fishery on the Patagonian Shelf (Rosenberg et al. 1990, Beddington et al. 1990, Basson et al. 1996), where intensive data collection, including daily radio reports of catch and effort by each vessel and supplemental biological data are collected at sea by observers. Essentially, seasonal trends in commercial CPUE are modeled using a Leslie-Delury depletion model, such that fishery closure may be implemented when CPUE falls to some target reference level. This model requires an estimate of population size before and during the fishing season, in order to make in-season adjustments to the effort level so as to maximize catch when recruitment is good and to minimize recruitment overfishing when recruitment is poor. This real-time assessment approach is ideal for managing annual squid species which are vulnerable to recruitment overfishing.

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Table 1. Annual catches (t) and TAC's by fishery area

	Catch					TAC	
Year	SA 2+3	SA 4	2-4 Total	SA 5+6	Total	SA 2-4	SA 5+6
53	4460	51	4511		4511		
54	6700	115	6815		6815		
55	7019	269	7288		7288		
56	7779	450	8229		8229		
57	2634	335	2969		2969		
58	718	84	802		802		
59	2853	258	3111		3111		
60	5067	24	5091		5091		
61	8971	50	9021		9021		
62	482	587	1069		1069		
63	2119	103	2222	810	3032		
64	10408	369	10777	360	11137		
65	7831	433	8264	522	8786		
66	5017	201	5218	570	5788		
67	6907	126	7033	995	8028		
68	9	47	56	3271	3327		
69	21	65	86	1537	1623		
70	111	1274	1385	2826	4211		
71	1607	7299	8906	6614	15520		
72	26	1842	1868	17641	19509		
73	622	9255	9877	19155	29032		
74	48	389	437	20628	21065		71000
75	3751	13945	17696	17926	35622	25000	71000
76	11257	30510	41767	24936	66703	25000	30000
77	32754	50726	83480	24795	108275	25000	35000
78	41376	52688	94064	17592	111656	100000	30000
79	88833	73259	162092	17241	179333	120000	30000
80	34780	34826	69606	17828	87434	150000	30000
81	18061	14801	32862	15571	48433	150000	30000
82	11164	1744	12908	18633	31541	150000	30000
83	5	421	426	11584	12010	150000	30000
84	397	318	715	9919	10634	150000	30000
85	404	269	673	6115	6788	150000	30000
86	1	110	111	7470	7581	150000	30000
87	194	372	566	10102	10668	150000	30000
88	272	528	800	1958	2758	150000	30000
89	3101	3899	7000	6801	13801	150000	30000
90	4440	6560	11000	11670	22670	150000	30000
91	1719	2277	3996	11908	15904	150000	30000
92	924	1076	2000	17827	19827	150000	30000
93	276	2398	2674	18012	20686	150000	30000
94	1954	4016	5970	18350	24320	150000	30000
95	48	984	1032	14058	15090	150000	30000
96	8285	445	8730	16969	25699	150000	21000
97	12616	2869	15485	13629	29114	150000	19000

TACs during 1974 and 1975 for SA 5+6 included *Loligo pealei* and *Illex illecebrosus*
In addition to SA 3+4 TACs in 1975-1977, countries without allocations were permitted 3,000 t each.

Table 2. Abundance indices from survey and fishery data

	USA Fall Survey		SA 4 July Survey		USA LPUE
Year	no/tow	kg/tow	no./tow	kg/tow	kg/tow
1967	1.57	0.242			
1968	1.64	0.307			
1969	0.59	0.073			
1970	2.26	0.268	5.6	0.4	
1971	1.68	0.337	28.5	2.8	
1972	2.19	0.292	6.6	0.7	
1973	1.47	0.353	10.9	1.5	
1974	2.82	0.392	13.4	1.8	
1975	8.74	1.417	44.8	5	
1976	20.55	7.018	231.2	42.7	
1977	12.62	3.740	50.9	9.5	
1978	19.25	4.529	16.4	2.3	
1979	19.42	6.053	91.4	14.2	
1980	13.81	3.285	23.3	2.2	
1981	27.10	9.340	35.5	4.9	
1982	3.94	0.602	26	2.1	38.5
1983	1.73	0.233	76.9	2.1	23.6
1984	4.54	0.519	14.1	1.5	56.4
1985	2.38	0.355	80.2	2.7	24.8
1986	2.10	0.257	7.7	0.4	45.2
1987	15.83	1.527	4.9	0.4	67.0
1988	23.22	2.997	47.3	2.7	67.8
1989	22.43	3.307	26.3	2.7	65.8
1990	16.61	2.401	40.6	4.8	31.2
1991	5.21	0.691	27.1	1.8	54.7
1992	8.24	0.804	121.7	7.3	46.2
1993	10.42	1.595	79	5.4	46.2
1994	6.83	0.860	45.3	4.2	
1995	8.01	0.700	33.9	2.4	
1996	10.76	0.926	11.9	0.9	
1997	5.83	0.521	52	4.8	
Average					
1967-1981	9.05	2.510			
1982-1997	9.26	1.143			

Table 3. Standardized, stratified mean catch per tow, in numbers and weight (kg), of Illex illecebrosus caught during autumn research bottom trawl surveys (offshore strata 1-40 and 61-76; Cape Hatteras to the Gulf of Maine) during 1967-1997.

Year	All sizes no/tow	CV (%)	All sizes kg/tow	CV (%)	Individual Mean Wt (g)	Prerecruit no./tow	Recruits no./tow
1967	1.57	17	0.242	17	147	0.04	1.53
1968	1.64	21	0.307	17	186	0.10	1.54
1969	0.59	23	0.073	26	121	0.09	0.51
1970	2.26	21	0.268	15	110	0.85	1.41
1971	1.68	12	0.337	14	206	0.20	1.48
1972	2.19	25	0.292	15	123	0.48	1.72
1973	1.47	24	0.353	25	242	0.04	1.43
1974	2.82	40	0.392	30	145	1.20	1.63
1975	8.74	36	1.417	18	143	3.98	4.76
1976	20.55	16	7.018	19	317	0.42	20.13
1977	12.62	18	3.740	18	299	0.72	11.90
1978	19.25	21	4.529	26	219	3.29	15.96
1979	19.42	11	6.053	11	305	1.31	18.11
1980	13.81	15	3.285	18	238	0.43	13.38
1981	27.10	32	9.340	40	327	0.22	26.88
1982	3.94	15	0.602	13	155	0.71	3.23
1983	1.73	14	0.233	13	134	0.16	1.57
1984	4.54	17	0.519	19	113	0.32	4.22
1985	2.38	17	0.355	18	147	0.19	2.19
1986	2.10	15	0.257	17	119	0.26	1.84
1987	15.83	31	1.527	29	92	0.84	14.99
1988	23.22	25	2.997	24	121	0.41	22.81
1989	22.43	45	3.307	57	118	1.05	21.38
1990	16.61	12	2.401	13	141	0.61	16.00
1991	5.21	17	0.691	18	129	0.22	4.99
1992	8.24	15	0.804	16	98	1.79	6.45
1993	10.42	19	1.595	20	159	0.15	10.27
1994	6.83	24	0.860	25	128	0.22	6.61
1995	8.01	30	0.700	39	84	0.82	7.19
1996	10.76	22	0.926	19	87	0.60	10.16
1997	5.83	24	0.521	17	89	0.74	5.09
Average							
1967-1981	9.05	22	2.510	21	209	0.89	8.16
1982-1997	9.26	21	1.143	22	120	0.57	8.69

Table 4. Correlations among indices of squid abundance. Each cell includes Spearman's correlation coefficient, probability value, and number of years. P values in bold are significant at the 0.05 probability level.

Index	SA 4 Catch	SA 5+6 Catch	SA 4 July survey no./tow	SA 4 July survey kg/tow	SA 5+6 fall survey no./tow	SA 5+6 fall survey kg./tow	SA 5+6 LPUE
SA 3 catch	0.3703	0.3885	0.3235	0.5632	0.5803	0.7002	-0.0945
	0.0133	**0.0211**	0.0931	**0.0018**	**0.0006**	**0.0001**	0.7700
	44	35	28	28	31	31	12
SA 4 catch		0.6661	0.2840	0.5992	0.5649	0.7076	0.0735
		0.0001	0.1429	**0.0008**	**0.0009**	**0.0001**	0.8203
		35	28	28	31	31	12
SA 5+6			0.1696	0.3391	0.2899	0.4568	-0.2977
			0.3880	0.0768	0.1136	0.0098	0.3473
			28	28	31	31	12
SA 4 July survey no./tow				0.8777	0.3098	0.3618	-0.3782
				0.0001	0.1086	0.0585	0.2253
				28	28	28	12
SA 4 July survey kg/tow					0.5087	0.6143	-0.1770
					0.0057	**0.0005**	0.5821
					28	28	12
SA 5+6 fall survey no./tow						0.9524	0.6970
						0.0001	**0.0118**
						31	12
SA 5+6 fall survey kg./tow							0.6164
							0.0328
							12

Table 5. The basis of real-time managmeent of *Illex illecebrosus*.

COMPONENT	APPROACH	EVALUATION
Set Target	Biological reference point	Rigorous justification may be difficult
	Avoid in-season closure	May be favored by industry if interannual variability is reduced
Set Threshold (to avoid)	Spring survey index	Not useful
	Leslie-Delury models	LPUE patterns useful for 7 of 12 years. Finer temporal scale (weeks) might clarify problems. Agreement with current surplus production model (same magnitude)
	Fall survey index	Promising, but need improved analytical model.(constraints)
	Indirect approach	Markov-type approach for estimating probability of meeting recruitment targets. Needs simulation study.
In-season Adjustments: Decision to Act	Delury estimator	** Limited data at present. Should improve with weekly LPUE data collection.
	Monthly LPUE vs later survey	Prediction of autumn survey index from June LPUE may work for Class 4 vessels.
In-season Adjustment: How to do it	Reduce TAC	
	Reduce effort	Used in Falkland Islands but controversial
Post Season Assessment	Surveys	Autumn survey may be useful

** Requirements for catch and effort data collection:
- By individual vessel
- Daily (though weekly or 10-day period may be adequate)
- By fishing area (e.g. 3-digit statistical area)
- Total removals (catch + discards)
- One or more measures of effort (e.g. hours jigged, days fished).

Requirements for weekly biological data collection, by at-sea observers, on selected vessels:
- Length frequency of the catch (usually by sex)
- Weight-length sub-samples (usually by sex) [Essential]
- Sexual maturity
- Sex ratio

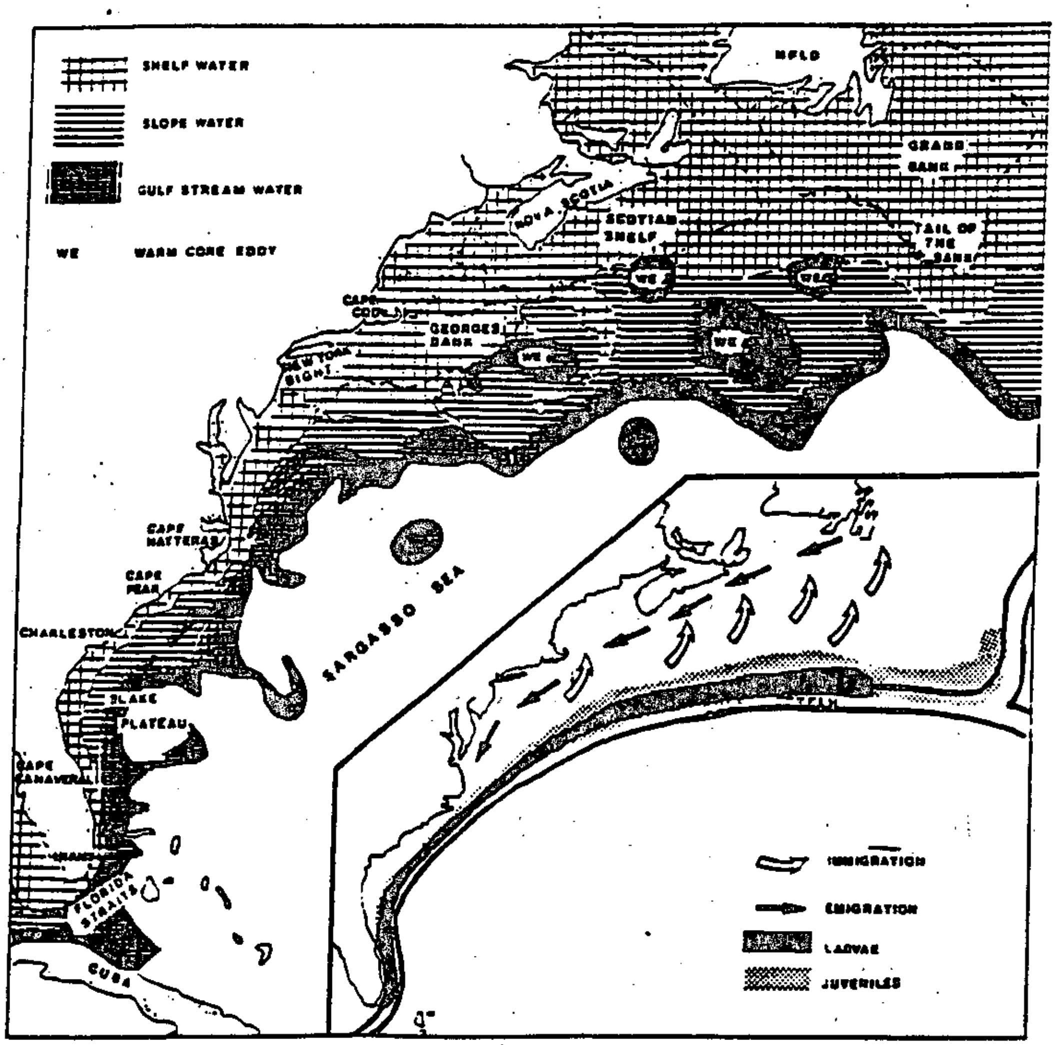

Fig. 1. Schematic representation of the early life history of short-finned squid in relation to dynamics of the Gulf Stream System (from Rowell and Trites 1985).

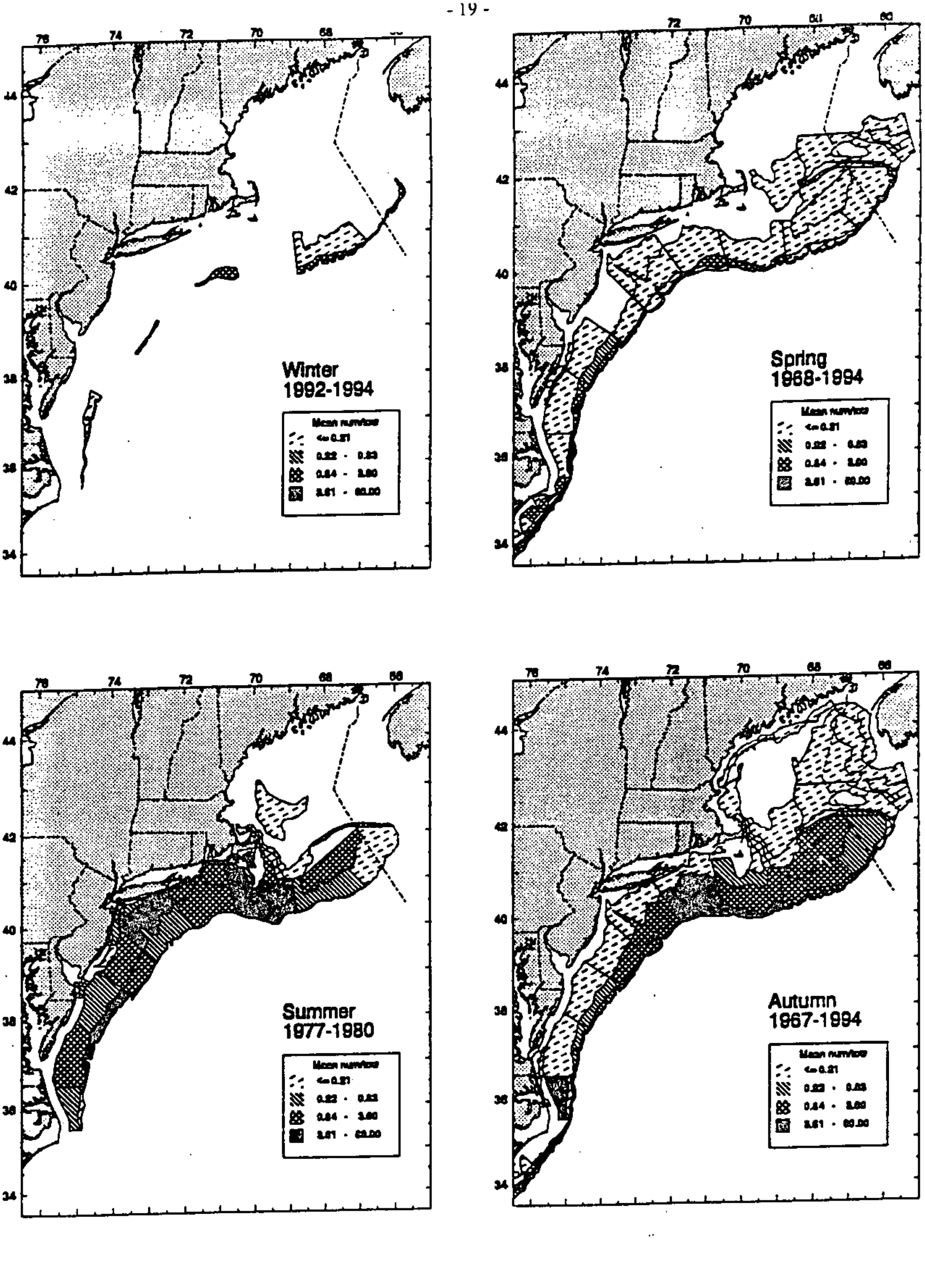

Fig. 2. Mean number per tow of *Illex illecebrosus* pre-recruits (≤10 cm), by survey stratum, during NEFSC research vessel bottom trawl surveys.

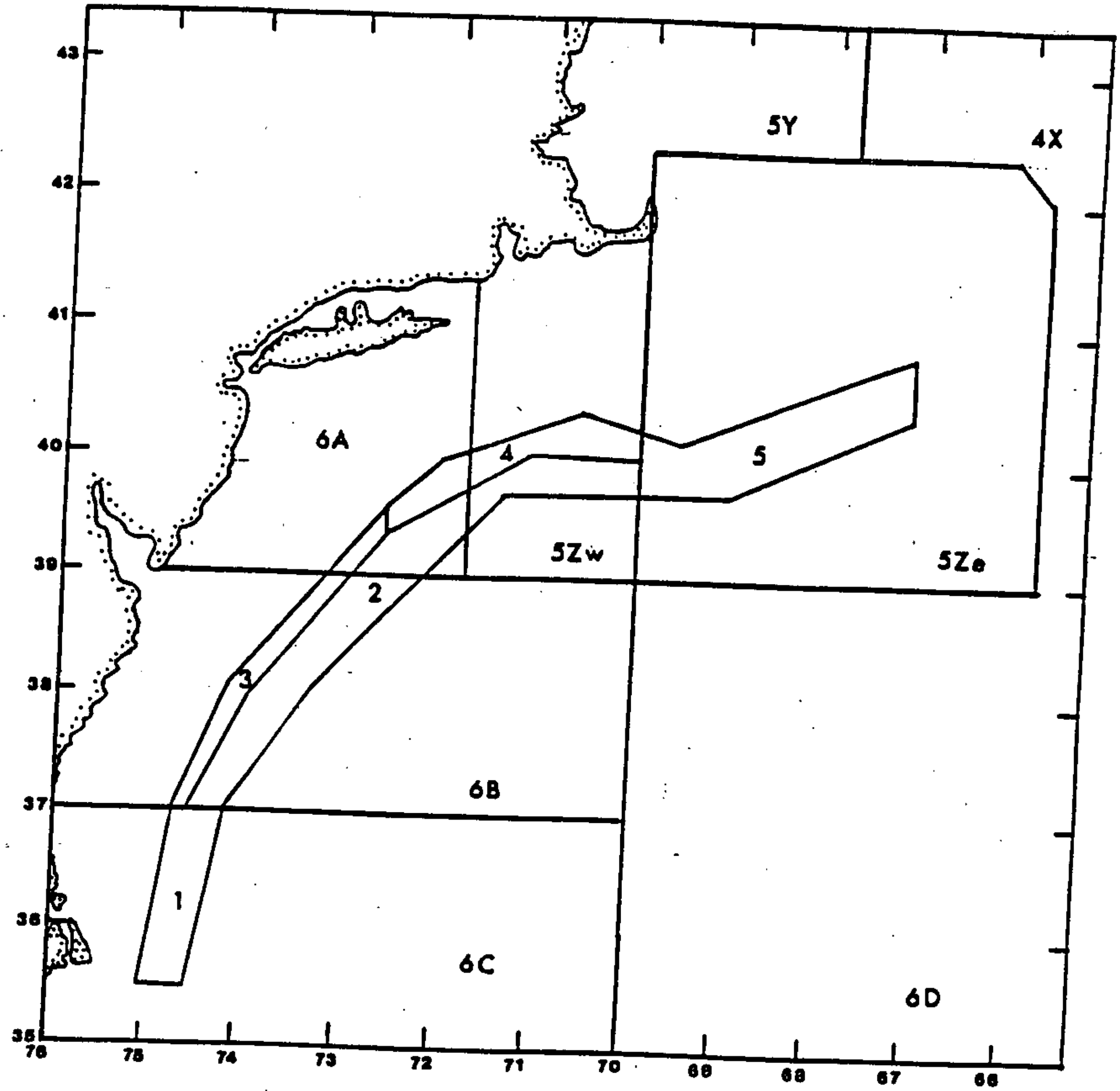

Fig. 3. Squid windows in the US Fishery Conservation Zone.

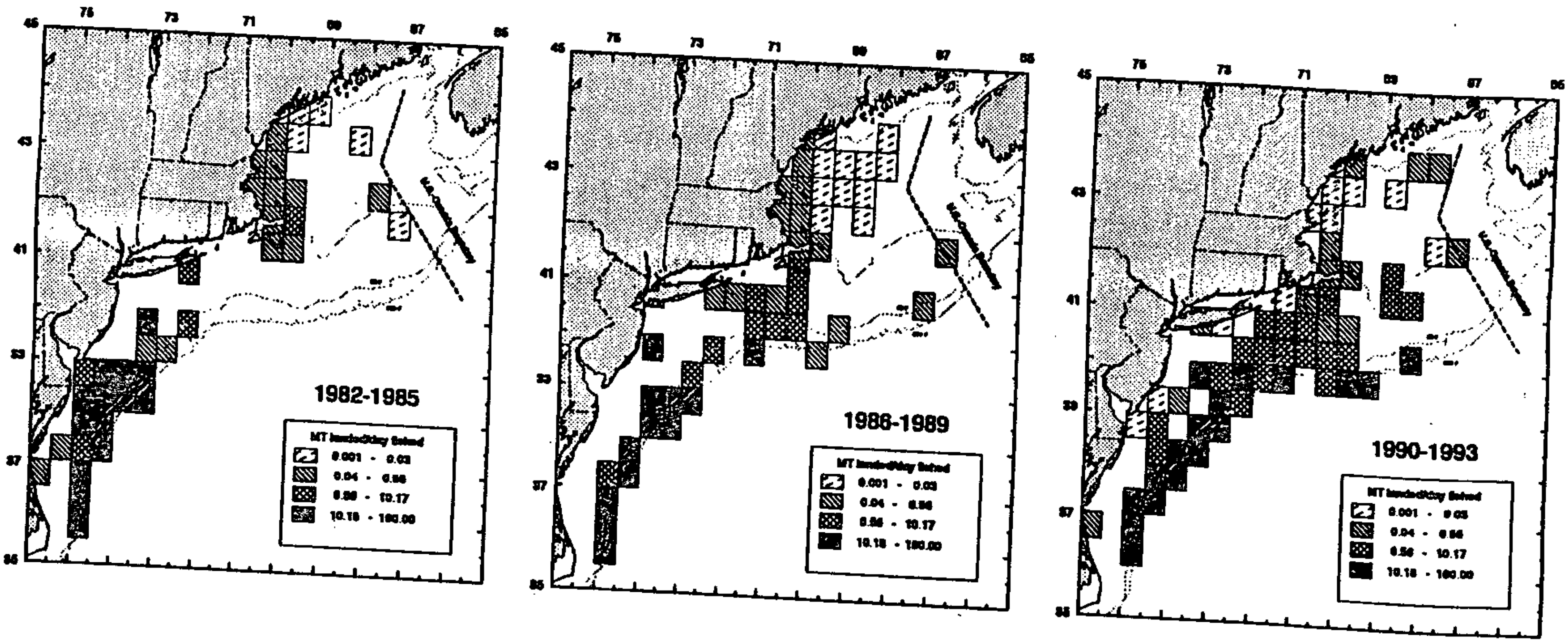

Fig. 4. Landings per unit of effort (mt landed per day fished) of *Illex illecebrosus* in the US EEZ bottom trawl fishery during 1982-93.

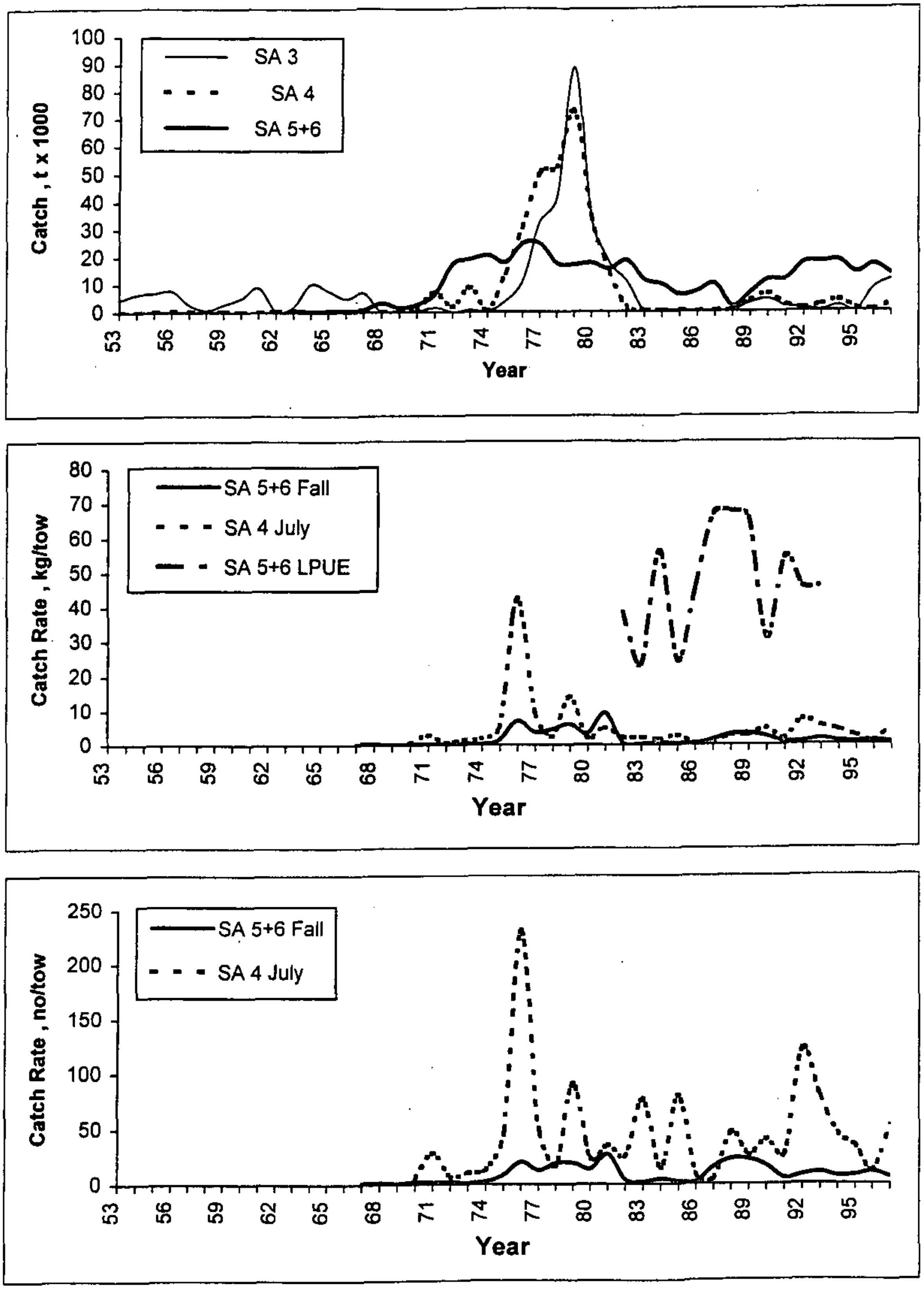

Fig. 5. Trends in annual landings and biomass indices by fishing area.

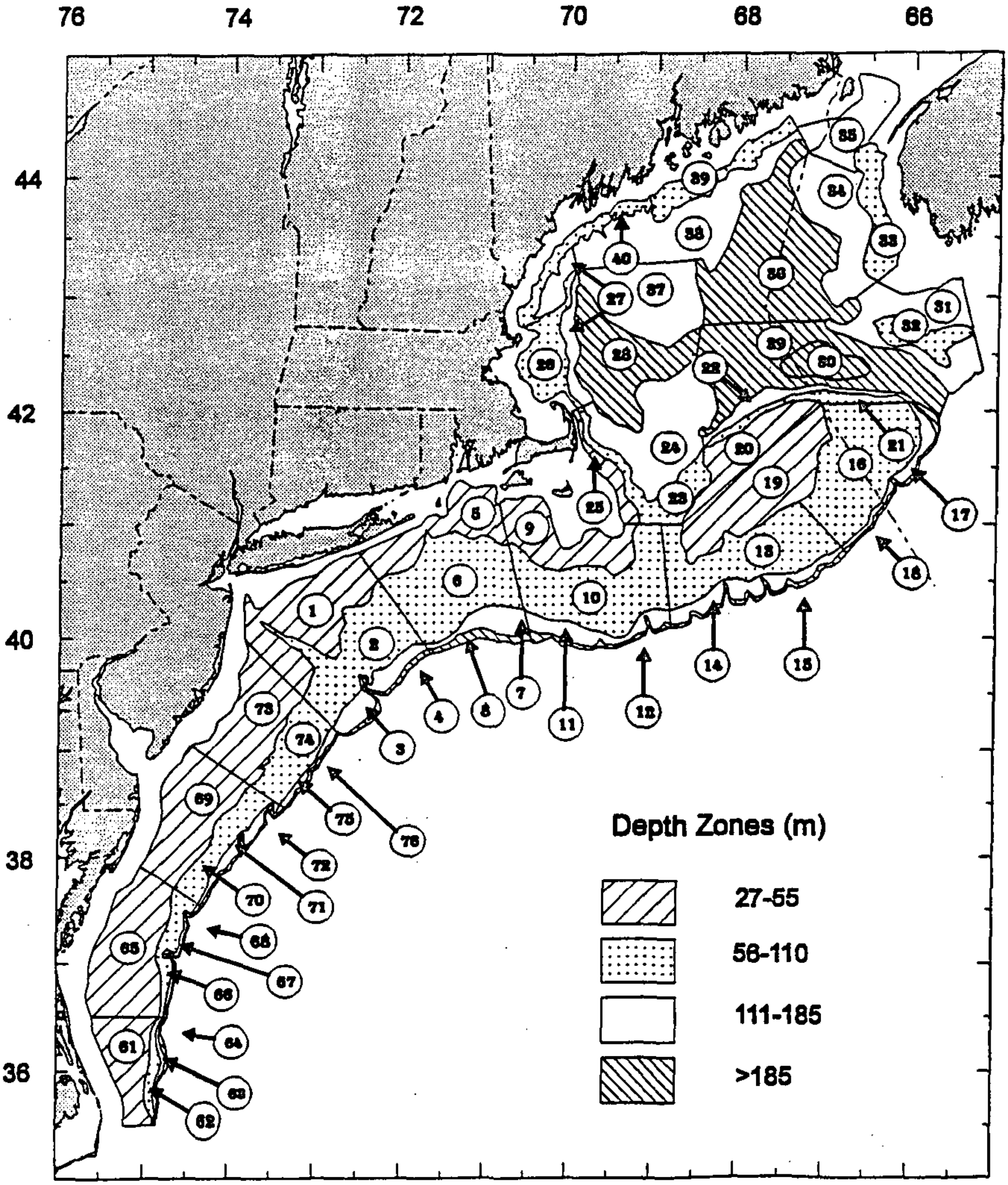

Fig. 6. Area of the Northwest Atlantic *showing offshore strata sampled during* NEFSC bottom trawl surveys.

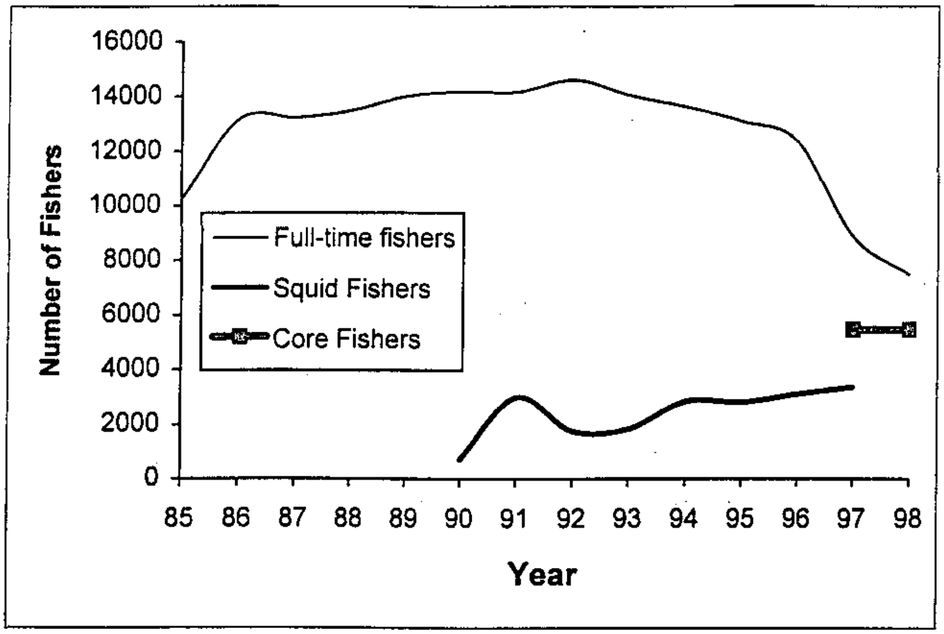

Fig. 7. Number of full-time fishers and licenced squid fishers at Newfoundland, 1985-97.

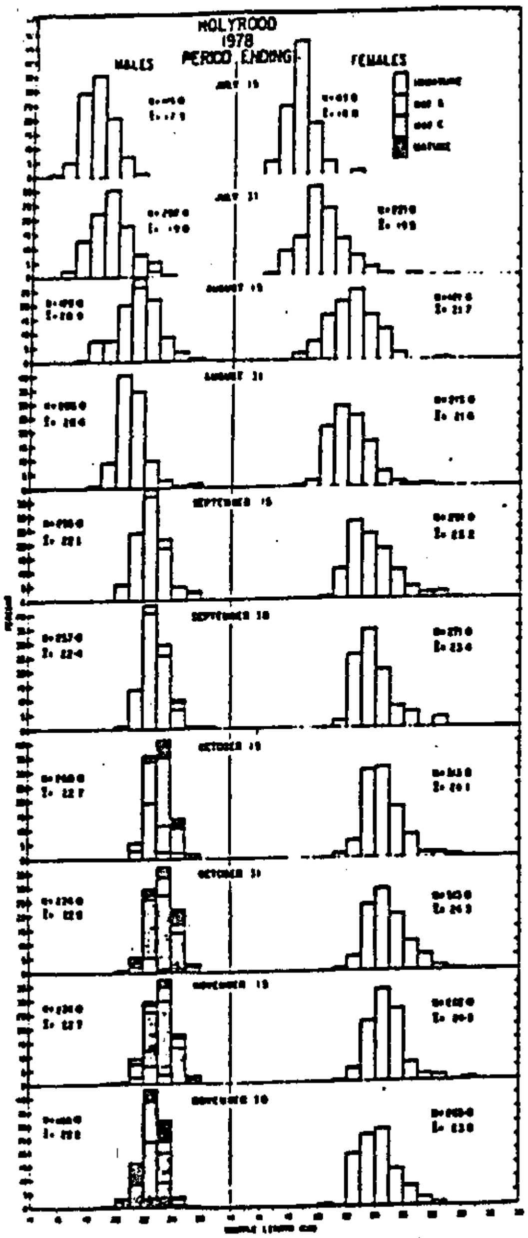

Fig. 8. Length frequencies and maturity stages by sex for bi-weekly periods in 1978 at Holyrood (SA 3).

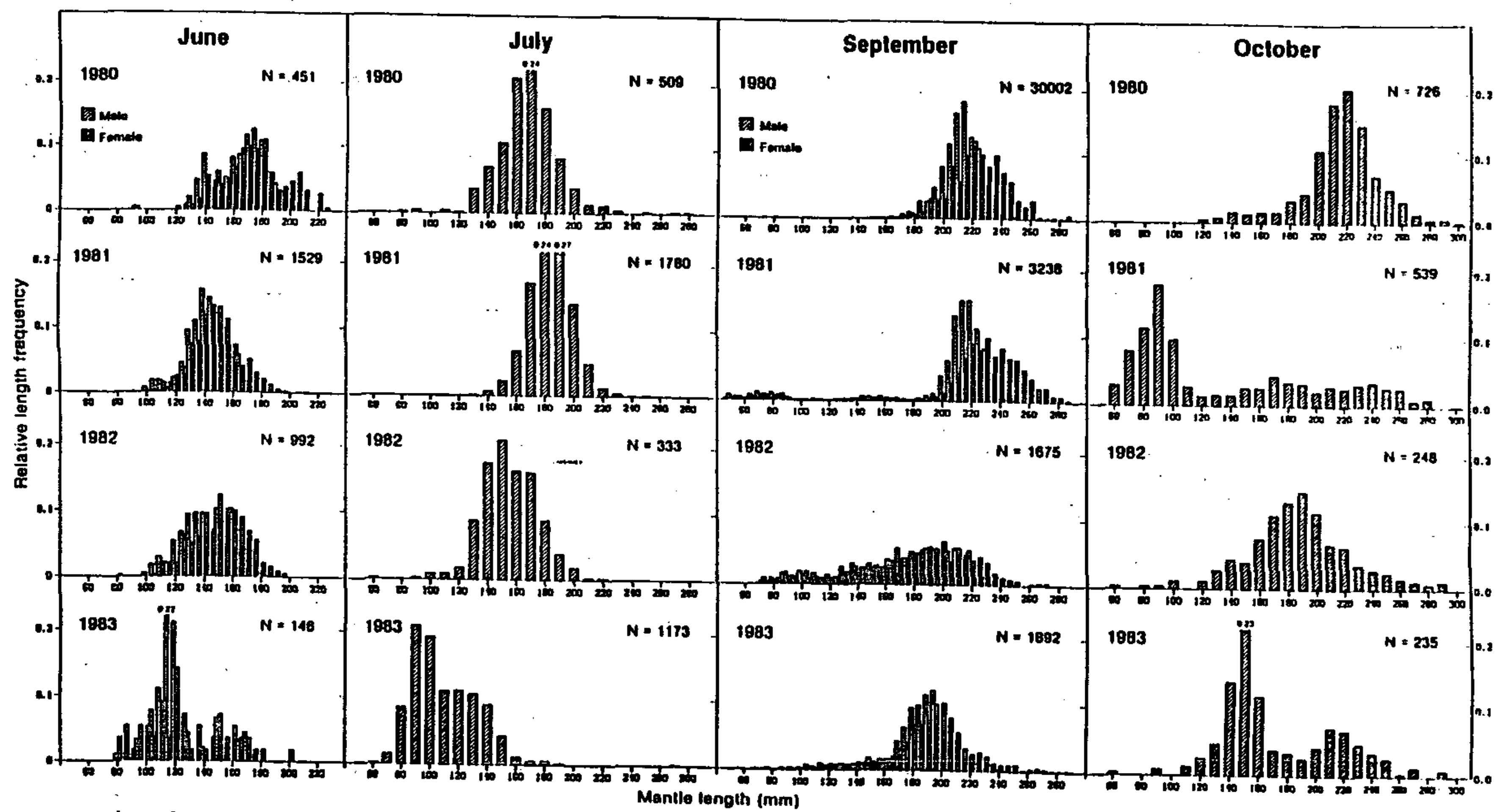

Fig. 9. Length frequencies of short-finned squid in June-July, September and October surveys of the Scotian Shelf (SA 4) in 1980-83. (Males and females are shown separately for the June and September periods.)

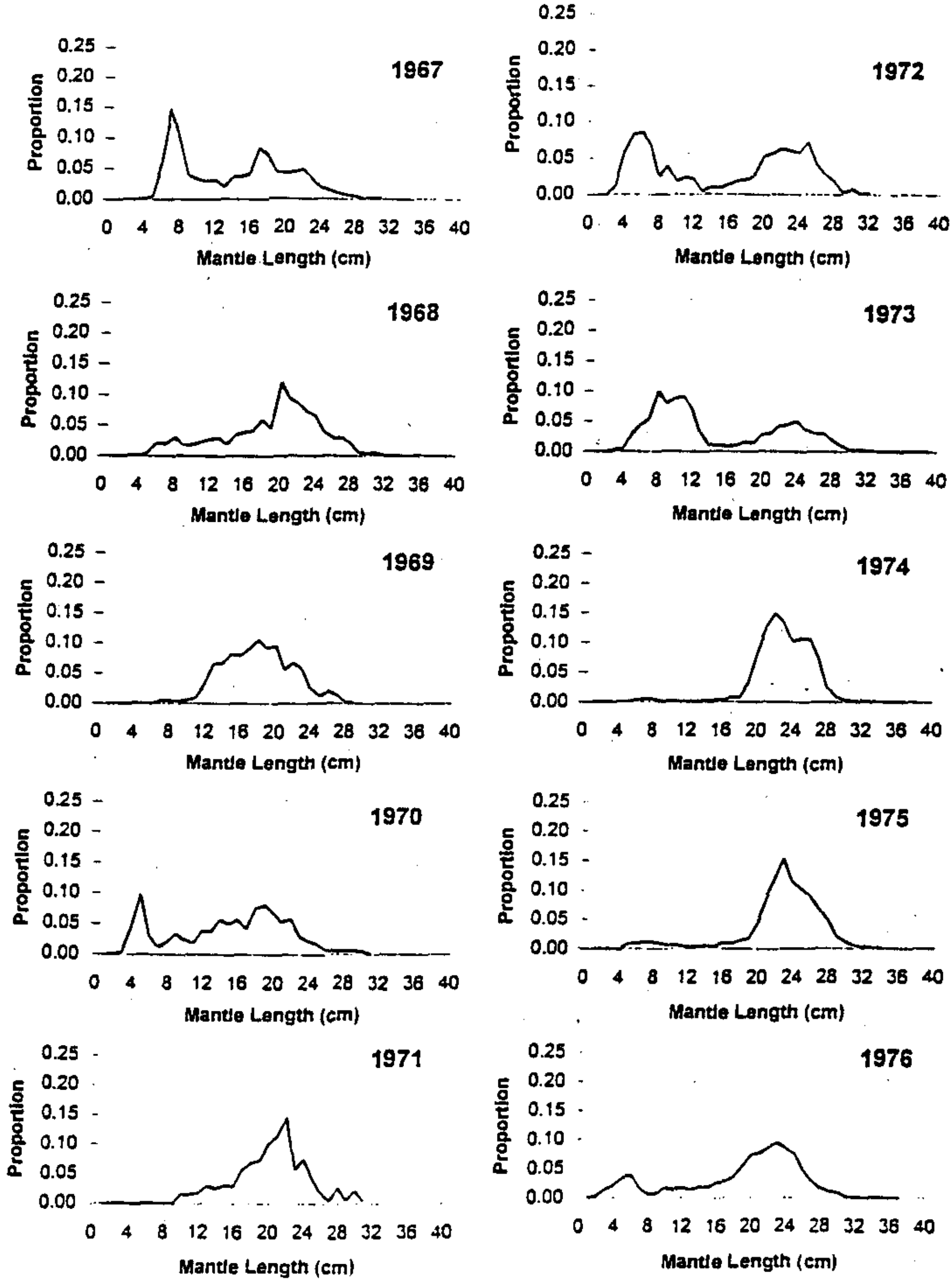

Fig. 10 Length-frequency distributions (stratified mean number per tow) of *Illex illecebrosus* from US research bottom trawl surveys during autumn, 1967-97.

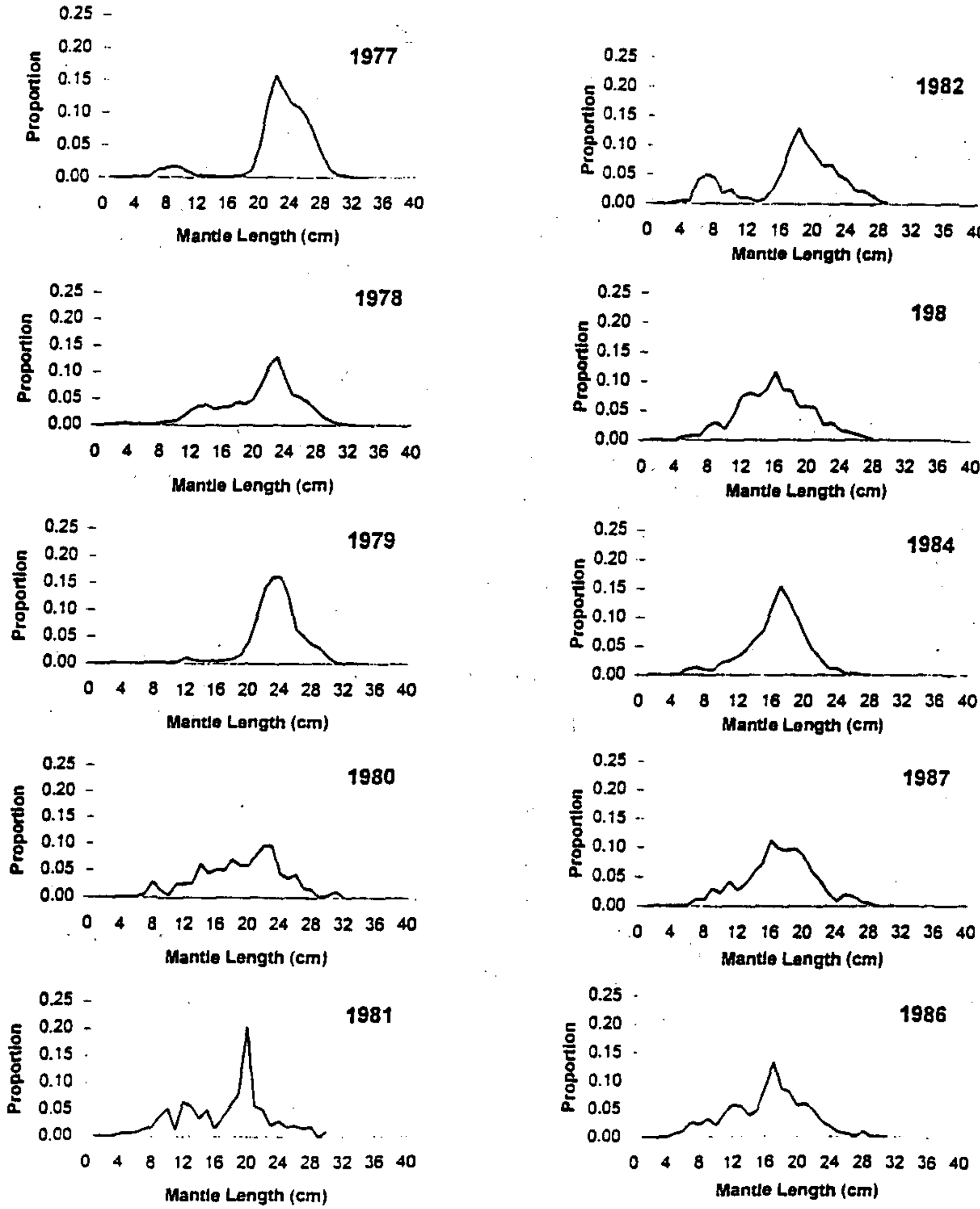

Fig. 10. Continued ...

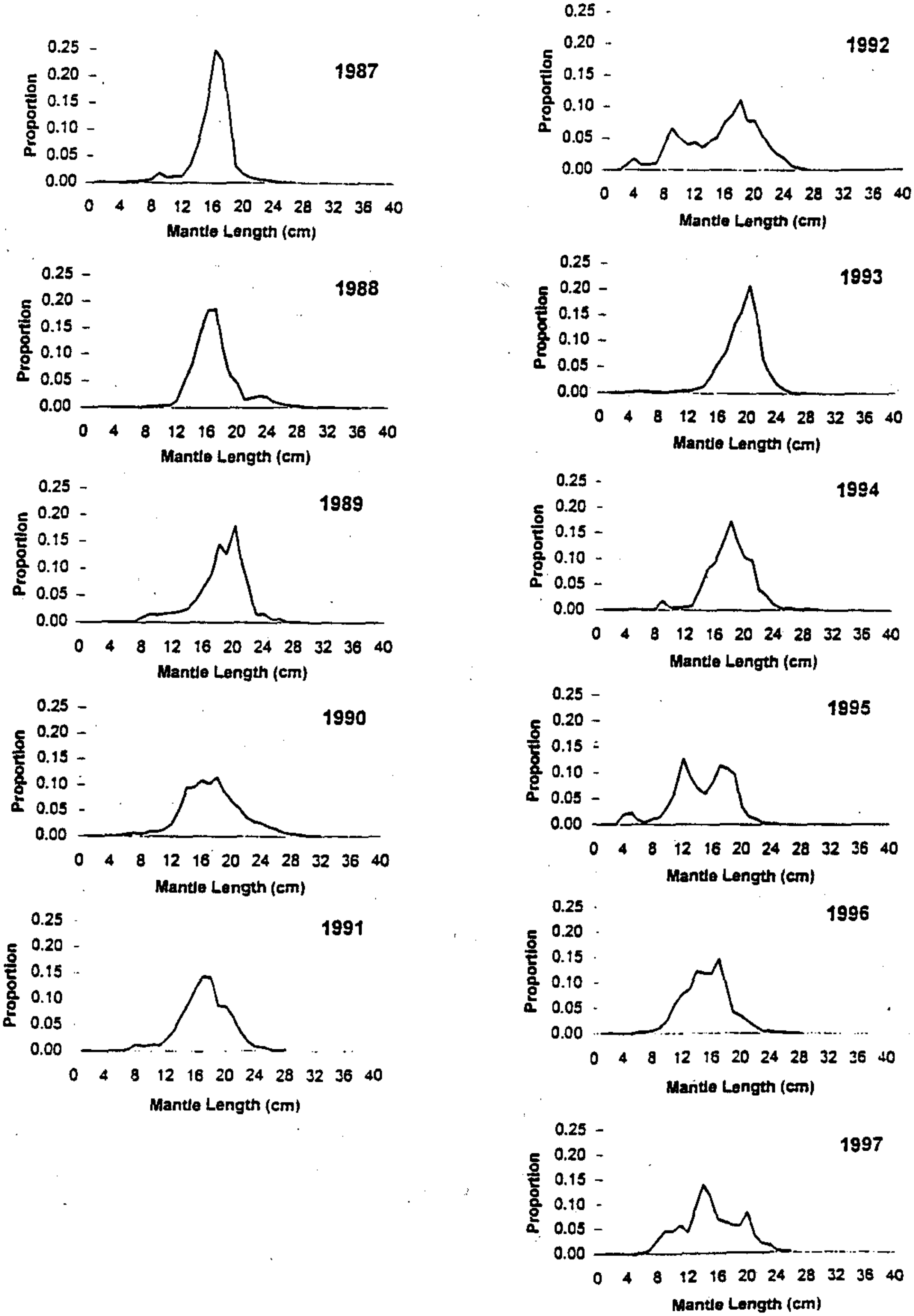

Fig. 10. Continued ...

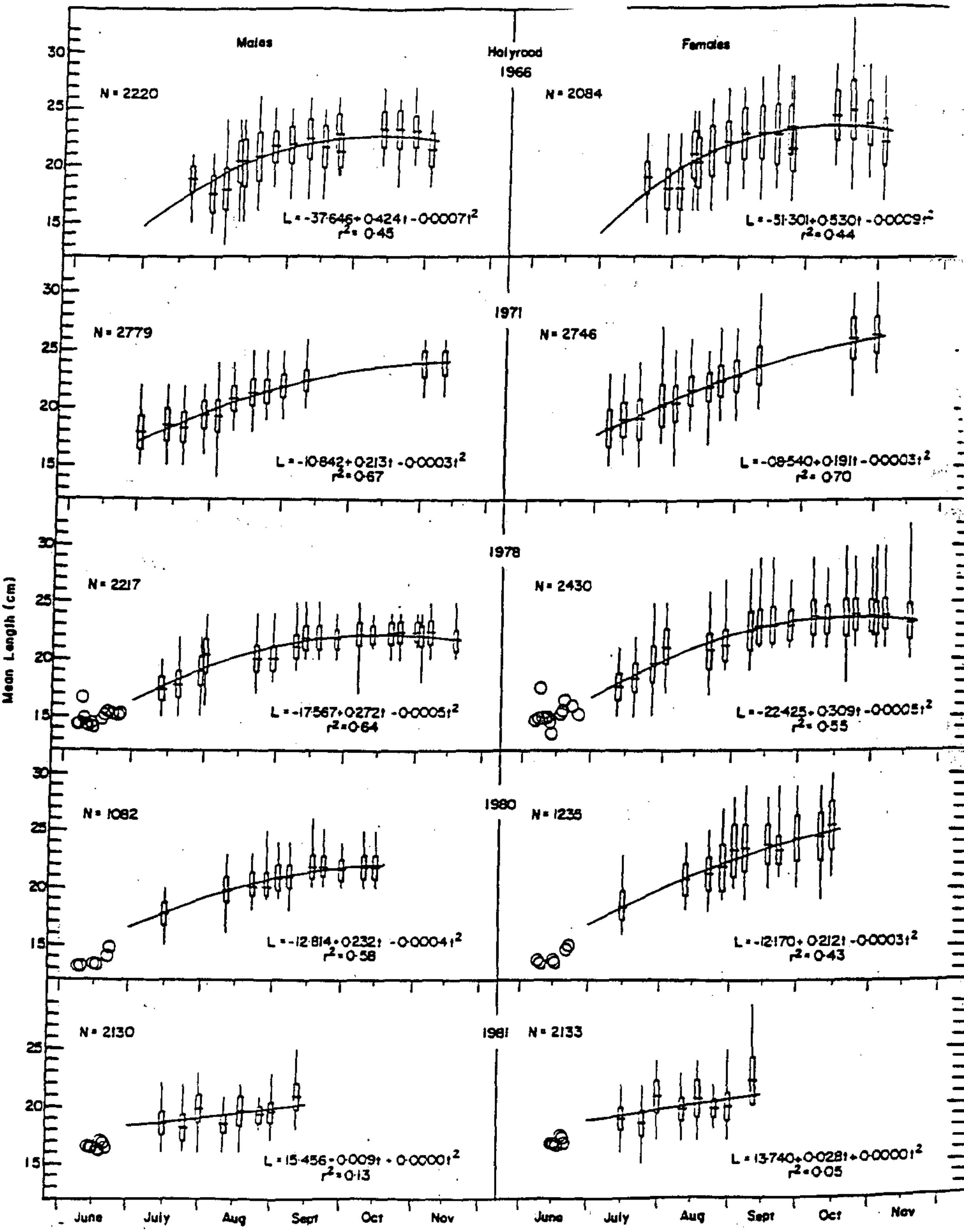

Fig. 11. Polynominal models applied to seasonal mean length data, by sex, from the Newfoundland inshore commercial jig fishery. Open circles represent mean lengths from spring offshore bottom trawl surveys.

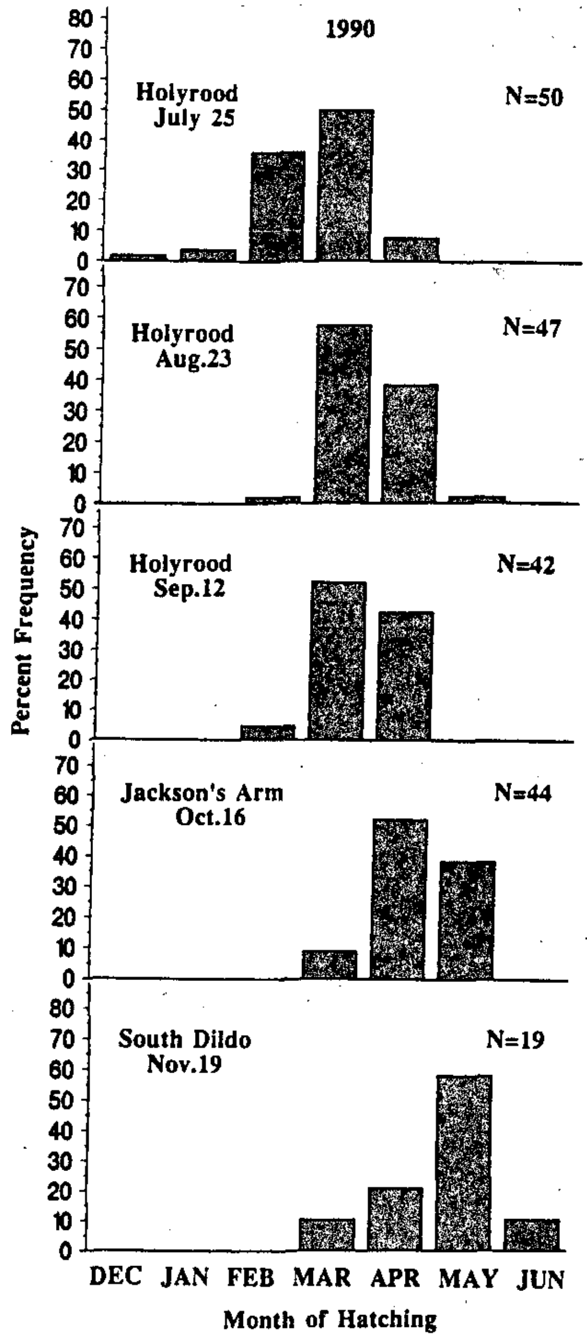

Fig. 12. Distribution of months of hatching of short-finned squid at Newfoundland, from statolith analysis, for successive sampling dates in 1990 (from Dawe and Beck 1997).

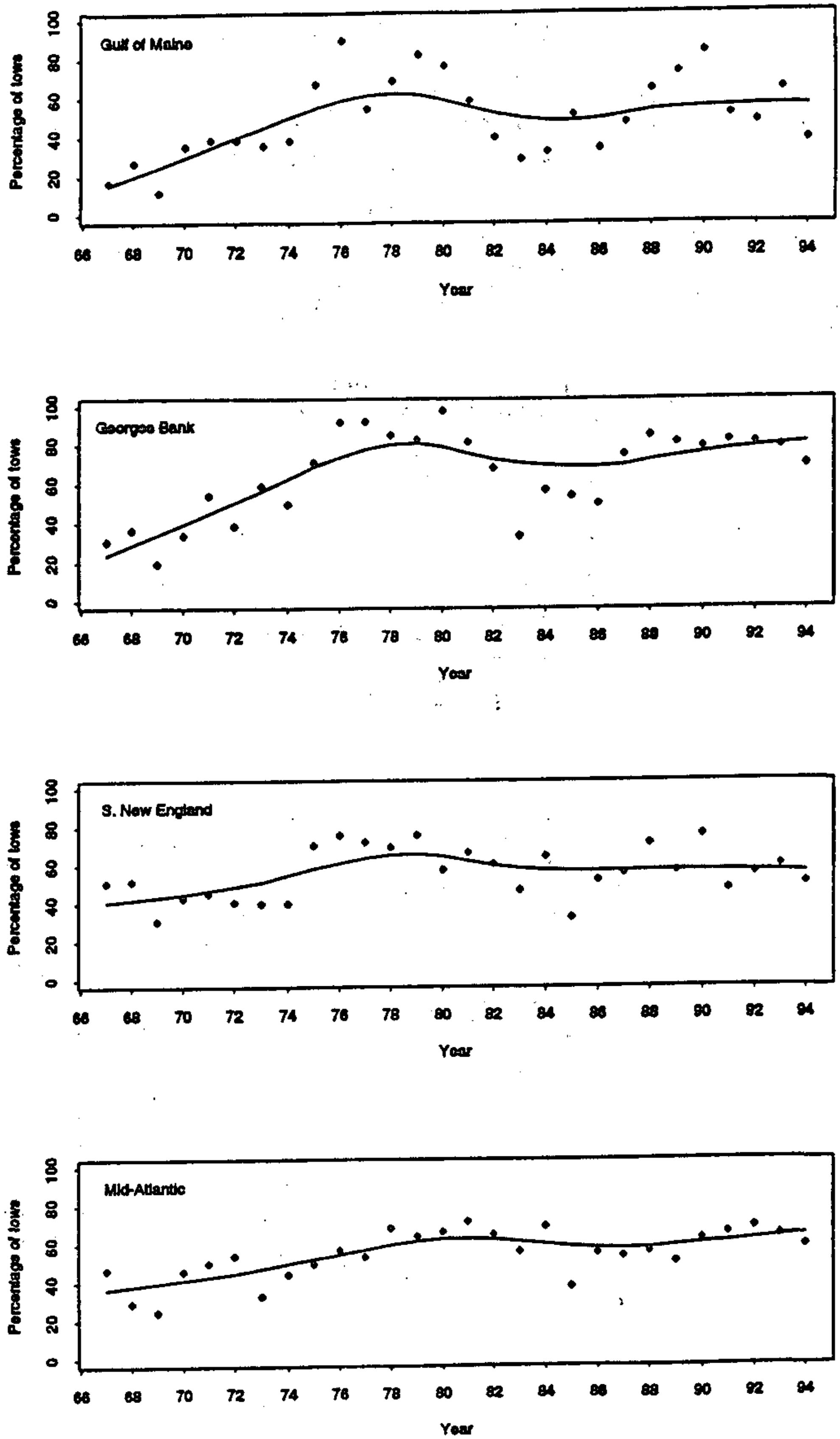

Fig. 13. Proportion of tows, by region, in which *Illex illecebrosus* were caught during NEFSC autumn bottom trawl surveys, 1967-94. Line represents LOWESS smoothed estimate with tension parameter of 0.5

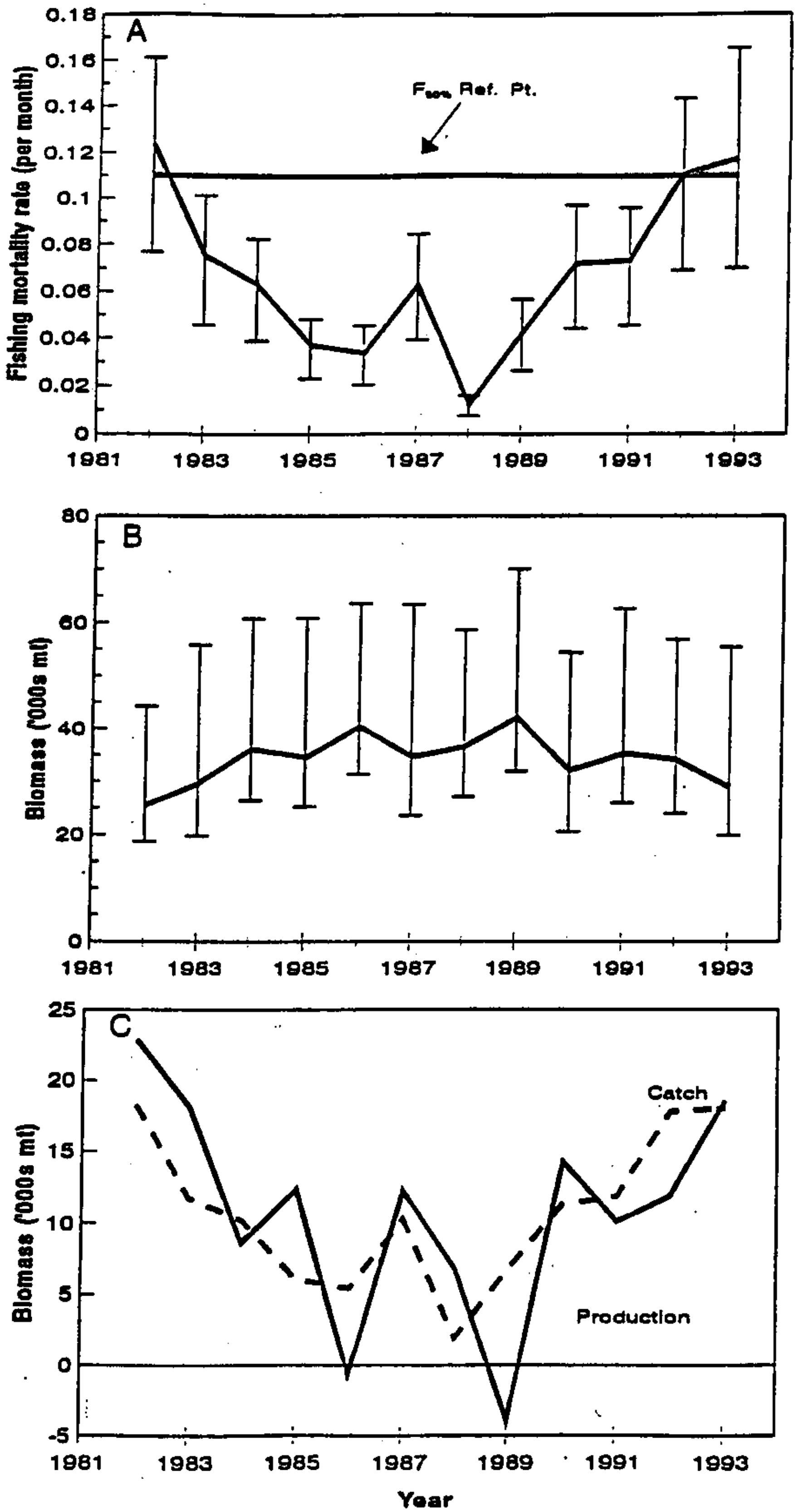

Fig. 14. Median fishing mortality rates, in the U.S. EEZ *Illex illecebrosus* fishery, with interquartile ranges derived from bootstrap estimation (A), median initial biomass estimates with interquartile ranges (B), and annual catches with estimated median annual production (C). Negative production in year t implies a decrease in initial biomass in year t+1.